Mitigating Risks in Pedestrian Pathways of Railway Station Districts: A Parma Case Analysis.

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Abstract. Enhancing walkability can involve optimizing pedestrian movements, ensuring both convenience and safety. This proves to be particularly relevant in the context of railway stations as they can be identified as collectors of urban mobility flows and at the same time as central and interconnected urban spaces, able to give integrated responses to new social needs linked both to daily life and tourism. Thus, enhancing active mobility in these areas includes facilitating seamless access to the station, platforms, and surrounding areas, thereby promoting sustainability in transportation, encouraging an active lifestyle, and enhancing the overall experience for railway station users. To address walkability risks within railway station districts, the study seeks to contribute to minimising security risks and optimizing safety perceptions on pedestrian paths and crossings. Leveraging the Parma case study, the research introduces a methodology for evaluating walkability within a specified buffer zone around the station, using two Key Performance Indicators (KPIs) defined as Safety and Security, applied to the pedestrian network graph. The research proposes a methodology considering specific factors relevant to the Safety and Security KPIs. The results highlight critical issues within the study area, pinpointing high-risk zones through graphical representation. Results might help prioritising interventions, providing essential support for sustainable mobility planning. Future research endeavours will encompass an expansion of the analysis with additional datasets, aiming to identify further essential KPIs for assessing walkability comprehensively.

Keywords: GIS · Walkability · Safety and Security · Railway Station District

1 Introduction

In recent years, there has been an increasing emphasis on the principles of sustainable urban development and mobility, as outlined in Sustainable Development Goal No. 11, and exemplified by major metropolitan cities such as Barcelona, Paris, and Milan [1–4]. This shift in paradigm, underlining the significance of prioritizing sustainable and active mobility as a primary mode of transportation, is widely recognized in the scientific

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community [i.a. 5, 6]. Walking, specifically, emerges as a central element not only for its environmental benefits but also for its substantial positive influence on individual health, encompassing both mental and physical well-being, as well as overall quality of life [i.a., 7–10].

Integration of spatial planning and urban planning, as advocated by several scholars [i.a. 11], is key to achieving sustainable urban mobility. Thus, concurrent with this transition is the imperative to regenerate public open spaces and pedestrian paths to foster safer, more appealing, and comfortable active mobility travel [12–14].

Acquisition and assessment of comprehensive data pertaining to the urban context and attributes of pedestrian infrastructure becomes a key element for identifying critical scenarios and planning effective strategies and interventions. Despite the abundance of literature presenting methodologies for studying and assessing walkability [i.a. 15–18], a universally adopted approach remains elusive [19]. While many existing methodologies share similarities, none have achieved widespread adoption. Moreover, comprehensive methodologies offering a holistic perspective on walkability are relatively underexplored and underutilised. The challenge inherent in this more holistic approach lies in the intricate nature of data collection and the complexities in its practical application by public administrations and stakeholders.

Within this framework, the authors have developed a methodology to evaluate the pedestrian infrastructure, providing insights into the urban environment's efficacy in promoting and facilitating pedestrian mobility. The research focuses on delineating criteria and Key Performance Indicators (KPIs) rooted in the principles of accessibility, safety and security, inclusive design, and enjoyment.

This contribution presents the methodology for calculating the defined KPIs of Safety and Security and its application to the case study of the station district of a medium-sized city in the Emilia-Romagna region, Parma. The KPIs of Safety and Security assess the safeguarding level for pedestrians within the urban environment, identifying potential risks and ensuring a secure experience for users. This aspect of walkability proves to be of particular relevance in the surrounding area of train stations and transit environments [20–23] as they can be identified as collectors of urban mobility flows and at the same time as central and interconnected urban spaces, able to give integrated responses to new social needs linked to daily life and tourism.

The paper is structured as follows: Sect. 2 describes a literature review focusing on relevant features for evaluating safety and security, and the station district delimitation. Section 3 outlines the proposed methodology for calculation of the Safety and Security KPIs. Section 4 introduces the case study district and presents the methodology's application results. Finally, Sect. 5 provides conclusions on the methodology's application to the proposed case study, highlighting its strengths and limitations, and suggests potential avenues for further research.

2 Literature Review

2.1 Factors Affecting Safety and Security

As highlighted in the introduction, various methodologies have been employed to assess walkability in urban areas [24]. Within this context, road safety and protection from crimes (i.e. social security) emerge as distinct yet essential factors shaping individuals' inclination towards active modes of transportation. Indeed, the susceptibility of pedestrians and non-motorized users to road accidents [25], as well as the documented correlation between personal security perceptions and transportation choices, [26, 27] are well-documented in the literature.

The table provided below (Table 1) outlines the principal characteristics of both the urban environment and pedestrian infrastructure deemed significant in enhancing safety and security aspects of walkability, as discussed in the literature.

Regarding the improvement of road safety, central elements include reducing speed limits alongside safeguarding the pedestrian infrastructure from vehicular traffic. As emphasized by the Mid-American Regional Council (MARC) [28], heightened vehicle speeds amplify the risk of accidents, as faster speeds diminish drivers' capacity to identify and evade potential conflicts [31]. Furthermore, high-speed collisions between pedestrians and vehicles increase the probability of fatal outcomes [30, 31]. Consequently, when speed reduction efforts [32] are not possible, it is important to incorporate protective features for areas dedicated to vulnerable users (e.g., kerbs, bollards, trees, etc.) [28, 33–35].

Alongside the aforementioned factors, another relevant element for ensuring road safety is the presence of dedicated signage and markings [28, 36–38] as these elements enable pedestrians and other road users to clearly identify the dedicated area for pedestrian movement and crossing.

Regarding pedestrian crossings, safety can be further enhanced by increasing visibility through measures such as curbs extensions to restrict vehicle transit areas and removing obstructive elements like parked cars or urban furniture [28, 32, 37–40]. Additionally, improving lighting systems is crucial to ensure that pedestrians are visible to approaching vehicles [28, 32]. The installation of traffic lights also plays a significant role in promoting safer crossing experiences [33, 38, 40].

An important aspect to consider regarding crossings is their typology, which impacts both safety and security. Raised crossings enhance pedestrians' visibility for vehicle users while also compelling vehicles to reduce speed near them [28, 33, 37, 39, 41, 42]. Conversely, pedestrian overpasses and subways completely separate pedestrians from vehicles, allowing safety during crossings of high traffic roads but potentially impacting social security [32, 43, 44].

Lastly, other elements related to social security on pedestrian paths include adequate lighting [24, 45–47] and the vibrancy of the street environment [47–49].

Table 1. Literature review on factors affecting road safety and social security.

Factor	References
Vehicular speed limit	[28–33]
Protection from vehicular traffic	[28, 33–35]
Signage and Markings	[28, 36–38]
Crossing visibility	[28, 29, 32, 37, 38, 40]
Traffic light	[33, 38, 40]
Crossing typology (road level or raised)	[28, 33, 37, 39, 42]
Crossing typology (overpass or subway)	[32, 43, 44]
Lighting	[24, 45–47]
Road vitality and economic activities	[47–49]

2.2 Station District Definition

The concepts of safety and security assume a peculiar meaning when applied to the area surrounding metro or railway stations [50]. The station and its surroundings are places where different needs take places and where the conflict between the mobility infrastructure and the city is more intense [51]. This complexity is reflected in the duality infrastructure node/urban place which constitute one of the main conceptual frameworks used in literature to explore the issue [52, 53]. In fact, the station neighborhood is the urban area where the integration of mobility and urban development agendas is more needed, not to mention other social, economic, and cultural aspects [54]. Transportation nodes attract and concentrate different flows of diverse users and travelers, according to its relevance [55].

To delineate the boundaries of the station environment, Bertolini [52] and Pucci [56] suggest several approaches. These include defining a walking radius of influence based on time or distance, investigating historical form or topographical landmarks, identifying an urban transect centred around the station, or considering a defined perimeter for transformation or redevelopment projects. However, despite these proposals, the definition remains ambiguous and does not clearly establish the limits of this context. Yang also identifies a possible way to assess a station area of influence by determining a suitable walking distance to access the station, with additional other approaches emphasising criteria such as urban compactness or focus on specific urban design features [57].

In conclusion, for the purposes of this study, the station district area is delineated using a 1-km isoline originating from the station and distributed along the road graph. This isochrone corresponds approximately to 15-min walk at a 4 km/h speed. This choice does not take into account impedance factors, such as lower speeds of vulnerable users (elderly people, children) and is purposedly made to consider the broadest possible area of analysis.

3 Materials and Methods

This section describes the methodology used for calculating the KPIs of Road Safety and Social Security respectively.

As previously stated, the KPIs of Safety and Security assess the protection level for pedestrians within the urban environment by identifying potential risks and ensuring a secure experience for pedestrians. The Road Safety KPI focuses on assessing conflicts with motor vehicles and the risk of road accidents, while the Social Security KPI concentrates on factors related to the sense of social security, such as exposure to potential crimes (e.g. theft or vandalism).

The aim of this methodology is to create a systematic data collection protocol that can ensure adaptability, reproducibility, and transferability to other urban contexts. Thus, some of the attributes listed below could prove to be less relevant in specific urban contexts and be excluded from the calculation of the KPI to make it more adaptive in relation to the characteristics of the area.

To assess the degree of safety and security of the pedestrian infrastructure, a comprehensive approach is adopted, based on a review of the scientific literature (Sect. 2.1). This guides the development of a systematic data collection protocol, which includes searching for data from official sources and carrying on remote and in-field inspections. Furthermore, the observation phase is useful to grasp features, vulnerabilities, and peculiarities of paths at different scales. Surveys' results are then represented through a graph structure.

Subsequently, the assessment process assigns a numerical value to each of the domains of factors analysed by the data collection protocol. The highest value within each domain identifies the optimal condition for promoting road safety or social security (e.g. presence of lighting along the path). However, in certain instances, the maximum value identified within the domain corresponds to 0, for example with signage and markings, whereas present. This occurs when the characteristics being studied are tightly regulated by existing standards, indicating that they should already be met in the construction phase. These numerical values are then used to calculate the KPIs.

The attributes of pedestrian infrastructure and its urban context considered for these calculations are listed in Table 2, and further classified for each individual KPI.

While most factors are determined by assigning specific levels to the analysed characteristics, the Facilities density factor involves a spatial analysis using buffer areas. A 15-m buffer is applied from the path segment, and the count of services within each buffer is calculated. This enables the identification of services along each segment of the pedestrian infrastructure. Subsequently, the number of services is divided by the length of the segment. The resulting value is then normalized between 0 and 1 relative to the maximum density identified across all segments in the city under study. Services considered for this Security KPI include services where people gather and remain open in the evening hours, such as catering activities and commercial activities fostering social presence along the path (i.e. shops).

As evidenced by the attributes list under consideration, it is useful to provide a differentiation criterion based on the segment type, to distinguish between segments representing pedestrian paths and those representing pedestrian crossings. This subdivision is justified by two main considerations: firstly, the distinct attributes characterizing

Table 2. Safety and Security KPIs - Evaluation criteria adopted, and values assigned.

KPI	Attributes	Evaluation	Values
Road safety	Protection from vehicular traffic	High or no interaction	1
		Medium	0
		Low	−1
		Absent	−2
	Speed limit	None	2
		30 km/h	1
		50 km/h	−1
	Crossing location	Road level	−1
		Artificial bump	1
	Crossing visibility	High	1
		Medium	0
		Low	−1
	Traffic light	Yes	1
		No	0
	Signage	Yes	0
		No	−1
	Markings	Yes	0
		No	−1
Social security	Crossing location	Overpass	−1
		Subway	−1
	Lighting	Yes	1
		No	−1
	Facilities density (Food services + Shops)	Number of facilities/segment length	

crossings require a separate analysis from other segments, respecting the presence of certain specific characteristics that relate exclusively to pedestrian crossings. Secondly, crossings emerge as critical points associated with a higher risk in interactions among vehicles and vulnerable users, whereas interaction with vehicles should be restricted or absent in pedestrian paths. Thus, for the assessment of the Safety and Security KPI, pedestrian paths and pedestrian crossings are considered separately.

The table below (Table 3) delineates the attributes considered for each segment type (i.e. paths and crossings).

Each KPI is respectively derived by calculating the average of the appropriate factors.

The values obtained, for both KPIs, are then normalized between 0 and 1 based on the maximum and minimum values obtained through the calculation. The normalization

Table 3. Selection of distinct attributes for pedestrian paths and crossings.

KPI		Attributes	Criteria	
			Path	Crossing
SAFETY AND SECURITY KPIs	Road Safety	Protection From Vehicular Traffic	•	
		Speed Limit	•	•
		Crossing location		•
		Crossing visibility		•
		Traffic Light		•
		Signage	•	•
		Markings	•	•
	Social Security	Crossing location		•
		Lighting	•	•
		Facilities Density (Food Services + Shops)	•	

process standardizes data, facilitating equitable comparisons across diverse KPIs (i.e. for paths and crossings) and enabling a more precise assessment of overall performance. This systematic approach ensures a comprehensive evaluation by accounting for variations in scale and magnitude, thereby enhancing robustness and reliability.

For the analysis of the designated case study and the graphical representation of associated maps, pertinent data are systematically gathered from various official sources. These sources include the Geographical Information System managed by the Municipality of Parma and the Geoportal administered by the Emilia-Romagna Region. They provide cartographic data on buildings, road networks, railway lines, road accidents, urban lots, green areas, and water bodies. Public data sources, such as OpenStreetMap, are accessed to identify existing public facilities, secondary schools, and commercial establishments. Specifically, for commercial services, information is extracted from the Points of Interest (POIs) layer in OpenStreetMap. The focus is on services with attribute codes 23xx and 25xx to ensure a targeted and relevant dataset for the Social Security KPI. Furthermore, data on pedestrian paths and crossings, along with their attributes, are collected through on-site surveys conducted by the authors.

4 Results and Discussion

4.1 Case Study: Parma's Railway Station District

The case study selected for testing the methodology involves the surrounding area of Parma's railway station, situated in the Emilia-Romagna region of Italy, within a 1-kilometre isoline from the station (Fig.1).

Parma serves as the capital of the province and is categorized as a medium-sized city (approximately 198,000 inhabitants in 2023 [58]), easily accessible on foot due to its size and layout.

Renowned for its historic landmarks, including monumental buildings, museums, and theatres, as well as its food and wine productions, the city notably held the title of European Capital of Culture for the two-year period spanning 2020 and 2021 [35]. Parma attracts a significant influx of tourists, with nearly 400,000 visitors annually, a figure steadily increasing according to statistics from the Emilia-Romagna Region [59].

Moreover, Parma is recognized as a university hub, boasting a student population of 30,600 as of 2021 [60], including a considerable number of non-local students. Additionally, as the provincial capital, Parma also draws secondary school students from surrounding areas.

The railway station in Parma is a medium to large-sized facility, accommodating a daily average of passengers ranging between 10,000 and 25,000 [61]. Strategically positioned on the periphery of the city's historic walls, the station can potentially make the city centre easily accessible on foot.



Fig. 1. Parma's railway station. Source: authors' elaboration.

The area surrounding the railway station (Fig. 2) includes four districts of the municipality of Parma: Centro Storico (south-east), Oltretorrente (south-west), San Leonardo (north), and Pablo (north-west). The urban fabric is characterized by predominantly residential buildings, while economic activities are primarily concentrated within the historic centre and along via Trento, extending northwards from the station.

Relevant public facilities within the study area include a secondary school and one of the University of Parma's premises. Furthermore, extending the walking time from the station by two minutes grants access to the University of Parma's headquarters, and seat of the Faculty of Law.

In terms of mobility, the case study area experiences various restrictions on motorised private vehicles. Specifically, the entire Centro Storico district, along with a portion of the Oltretorrente district and the immediate vicinity of the train station, are subject to limited traffic (Limited Traffic Zone - LTZ). Moreover, vehicular mobility faces an added constraint due to the presence of a 30 km/h speed restriction zone (Zone 30) in the northeastern part of the San Leonardo district. Regarding the infrastructure network related to active mobility, a preliminary assessment confirms its extensive coverage throughout the study area, potentially providing a high level of pedestrian accessibility.

In terms of traffic accidents, an analysis of pedestrian-related road accidents from the year 2022 [62] shows numerous crashes within the study area, with a notable concentration near the station and along the via Trieste Road axis.

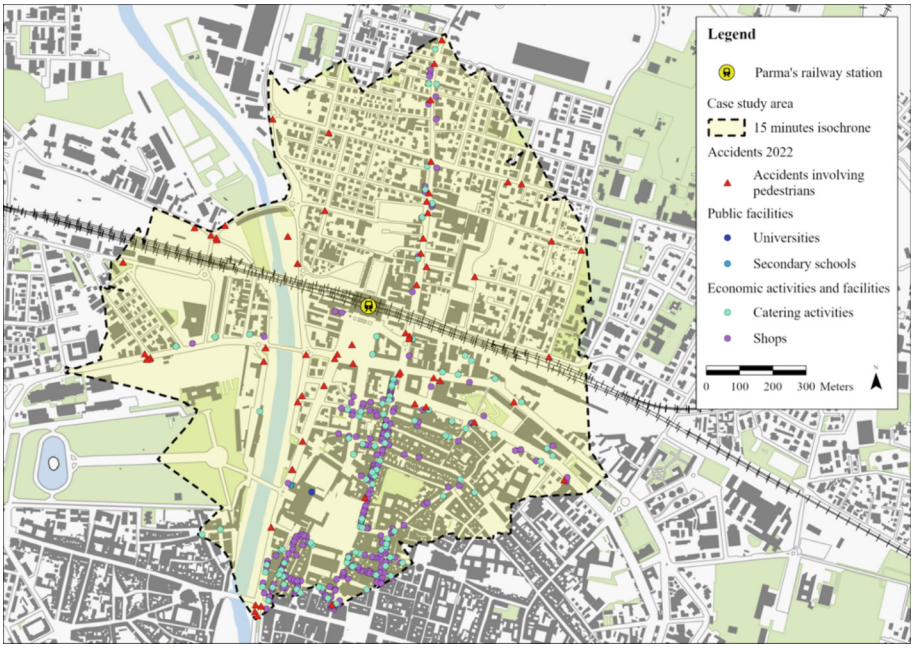

Fig. 2. Case study area with relevant data considered. Source: authors' elaboration.

4.2 Safety and Security KPIs Assessment Results

As previously defined, the Safety and Security KPIs encompass complementary aspects. Firstly, the results obtained for each KPI are presented, followed by an analysis of the

overall values assigned to each segment of the pedestrian infrastructure for the Safety and Security KPIs.

The results are visually represented using a natural interval scale (Jenkins) and a graduated colour scale ranging from red (highlighting critical segments) to green (indicating segments with favourable characteristics). To enhance clarity in distinguishing between pedestrian paths and crossings, it is decided to represent the latter using point geometry.

The analysis of the Road Safety KPI (Fig. 3) reveals that segments linked to pedestrian paths, situated south of the railway line and east of the Parma River and encompassing the Centro Storico district, are characterised by an overall good level of road safety. Furthermore, as previously mentioned, the area is also included within the LTZ, resulting in reduced vehicular traffic flows. Additionally, further improvement is anticipated with the implementation of a Zone 30 in this area, as indicated by Parma's Traffic Management Plan [63], which will further positively impact the assessment of road safety in the area. Critical segments, on the other hand, are primarily located in the northern part of the analysis area, corresponding to the San Leonardo district and northwest of the study area (i.e. Pablo district). However, a notable exception exists within these areas of concern, represented by a small portion of the San Leonardo district located to the northeast, where the level of road safety is notably less critical. This exception is justified by the presence in that area of a Zone 30. It is important to highlight that, despite the critical nature of these segments, except for via Trento, via Venezia, viale Europa, and viale Piacenza,

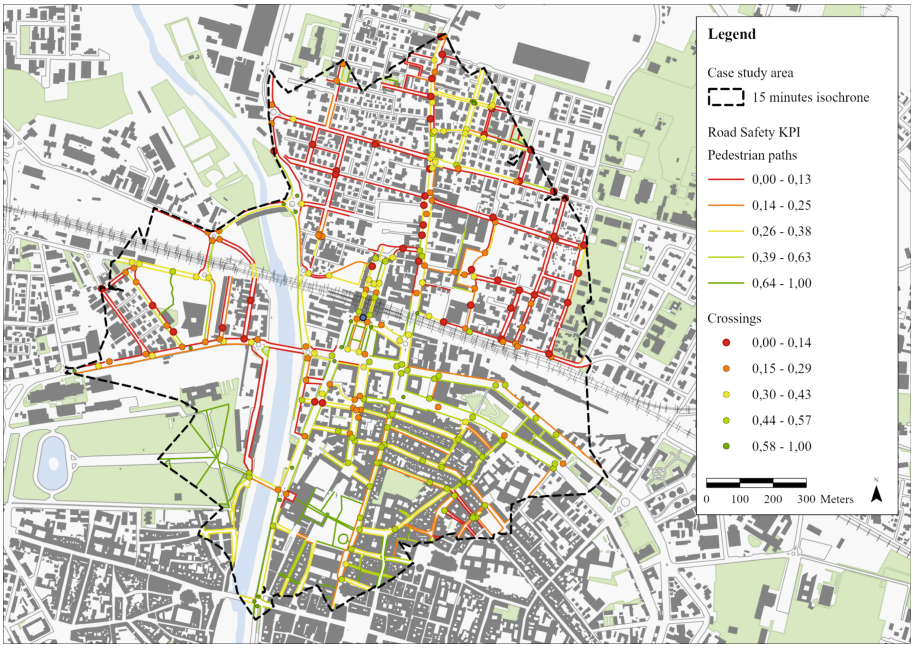

Fig. 3. Road Safety KPI. Source: authors' elaboration.

they are predominantly located within residential areas. Consequently, the vehicular and pedestrian flow along these roads is low, as their local street function suggests.

Turning to pedestrian crossings, the situation closely reflects that highlighted by pedestrian paths. However, it is necessary to emphasize that numerous crossing infrastructures are absent, particularly in the predominantly residential areas within the San Leonardo district. The most critical area is represented by the via Trieste axis where, in addition to a high criticality of pedestrian crossings, numerous accidents involving pedestrians are also recorded. This could be due not only to the limited safety of the crossings but also to a reduced number of crossings or suboptimal location.

Moving on to the Social Security KPI (Fig. 4), it is necessary to begin with a premise regarding the evaluation assigned to pedestrian crossings. Indeed, one of the protocol factors considered (i.e. the presence of pedestrian overpasses or subways) appears to have minimal relevance for this specific study area.



Fig. 4. Social Security KPI. Source: authors' elaboration.

Notably, the area lacks such infrastructure typologies, thereby making the social security assessment of crossings solely reliant on the presence of lighting. Consequently, for this KPI, pedestrian crossings are categorized with values equal to either 0 or 1. As for the evaluation of social security for pedestrian paths, it is possible to highlight how the most critical areas are represented by residential areas where the presence of commercial activities considered by the protocol is absent or extremely reduced. Additionally, a concentration of critical segments and crossings can be noted in the immediate vicinity of the station. This can strongly affect people's propensity to walk, as even a single

portion of the path, albeit limited, if present within the user's route, can compromise their modal choice or lead to route variations that can still discourage walkability. Overall, the outcomes highlight significant disparities between the northern and southern areas of the railway station, outlining distinctive urban peculiarities. These zones are primarily distinguished by their morphological and functional characteristics, revealing notable differences in terms of walkability. The southern portion stands out for its densely compact urban configuration, primarily represented by the historic center, whereas the northern zone is characterized by being a predominantly residential periphery with an industrial history. This diversity in urban contexts is directly reflected in walkability metrics, which are affected by the various morphologies and differing infrastructural provisions, influencing commuting habits and the accessibility of public spaces in both areas. Considering the KPIs, it is possible to observe how the evaluation of segments and crossings in the southern portion of the historic center is less critical than the conditions identified in the northern portion. Nevertheless, a further distinction should be made for the two northern portions of railway station, represented by the San Leonardo district and in a minor part of the northwest portion represented by the Pablo district, as they have the most critical conditions. Additionally, a concentration of pedestrian crossings in critical conditions is also found in the central portion of the study area near the station. Lastly, it can also be noted how the Road Safety KPI shows more critical issues than the Social Safety KPI, as expected given the greater number of factors considered.

The following figures (Fig. 5 and Fig. 6) show some examples of relevant paths and crossing evaluations collected across the station district area.



Fig. 5. Road safety. Frome left to right, examples of pedestrian path values, from excellent to poor. Source: authors' audit.





Fig. 6. Social Security. Frome left to right, examples of pedestrian path values, from excellent to poor. Source: authors' audit.

5 Conclusions

As highlighted in the introduction, promoting active mobility is crucial for achieving broader sustainable development goals. This underscores the need of improving walkability of infrastructures and urban areas. Despite the abundance of literature presenting methodologies for studying and assessing relevant pedestrian infrastructures and urban context characteristics for walkability, a universally recognized approach has yet to be established. Furthermore, public administrations and stakeholders often encounter challenges due to the intricate nature of data availability and collection when implementing such methodologies.

In this context, the aim is to develop a methodology for assessing several aspects pertaining to walkability through a set of KPI, using GIS analysis. The goal is to ensure the adaptability, reproducibility, and transferability of the methodology to other urban contexts. Additionally, this methodology could also guide the programming of public interventions and urban planning decisions. For instance, it could be employed to identify urban areas requiring priority regeneration interventions, enabling local authorities to allocate available resources more efficiently. Furthermore, it could be utilised to expand low-speed zones (30 zones), thereby contributing to improving road safety. Moreover, this methodology could be adopted as a standard protocol for ongoing projects, allowing for ex-ante evaluation and ex-post monitoring. This would enable the monitoring and evaluation of the effectiveness of actions taken to improve urban walkability over time, providing valuable empirical data to guide future interventions and enhance urban policies.

Thus, the paper presents the development of a methodology for calculating the defined KPIs of Safety and Security based on factors identified within the existing literature. These KPIs are developed to identify the major critical points of pedestrian paths and crossings from the perspective of these two complementary themes.

The methodology is applied to the case study of the station district of the city of Parma in the Emilia-Romagna region. Parma's station district, as explained in Sect. 3.2, is of particular interest for integrating urban and mobility aspects related to safety and security due to its localization within the city context and relevant flows that its station experiences. The results of the methodology application validated the consistency of road

safety and social security assessments with the assessed on-field situation. Furthermore, comparing the Road Safety KPI with actual road accidents involving pedestrians further underscored the effectiveness of this tool in evaluating road safety within pedestrian paths and crossings.

However, further research developments could refine the assessment system. Firstly, recalibrating the Road Safety KPI to consider road and pedestrian path typology as suggested. In fact, elements of protection from vehicular traffic may vary in importance depending on the classification of the road and pedestrian infrastructure typology (e.g. virtual footpaths or pedestrian lanes). In this scenario, it might be advantageous to consider these factors in their various combinations to identify optimal and critical conditions. Secondly, the Road Safety KPI could be further implemented through the assessment of wayfinding signage along the path. In fact, the presence of easy-to-understand directions indicated through wayfinding signage allows the user to orient himself in space and to reach different destinations through clear and safe paths.

Thirdly, there is potential to expand the Social Security KPI to encompass additional attributes derived from users' perception of security. This is crucial because areas that meet physical security criteria may still be perceived as unsafe by users. It is then possible to consider additional elements related to the quality of the urban context such as the presence of abandoned areas and buildings, litter, or other degradation elements.

Moreover, an additional development of this study could involve correlating these measurable aspects of pedestrian infrastructure security, as evaluated by the proposed methodology, with statistical data on petty crimes. Conducting a comparative study between infrastructure characteristics and adverse events could refine the model and help prioritize interventions.

Additionally, assessing how results change with varying selected station district areas could be valuable. There is no unique method for considering the station district area, and it would be interesting to explore how different calculation of the station district could add value to the model application.

In its future developments, the methodology plans to consider additional KPIs to cover aspects such as accessibility, enjoyment, and inclusive design, with appropriate datasets and audit protocols. Applying the comprehensive methodology in various case studies could provide support in formulating intervention strategies aimed at improving walkability and planning public space regeneration interventions in a complex interaction area like a station district.

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