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Towards Safer and More Walkable Cities: A Spatial Approach in Sustainable Urban Mobility Plans

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Abstract

Sustainable Urban Mobility Plans (SUMPs) guide strategic urban mobility toward safer, low-impact modes. Designing and maintaining networks that reduce car dependency requires assessment of walkability and pedestrian safety. This study analyzes the road network of Vittoria (Ragusa, Italy) to support the SUMP with a scalable methodology. Geometric-functional attributes surveyed on-site are integrated with spatial accident data and evaluated qualitatively and quantitatively. The workflow includes: (i) study area definition; (ii) network model reconstruction and data collection; (iii) integrated database construction and spatial analysis in QGIS. Indicators cover carriageway width, sidewalk provision and width, crossings, access ramps, gradient, continuity, and exposure to vehicle-pedestrian crashes. Buffer-based hotspot analysis around high-risk nodes supports a walkability evaluation with additional parameters. Results highlight issues poor sidewalk maintenance, discontinuities, missing ramps and signage, that hinder walkability and may reduce safety. These findings can guide targeted interventions and offer a practical tool for integrating walkability analysis into SUMPs.

Keywords: Walkability; Sustainable Urban Mobility Plans (SUMPs); Spatial Analysis; Pedestrian Safety; Infrastructure Assessment.

1. Introduction

Urban planning and mobility planning should necessarily be integrated in a modern city (Cervero, 2001; May, Kelly, & Shepherd, 2006). In the past, urban planning focused mainly on zoning, defining land uses and building types, while mobility played a marginal role, limited to ensuring the mobility of people and goods by the current available transport means. Modern cities, designed with a regular grid layout, have improved the subdivision into neighbourhoods, the optimization of space and the connectivity of the

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road network without, however, integrating the two planning concepts (Ellickson, R. C. 2012). In recent years, mobility planning has evolved and integrated planning tools have become established. In Europe, awareness of these issues has grown significantly since 1987, following the introduction of the sustainable development concept in the Brundtland Report (Brundtland, 1987) and, more concretely for mobility, through the Sustainable Urban Mobility Plan (SUMP) approach, now the principal EU framework for city mobility strategies (European Commission, 2021). In Italy, transport planning is regulated at a strategic level by the Sustainable Urban Mobility Plans (SUMPs) where sustainability is intended from an economic, social and environmental point of view (Torrisi et al., 2020; Torrisi et al., 2021). The Ministerial Decree of 4 August 2017 (No. 397) made SUMP adoption mandatory only for metropolitan cities, consortia of municipalities and municipalities with more than 100,000 inhabitants, with subsequent amendments providing clarifications and linking plan adoption to funding (Ministry of Infrastructure and Transport, 2017, 2019). EU policy further reinforces these priorities: the New EU Urban Mobility Framework and the EU Road Safety Policy Framework 2021–2030 call for active-mobility infrastructure and explicit protection of vulnerable road users on the path to Vision Zero (European Commission, 2021). Globally, the World Health Organization estimates 1.19 million road-traffic deaths per year, with pedestrians bearing a disproportionate burden in urban settings (World Health Organization, 2023).

A robust literature links built-environment features—density, diversity, design, destination accessibility, and distance to transit, to mode choice and walking activity (Ewing & Cervero, 2010), while network configuration shapes pedestrian flows and exposure (Hillier, 1996). Empirically, GIS-based safety analyses that integrate crash records with spatial attributes are widely used to detect hotspots and correlate injury severity with road, land-use, and population factors (Hu et al., 2020). Importantly, pedestrian injuries are not limited to collisions: Swedish national register data show that pedestrian fall injuries—often associated with surface conditions and maintenance—account for roughly one third of traffic-environment injuries and nearly half of those causing long-term impairment, with higher incidence among middle-aged and older women (Amin et al., 2022). Evidence from Central and Eastern Europe further documents the severity of pedestrian crashes in urban areas and the influence of crossing design and infrastructure quality (Levulytė-Staškevičienė, 2017; Macioszek, Granà, & Krawiec, 2023).

As emerged from the above-mentioned works, a key aspect of reducing the risk of pedestrian accidents is the analysis of geometric and functional characteristics of pedestrian infrastructures, which helps to identify critical issues and provides valuable support for improving the infrastructure and consequently pedestrian safety. In this regard, the study develops a scalable spatial workflow to support the SUMP of Vittoria (Ragusa, Italy). On-site surveys of geometric and functional attributes are integrated with spatialized police crash data and analyzed in QGIS. Indicators include carriageway width, sidewalk presence and width, marked crossings, curb-ramp availability, gradient, continuity, and exposure to vehicle–pedestrian crashes. Buffer-based hotspot analysis around high-risk nodes complements a qualitative appraisal, enabling a walkability-and-safety screening consistent with SUMP diagnostics and target-setting. Our methodological approach, adopted to perform the walkability analysis, integrated qualitative and quantitative evaluations of the geometric and functional attributes surveyed on site with accident statistics. The research is divided into three main phases:

(i) definition of the study area; (ii) collection and organisation of data and construction of the model in a GIS environment; (iii) calculation of indicators and spatial analysis.

The results reveal maintenance deficits, discontinuities, missing ramps, and inadequate signage, factors that impede walkability and likely elevate risk, thus informing targeted interventions and offering a practical template for embedding walkability and pedestrian-safety analysis into SUMPs. The paper is divided into four main sections. The first introduces the research problem and illustrates possible solutions; the second, dedicated to materials and methods, describes the case study, the datasets used, and the methodological approach adopted for the analysis. The third section presents the results through illustrative maps and tables, accompanied by a brief discussion on the main findings. Finally, the fourth part concludes the study and suggests possible developments and directions for future research.

2. Materials and methods

This section outlines the methodological approach adopted to perform the walkability analysis combined with socio-economic data and accident statistics. The work is structured into several operational phases. First, the study area was identified, and then it was reconstructed within a GIS environment. Based on the network modelled using links and nodes, the input data were collected and organized to support spatial analyses. Finally, the creation of a structured database supported spatial analyses aimed at evaluating walkability, through the assessment of geometric-functional attributes of the pedestrian network and the identification of its main critical issues.

2.1 Study Area Definition

The first phase involves defining the study area and identifying its main key territorial features.

Research activities focused on analysing the road network of the Municipality of Vittoria (Ragusa, Italy). Located at an altitude of 168 m a.s.l., it is characterised by essentially flat terrain and covers an area of 182.48 km². As of 15 December 2022, it had a resident population of 63,316 inhabitants, with a population density of 346.98 inhabitants/km² (ISTAT data). The municipal area also includes Scoglitti and borders the municipalities of Acate, Ragusa, Comiso and Chiaramonte Gulfi. Founded in 1607, Vittoria is characterised by a grid-like urban layout featuring regular roadways composed of wide streets with a straight alignment (Fig. 1).

This area was selected because, during the elaboration of the Sustainable Urban Mobility Plan (SUMP), the Municipality had recently commissioned an extensive field survey campaign and expressed its intention to provide detailed information and supporting data that it already possesses.

From an urban and territorial perspective, the Municipality of Vittoria is a particularly significant case. It features a regular and compact urban layout resulting from planned development but also presents several critical issues. The first of these concerns traffic congestion: Vittoria is one of the most populous municipalities in the province of Ragusa, playing a central role in the local economy due to the presence of one of the largest fruit and vegetable markets in Southern Italy. This leads to substantial heavy vehicle and commercial traffic, adding to daily urban mobility and increasing congestion in certain areas.

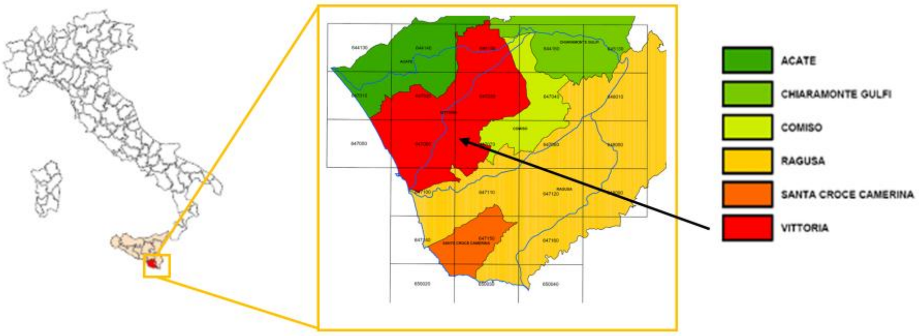

Figure 1: The territorial context of the municipality of Vittoria and the surrounding cities.
Source: Authors elaboration from ''Piano Stralcio di Bacino per l'Assetto Idrogeologico (P.A.I.)''

Another critical issue is the inadequate pedestrian infrastructure, as highlighted in the preliminary technical documents prepared for the SUMP. These documents revealed shortcomings in both pedestrian safety and road infrastructure.

Finally, Vittoria has many points of interest (POIs), such as educational institutions, hospitals and areas of high economic activity (e.g. local markets and the historic city centre). The significant demand for pedestrian mobility generated by these POIs fully supports the need for a walkability analysis.

Specifically, the study area includes the entire city centre of Vittoria. For analytical purposes, the urban fabric was divided into 12 grids, shown in the aerial photograph below (Fig. 2), which served as the basis for the subsequent data collection. However, subsequent phases of the analysis focused on the urban core only, excluding grids 10 and 11, which are more peripheral and of minor interest.

Figure 2: Identification of the study area and subdivision in grids
Source: Authors elaboration from Google Earth

2.2 GIS-Based Reconstruction and Data Collection

The second phase involves collecting the data required for the following spatial analyses. The road network of the study area was reconstructed and digitalised in a Geographic Information System (GIS) environment using QGIS software and modelled as a graph consisting of a set of links and nodes. Based on this, the data for subsequent spatial analysis and assessment of the main critical issues was acquired and then organised in a georeferenced database. Specifically, the graph was extracted from OpenStreetMap (OSM), with each road segment (link) and intersection (node) associated with a unique numerical ID for identification purposes. The portion of the graph identified for the study area comprises approximately 1,800 links and 1,300 nodes. The attributes selected for the characterization of the road network in the study area refer to the geometric and functional features of the pedestrian infrastructure, as summarized in Table 1. They were distinguished for sidewalks and pedestrian crossings and initially assessed from a qualitative point of view and then converted into quantitative assessment to support the overall walkability evaluation.

These attributes were surveyed and the data was collected through remote surveys using software such as Google Earth and Google Street View. Then, this was validated through subsequent on-site inspections, regarding road and sidewalk width, condition of maintenance and pedestrian crossing provision.

In addition, the Municipality of Vittoria provided data on accidents that occurred in this area between 2019 and 2022 in order to conduct further analysis. The accidents were classified by type: (i) accidents with no injuries, (ii) accidents with injuries, and (iii) fatal accidents. The presence of pedestrians involved in each accident was also taken into account.

Table 1: Walkability indicators

Indicator	*Qualitative assessment*	*Quantitative assessment*
i_1 link type	Pedestrian; Vehicular	/
i_2 sidewalk provision	Both sides; Right side only; Left side only; Not present	2; 1; 1; -1
i_3 sidewalk width	Both sides [>1.5m]; Both sides [>90cm and <1.5m]; Right/left sides [>1.5m]; Right/left sides [>90cm and <1.5m]; Not present	2; 1,5; 1; 0,5; -1
i_4 sidewalk access ramps	yes; no	1; -1
i_5 gradient	low gradient [<6%]; high gradient [>6%]	1; -1
i_6 presence of lighting	yes; no	1; -1
i_7 sidewalk maintenance*	Sufficient; Insufficient	1; -1
i_8 continuous path	yes; no	1; -1
i_9 crosswalk provision	yes; no	1; -1
i_{10} crosswalk access ramps	yes; no	1; -1
i_{11} obstacles on sidewalk	no; yes	1; -1

* evaluated based on the quality of the sidewalk surface (regular, continuous surface without defects vs. presence of potholes, cracks, rutting, localized depressions or surface disintegration)
Authors elaboration.

2.3 Database Structuring and Spatial Analysis for Walkability Evaluation

The third step involved creating a structured database containing the surveyed road network attributes and accident data to conduct the spatial analysis.

Thematic maps associated with the surveyed network attributes and accident data were then created using QGIS software, enabling the effective identification of main critical points across the analysed network links.

Specifically, the following thematic maps were generated:

- Cross-sectional dimension
- Sidewalk provision
- Sidewalk width
- Crosswalk provision
- Location and number of vehicular accidents;
- Buffers at node with pedestrian accidents.

Based on the last map, nodes where pedestrian accidents occurred were identified, and 100-meter buffer zones were generated around them. A walkability analysis was performed within these areas of influence, aiming to evaluate the infrastructural characteristics of the road segments included in the buffers and to identify potential criticalities related to walkability. In this regard, building upon the methodology proposed by (Ignaccolo et al., 2020), this study revises and adapts the calculation of Walkability Index (Eq. 1) to compute a Zone Walkability Index $ZWI_{b_i,r}$ for each buffer b_i with radius r around nodes with pedestrian accidents occurred, following Eq. 2:

$$WI_{l_j} = i_2 \times \left[1 + \frac{(i_3+i_4+i_5+i_6+i_7+i_8)}{7}\right] + i_9 \times [1 + \frac{i_{10}+i_{11}}{2}] \tag{1}$$

$$ZWI_{b_i,r} = \frac{\sum_{i=1} WI_{l_j}(b_i)}{n_{b_i}} \tag{2}$$

where: n_{b_i} is the number of links l_j within the buffer b_i;

WI_{l_j} is the Walkability Index of link l_j within the buffer b_i.

Finally, the $ZWI_{b_i,r}$ is normalized in order to allow for meaningful spatial analysis across the study area.

3. Results and discussion

This section provides an in-depth examination of the geometric and functional characteristics of the road network through targeted spatial analyses. It then investigates the spatial distribution of road accidents to highlight high-risk areas. Finally, it assesses pedestrian mobility quality by identifying critical issues that may hinder walkability within the analyzed urban environment.

3.1 Spatial analysis of geometric-functional network attributes

The spatial analysis of the pedestrian network infrastructure was based on the previous extensive survey campaign and the creation of a georeferenced database in QGIS. Figure 3 shows the width of the streets, including the possible presence of parking areas, but not the extension of sidewalks. This map shows that most of the streets in the study area are one-way. In terms of carriageway dimensions, about half of the street segments fall within the 3.5–6-meter range, while the rest measure between 6 and 9 meters. In a grid-like urban layout such as that of Vittoria, where frequent intersections and stop signs naturally limit vehicle speeds, these carriageway dimensions offer valuable potential for street redesign. Wider sections could be reconfigured to support sidewalk extensions or the inclusion of cycling infrastructure, where appropriate.

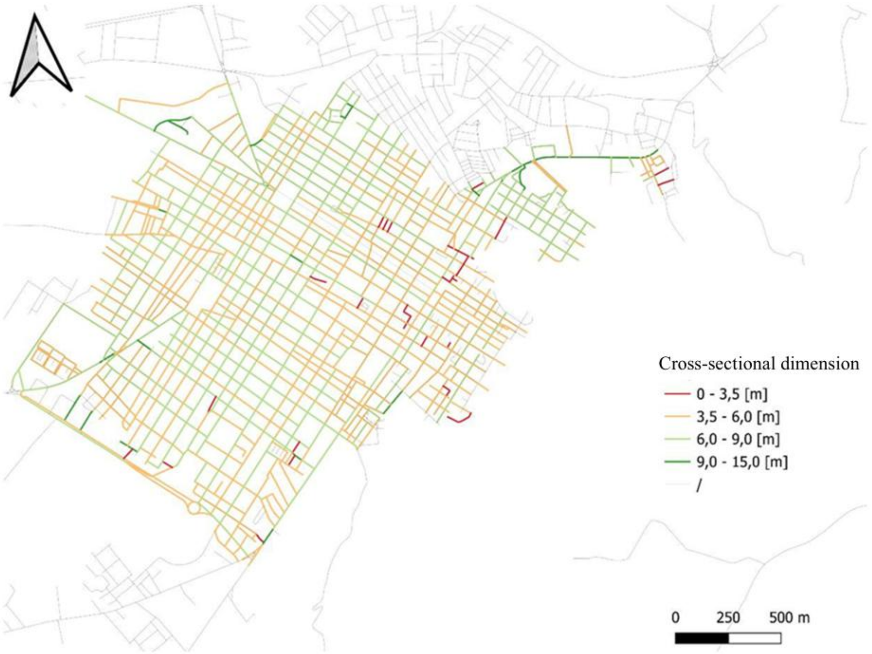

Figure 3: Cross-sectional dimension
Source: Authors elaboration

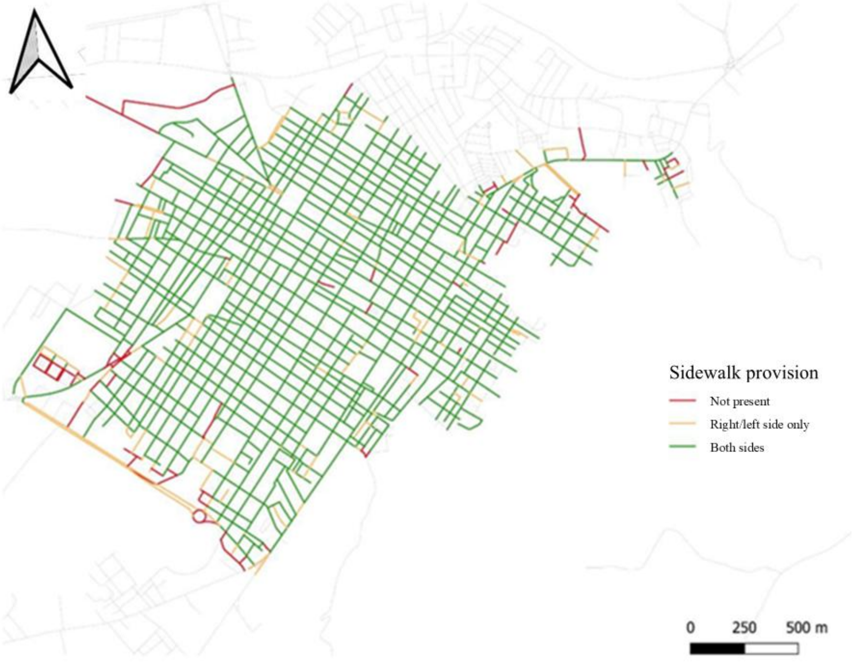

Fig. 4 Sidewalk provision
Source: Authors elaboration

Figures 4 and 5 show the sidewalk provision (on both sides or only one side) and the width, respectively. According to this analysis, sidewalks are recognized only if their width exceeds 90 cm; widths below this threshold are not classified as sidewalks. It shows that around one hundred links have no sidewalk provision, but these are generally short segments located in peripheral areas. However, Figure 6 illustrates analyses the presence of pedestrian crossings along roads and at intersections. It emerges that pedestrian crossings are not widely distributed throughout the study area. Only 15% of links feature zebra crossings, whereas over 1,500 links lack any pedestrian crossing facilities.

Fig. 5 Sidewalk width
Source: Authors elaboration

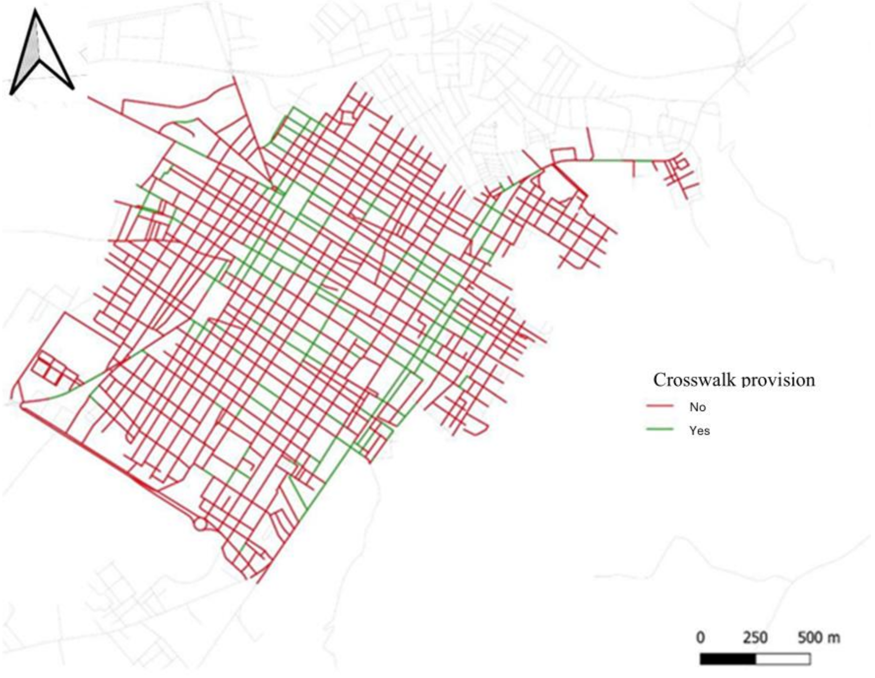

Fig. 6 Crosswalk provision
Source: Authors elaboration

3.2 Accidents spatial analysis

Examining urban accident data between 2019 and 2022 revealed that, although the absolute number of fatal accidents was not very high, vulnerable groups were involved. As shown in Table 2, the number of accidents was also recorded after classifying them by type.

Table 2: Summary table of the road accidents analyzed in the study

Analysis period	2019-2022
Total accidents	446
Non-injury accidents	264
Injury accidents	180
Fatal accidents	2
Pedestrian-involved accidents	*9*

Authors elaboration.

Figure 7 illustrates the results of the spatial analysis concerning nodes involved in accidents. These nodes are represented on the map according to the number of accidents that occurred at each location, ranging from a minimum of one to a maximum of nine accidents.

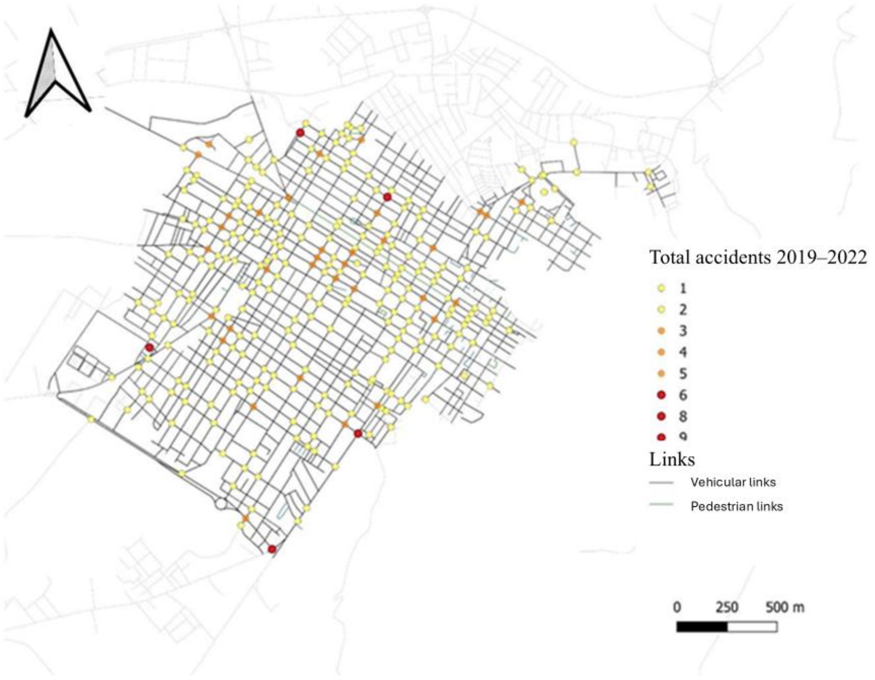

Fig. 7 Location and number of vehicular accidents
Source: Authors elaboration

In this regard, Figure 8 presents a series of images documenting the main issues observed at the nodes highlighted in red in Figure 7, which correspond to intersections with the highest accident rates. Figure 8a illustrates one of the most prevailing issues across the entire urban road network: the absence of horizontal and vertical signage. This creates a high level of uncertainty when executing turning manoeuvres, consequently increasing the risk of accidents.

Figure 8b shows where visibility is affected, especially close to intersections, where there are often traffic islands covered in vegetation. The height of the vegetation often exceeds that of a vehicle's windscreen, thereby limiting visibility between road users. These elements actually compromise the ability to correctly assess traffic conditions from other directions. Consequently, to obtain an adequate view when crossing the intersection, vehicles must partially advance into the conflict area, thus increasing the risk of conflicts. Figure 8c shows a recurring problem of illegal parking occupying road lanes. This leads to particular criticality in the proximity of intersections, where the maneuvering space is reduced and the visibility required for safe turns is compromised.

Although vertical signs are present in Figures 8d and 8e, there are critical issues related to their positioning. At several points along the road network, the signs are either insufficiently high or partially covered by vegetation, which compromises their visibility to road users.

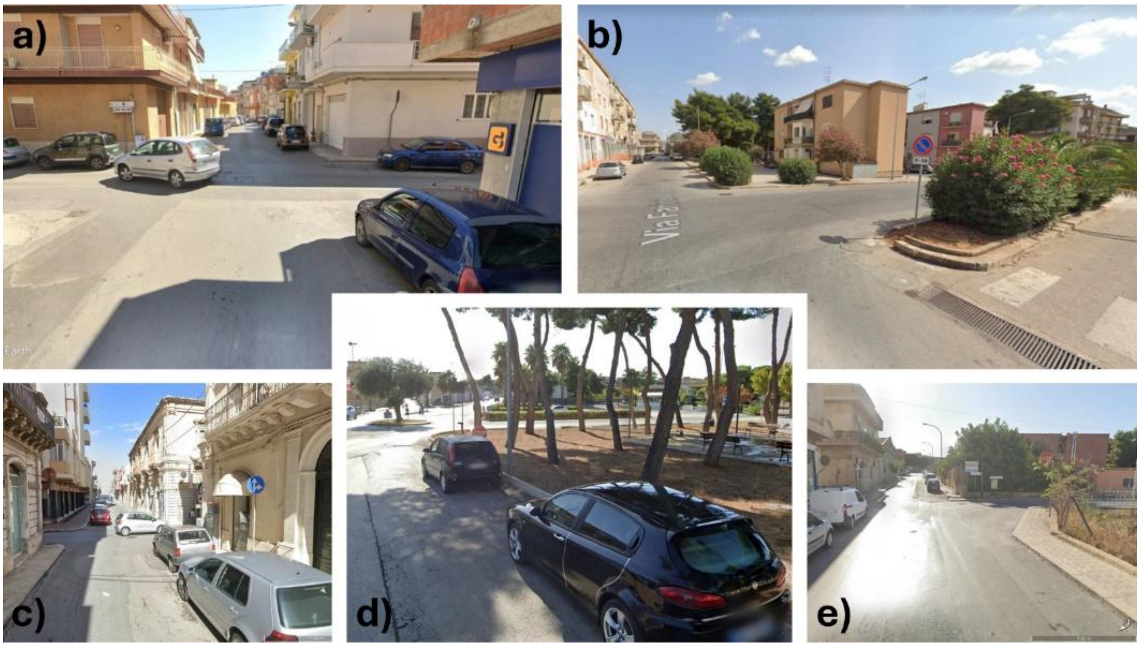

Fig. 8 Critical network nodes
Source: Authors elaboration

This was followed by conducting a spatial analysis of accidents involving pedestrians. To identify critical nodes in the urban road network, a spatial analysis was carried out, considering 100-meter buffer zones to define the influence area around each highest-risk node and to aggregate accident events accordingly. This approach led to the identification of seven critical areas (see Figure 9), covering a total area of around 31,400 m² (equivalent to 3.14 hectares). Walkability analyses were then conducted on these areas, as described in the next section.

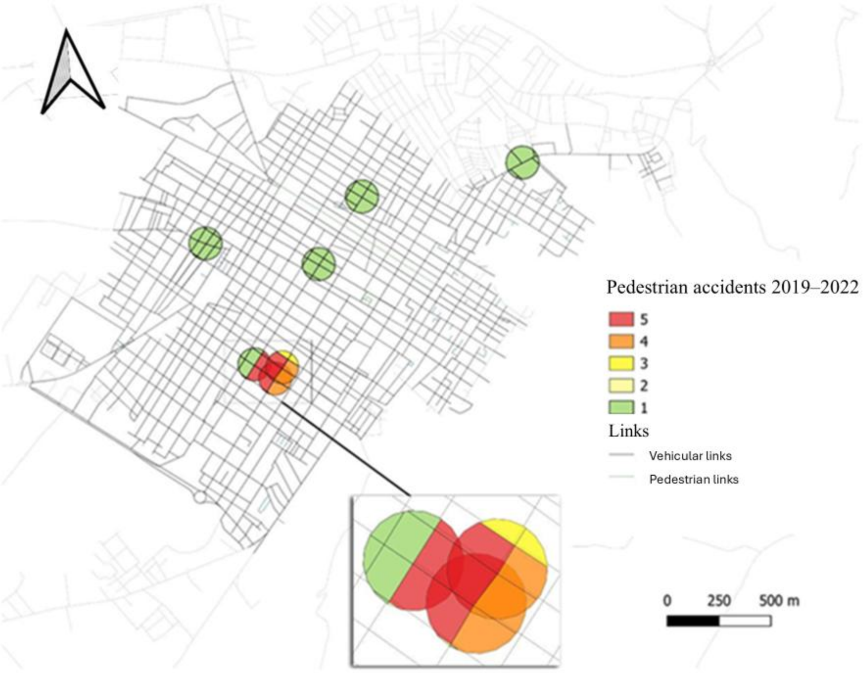

Fig. 9 Buffers of 100m at node with pedestrian accidents
Source: Authors elaboration

3.3 Walkability analysis and identification of critical issues

The walkability analysis, as specified above, was conducted on all road links within the 100-metre radius buffer areas around the seven nodes where pedestrian accidents occurred. On-site surveys were carried out in each area to collect the necessary data (according to Table 1) to calculate the WI. Once normalised between 0 and 1, it was plotted on the map in Figure 10, with the road links falling within the buffers. This enables an effective assessment of walkability conditions across the analysed areas.

Of the 110-street links analysed, 23 have a WI below 0.2, which indicates that conditions are insufficient for pedestrian mobility. Most of the links (73, or 67% of the total) have intermediate values, ranging from 0.2 to 0.6. Just 13 links (11% of the total) are in the upper classes, with a WI between 0.6 and 1, suggesting that only a small proportion of the examined road network offers adequate conditions for pedestrians. As shown in Figure 11, the key issues in the pedestrian network are highlighted. These are mainly due to the lack of ramps for access to the sidewalk (Figure 11a and Figure 11f), the absence of horizontal and vertical signs indicating the pedestrian crossings provision (Figure 11c), and parking vehicles on the same crossings (Figure 11d). Permanent obstacles along pedestrian paths (Figure 11b) and poor maintenance of the pavement surface (Figure 11e) are additional issues. These conditions significantly compromise the safety and functionality of the pedestrian network, particularly for people with reduced mobility or disabilities.

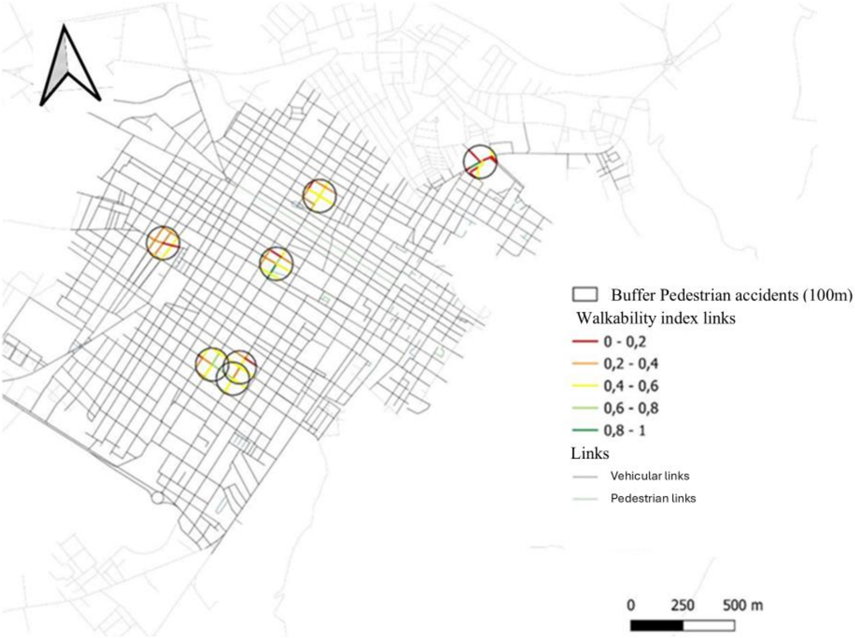

Fig. 10 Walkability Assessment inside buffer zones around pedestrian accidents locations
Source: Authors elaboration

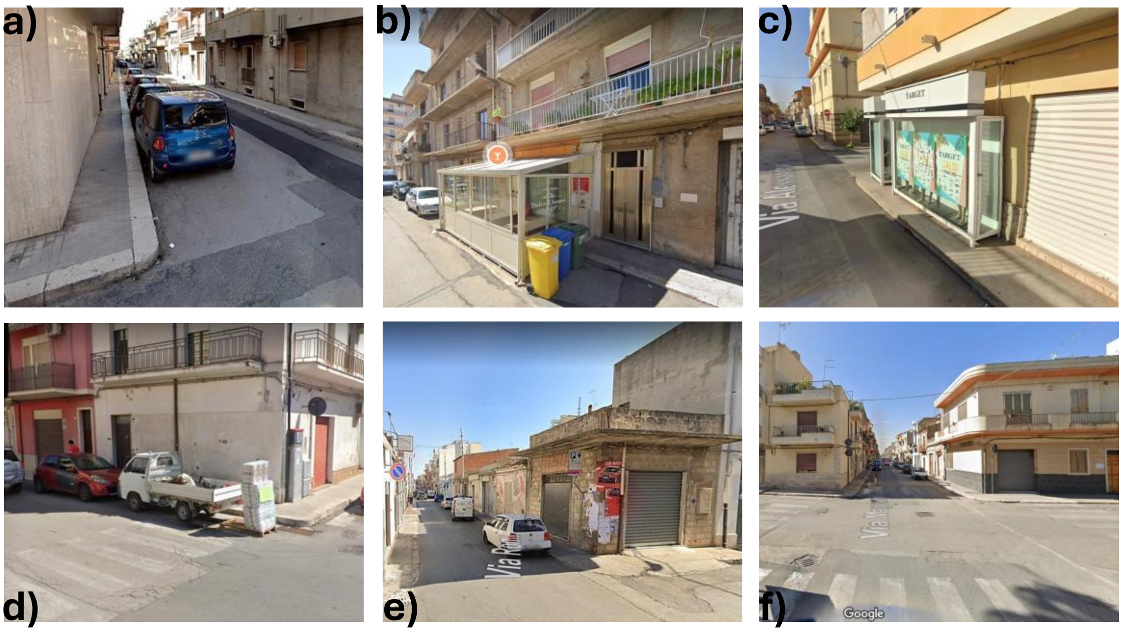

Fig. 11 Critical Issues of pedestrian network
Source: Authors elaboration

Based on the previously identified buffers, an overall assessment of walkability was conducted by calculating the $ZWI_{b_i,r}$, which is the average of the values of road segments within the relevant buffer. The results show values between 0.27 and 0.50, indicating that all the analysed areas are in the intermediate range and highlighting the need for generalised interventions to improve the quality of the pedestrian environment. To address these issues and enhance pedestrian walkability, it is recommended to implement low-cost and high-impact measures such as the provision of ramps at sidewalk access points, the regular maintenance of pavement surfaces, and the enforcement of regulations against illegal parking on pedestrian crossings. Additionally, improve pedestrian signage and ensure the removal of permanent obstacles can significantly increase both safety and walkability and would contribute to improving the overall quality, safety and walkability of the pedestrian network.

4. Conclusions

This work defined a methodology to identify critical areas within the urban network, with the aim of promoting walking. In particular, the quality of pedestrian infrastructures (i.e. pavements and crossings) was assessed to see whether they could constitute a viable alternative to private car use in urban centres. However, the lack of adequate infrastructures and the perceived sense of risk still lead many users to prefer the motorised vehicle, even for short journeys.

The proposed methodology integrates both infrastructural data and pedestrian accident data. The method was tested on the case study of Vittoria, one of the most densely populated municipalities in the province of Ragusa and a crucial hub for the local economy, causing intense commercial and heavy traffic that increases urban congestion in some areas. Through a spatial analysis based on buffers defined around the nodes with the highest number of pedestrian accidents, priority areas for intervention were identified, for which a Zonal Vulnerability Index (ZWI) was calculated as a measure of the quality of the pedestrian infrastructure: all the areas identified with critical buffers have values between 0.27 and 0.50, falling within the ‘insufficient’ range (0.2-0.6).

The analysis made it possible to identify the critical areas on which to operate, but also confirmed the very close correlation between the Zonal Vulnerability Index and the accident risks, reinforcing the validity of the method; these results are particularly useful within planning tools such as the PUMS, but also to support tactical planning, guiding the definition of targeted interventions able to immediately reduce pedestrian accidentality (often the most severe) and improve the perception of safety of resident users. Finally, the proposed strategy is easily replicable in different territorial contexts, offering local administrations an operational guide to concentrate resources and measures in the areas at highest risk, optimizing the use of available funding and promoting safer and more sustainable mobility.

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