Development of a Walkability Index in Support of Urban Planning Decision-Making

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Abstract. By 2030, cities will be home for more than 60% of the global population. In the drive for sustainability, the challenges facing urban planning will be particularly important. In this regard, walking emerges as a powerful tool. Walkable environments offer social, economic, and environmental benefits, but pedestrian mobility is often overlooked in urban infrastructure investments. Differently than the classical conception of "accessibility", "walkability" adds new emphasis on spatial quality and the capacity of the environment to encourage pedestrian mobility. Walkability is defined both as the degree to which open spaces encourage walking and, within suitable distances, the presence of accessible destinations. This article proposes a methodology integrating indirect audit and GIS-based for comprehensive assessment of walkability at the neighbourhood level. The results yield a gravitational accessibility measure enriched by a composite index, highlighting deficiencies in the open space system and guiding urban-planning interventions.

Keywords: First Keyword · Second Keyword · Third Keyword

1 Introduction

The escalating trend of urbanisation, with UN (United Nations) projections indicating that over 60% of the global population will reside in urban areas by 2030, presents significant challenges for sustainable urban development and public health [1]. Enhancing walking accessibility—or walkability—is increasingly recognised as a critical strategy to address these challenges. Walkable environments are linked to a multitude of social, economic, and environmental benefits [2], including improved public health through reduced chronic diseases [3, 4], lower air pollution [5], increased property values [6], enhanced social interaction and cohesion [7, 8], and various psychological benefits [9]. However, despite these clear advantages, investment in urban infrastructure often fails to adequately prioritise pedestrian mobility [10].

Historically, urban design since the advent of the automobile has predominantly favoured car-oriented layouts, with a strong emphasis on road and parking infrastructure. Consequently, retrofitting cities to be more pedestrian-friendly is not only costly but also confronts ingrained societal attitudes. The substantial long-term benefits of pedestrian-friendly policies are often underappreciated and overlooked in decision-making processes. This oversight is compounded by a general lack of comprehensive

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O. Gervasi et al. (Eds.): ICCSA 2025, LNCS 15898, pp. 197–209, 2026.
https://doi.org/10.1007/978-3-031-97657-5_12

data on pedestrian movements, preferences, and needs, hindering policymakers' ability to justify and prioritise investments in appropriate infrastructure. Furthermore, urban planning practices frequently lack standardised methodologies capable of holistically accounting for the physical, social, and environmental variables influencing walkability, which are applicable for both ex-ante and ex-post evaluations.

The current state of the art in measuring pedestrian mobility largely focuses on quantitative metrics related to the distribution and accessibility of spaces, services, and movement activities, typically expressed in terms of impediments such as journey time, cost, and distance [12, 13]. While these methods provide valuable data on network efficiency and spatial reach, they possess a significant limitation: a tendency to overlook the crucial qualitative aspects of the urban environment that actively encourage or discourage walking. Factors such as the perceived attractiveness, safety, and comfort of routes, as well as the nuanced effects of individual constraints and preferences, are often inadequately captured [13–16]. Thus, conventional accessibility measures fall short of providing a comprehensive understanding of walkability, representing a distinct gap in the current literature and practical tools.

To address this identified gap and advance beyond existing methodologies, our research introduces a novel framework for assessing the quality of the urban walking environment. This framework employs a hybrid quantitative-qualitative methodology, which innovatively combines established accessibility measures (e.g., proximity to essential services) with a detailed qualitative and quantitative assessment of key features within the open-space network. Our focus on open spaces—defined in urban planning as unbuilt, publicly accessible areas like parks, squares, sidewalks, and greenways—is deliberate. These spaces are integral to pedestrian mobility and offer the highest potential for positive transformation. Safe, accessible, and well-designed open spaces are crucial for a successful pedestrian network, offering pleasant environments that encourage walking as a primary mode of transport and improving connectivity between different urban zones, thereby making walking a more attractive option and reducing reliance on motor vehicles [17].

This comprehensive approach aims to overcome the limitations of previous methods by providing a more holistic measure of walkability. The findings are expected to have significant implications for urban planning, offering practical solutions and robust data to support policymakers in identifying priority areas for intervention and in championing investment in pedestrian-centric urban futures.

2 Literature Review

"Walkability" can be seen as a measure of the extent to which an environment contributes to the promotion of walking as the main form of transport [18]. This concept transcends the classic definition of pedestrian "accessibility" as the distribution of opportunities in space, and takes into consideration factors that shape the relationships between individuals and urban space [14] Many studies, however, apply the terms of accessibility and walkability interchangeably [19, 20]. Recently, [21] systematically reviewed the proliferation of the two terms in pedestrian research, revealing that they have typically been used as near synonyms, particularly in relation to road design.

Within the scientific debate, accessibility is often applied as an operational concept expressing the degree of connection of an area with respect to the surrounding environment, i.e. transport linkages between land uses [22]. Accessibility can also be defined as the potential for interaction with a specific place within urban space, thus as the measurement of impediments to movement [11]. The literature provides further definitions of accessibility based on the economic theory of random utility, which states that individuals are rational agents that behave to maximize their expected benefit or utility [23, 24]. According to such approaches, utility-based accessibility measures the ease of reaching destinations of value to the individual, considering their specific needs and preferences.

However, for pedestrians, these definitions may be limiting. According to Hess [25], for example, accessibility in regard to walking could incorporate the idea of reaching multiple destinations within comfortable times, such as between five and twenty minutes. The concept of the "15-min city" emphasizes the importance of having essential services within comfortable walking distance. Moreno et al. [26] propose that destinations can be classified in terms of the six fundamental social functions of living, working, caring, provisioning, and recreation. The purpose of travel, however, can vary depending on socioeconomic factors. Weng et al. (2019) [27] assessed the relative importance of services in categories such as education, healthcare, municipal administration, finance, telecommunications, commercial services and services for the elderly. The importance of these was evaluated through a questionnaire that asked respondents to specify the frequency of their visits to the services within a month. The results showed that distinct categories of the population visited services of different natures; for example, markets were more frequently visited by the elderly than schools.

Table 1 summarises six studies that, as in Weng et al. [27], propose methodologies for measurement of pedestrian accessibility to essential services at the neighbourhood level. Each study examines a different city, examining the proximity of essential services referenced by the planning documents for the different municipalities. Plan Melbourne 2017–2050 [28], for example, proposes that pedestrian accessibility to essential services can create healthier and more liveable communities, and that accessibility must be considered in relation to combinations of land uses, housing types and quality public transportation. Plan Melbourne introduces the concept of the "20-min neighbourhood" in three pilot projects: Croydon South, Strathmore, and Sunshine West, where 20 min is the desired limit for arrival to or return from a service, on foot. Examining the six studies for the different cities, we are able to identify seven service categories to which access is seen as essential for the activities of neighbourhood residents.

Both the academic and non-academic literature (scientific and grey literature) tend to define pedestrian accessibility quantitatively, as the sum of services and opportunities reachable on foot from a starting point, typically a person's residence. However, focusing solely on residence as the starting point for accessibility measures can be restrictive [29].

The levels of pedestrian mobility, however, does not depend solely on the distribution of activities and their distances from the individuals' residence [14]. Pedestrians will make their choices differently, varying their destinations and routes based on personal and environmental factors [30]. In recent years, therefore, there has been a trend

Table 1. Municipalities and proximity services.

		Edinburgh	Barcelona	Alghero	Krakow	Melbourne	Gothenburg
Mobility	Bus Stop	*	*		*	*	*
	Train Stop		*		*	*	
	Parking Spot	*					
	Bike Stop						*
Education	Nursery			*	*	*	*
	Preschool	*	*	*	*	*	
	Primary School	*	*	*	*	*	
	Secondary School	*	*	*		*	
	University			*			
	Library	*		*	*	*	
Food retail	Market	*		*	*	*	*
	Supermarket	*		*	*	*	*
	Restaurant	*		*	*	*	
	Bar	*			*	*	
Retail	Shop	*		*	*		*
Health	Assistance			*		*	*
	Clinic			*			
	Pharmacy					*	*
	Hospital			*			
Leisure	Cinema	*		*			*
	Theatre	*		*			
	Museum			*			
	Sport facility				*	*	*
	Gym				*		*
Urban space	Green area	*		*	*	*	*
	Square	*		*		*	*
	Playground	*			*		*
		[50]	[47]	[14]	[48]	[28]	[49]

towards including perceptive and social factors in measurement of "walkability", advancing a more multidimensional concept [15], in particular including consideration of the

environmental character of open spaces in the development of measures of pedestrian accessibility [15, 31].

Researchers have explored different spatial factors related to walkability. Cervero & Kockelman (1997) [32] found that higher building density, mixed land use, and well-designed urban landscapes can reduce car dependence and promote choices for mobility via public transportation, cycling and walking. The authors summarise the determining factors along dimensions of "Density, Diversity, and Design (3D)". Additional dimensions, including proximity to public transportation and destination accessibility, have been incorporated over time and the list of spatial factors associated with walkability has grown considerably. Ewing & Handy (2009) [33] classify the characteristics of the urban environment that encourage walking into five categories: imaginability, enclosure, human scale, transparency, and complexity. The London Planning Advisory Committee (2004) introduced the "5C" approach, emphasizing that pedestrian-friendly places should be "connected, convenient, comfortable, convivial, and conspicuous". Moura et al. (2017) [34] subsequently expanded this, arguing that citizens must be involved in shaping the walkable street environment, and therefore that planning must consider "coexistence and engagement".

The conceptualization of open space as a network of potential movement can assist planners in encouraging walking choices. Surfaces can be classified as exclusively pedestrian (e.g. pedestrian-only streets), mixed (parallel flows of pedestrian and vehicles), and crossing (signalled or non-signalled). Design should limit conflicts between cars and pedestrians through the separation of surfaces [35] and should provide plausible "desired lines" for pedestrian movement, including appropriate crossings.

In line with Blečić et al. (2020) [36], we survey the literature considering four factors in the conception of walkability in urban spaces: (1) efficiency and comfort; (2) safety; (3) pleasantness; and (4) attractiveness. Within each of these, we attempt to group the variables with the greatest influence on that factor of walkability. Our proposal is that design in consideration of these factors and variables can improve the potential of the built environment, allowing more effective use of opportunities. The factors are not mutually exclusive, but rather complement each other and contribute to a comprehensive evaluation of walkability. Table 1 summarizes found in literature and linked with the four factors of walkability.

Beginning from theoretical definitions, researchers have developed techniques for the assessment of walkability. These can be classified into two main operational categories: assessment at the macro level (city, city sector), and at the street or neighbourhood level.

The studies at macroscale apply factors such as connectivity, density and variety of uses into consideration in the measure of pedestrian accessibility [46]. A popular tool in this category is the Walk Score (2023) [47], which uses an algorithm to assign points to areas based on distance from services, population density and other metrics. The Walkability Index [48] considers building density, multifunctionality and connectivity (measured by calculating the frequency of road junctions in each area), as well as the net areas of commercial activities. The operability of macroscale studies is supported by GIS (Geographical Information System) software such as ArcGIS, GRASS or QGIS, which simplify data collection and processing. QGIS in particular is an easy-to-use

Table 2. Factors and ensamples of variables influencing walkability.

Factors	Description	Examples of Variables	References
Efficiency and Comfort	Convenience and ease of walking and no presence of difficulties and constraints. Includes physical features that affect pedestrian movement and the use of open space	Cost; Distance; Time; Route continuity; Protection; Lighting; Floor maintenance; Transit signals	[37–39]
Safety	Exposure of pedestrians to traffic-related risks (including conflict factors and interference or protection) and the sense of personal security understood as uncertainty transmitted by the urban environment	Traffic volume; Maximum speed; Street parking; Crossing geometry; Flow separation; Acoustic and Light signals; Crime rate; Lighting; Cleanliness level	[40, 41]
Pleasantness	"Vibrant" and "beautiful" atmosphere that features an urban design which encourages the pedestrian to spend time in that space	Space atmosphere; Aesthetics; Architectural and Urban design quality; Surface texture; Building permeability; Urban texture	[34, 42, 43]
Attractiveness	Presence, opportunities and services accessible on foot	Number; Density; Measure and Diversity of space uses; Hours of operation; Number of opportunities; Frequency of service	[14, 44, 45]

open-source platform, operable on a full range of functions using algorithms loaded as code or plugins.

Studies at the neighbourhood or street level, instead, typically assess the quality of paths, directing attention to the physical and perceptual characteristics of the built environment, such as sidewalk width, qualities of pavement, permeability of open spaces, but also the sense of security [49]. This type of evaluation can be carried out using surveys, interviews and questionnaires, and through direct audits by expert observers, analysing subjective factors related to walkability. The better-known direct audit methods include SPACES (Systematic Pedestrian and Cycling Environmental Scan), the PBIC Checklist (Pedestrian and Bicycle Information Center) and PEDS (Pedestrian Environment Data Scan). In place of visual checks at street level, the audit of the built environment can also be conducted by tools such as Google Street View [40, 41]. Differently than direct audit or interviews, some methodologies assess walkability though GPS-linked data provided by the mobile phones of pedestrians, or gathered using machine learning [51–53].

From this literature review, we can see that the concept of walkability has evolved over time, in particular taking on multidimensional and multiscale aspects for a fuller,

more wholistic vision of the relationships between pedestrians and urban space, and applying mixed tools of data gathering in assessment.

3 Methodology

Open spaces, in the context of urban planning, refer to areas that are not built upon and are typically accessible to the public, such as sidewalks, squares, parks and green spaces. Walkability is then understood as the degree to which the system of open spaces, and presence of destinations useful in daily life, encourages and supports walking as the mobility mode. The main objective of methodology presented in this paper is the creation of a walkability index at a neighbourhood scale, that can be implemented to support urban planning decision processes.

Figure 1 shows the methodology workflow, which consists of five phases. First, the open space system is identified and conceptualized as a network. Next, data on the system's components, as well as origins and destinations, are collected. Then, each component of the system is assigned a grade based on four factors, collectively forming the Walkability Index (W_i), thereby evaluating the quality of the open spaces. This W_i is then incorporated into the Total Walkability Score (TWS), an accessibility assessment that also accounts for the time needed to reach destinations. Finally, the Total Walkability Score helps identify the areas with the most critical issues, and guides the implementation of interventions.

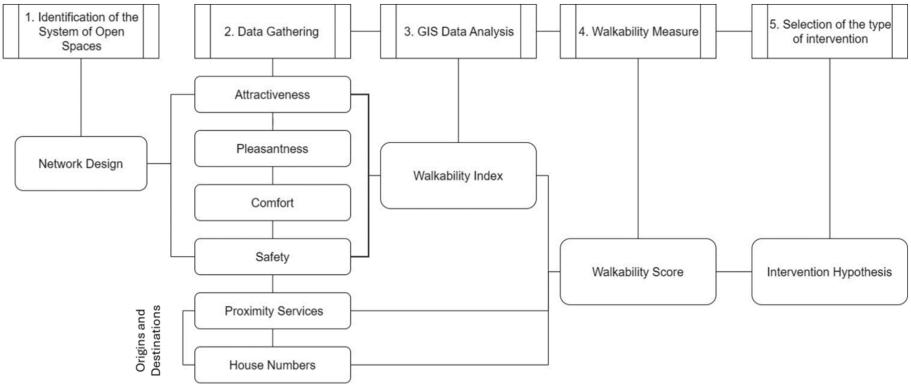

Fig. 1. Methodology workflow

The proposed measure takes the name of Total Walkability Score (TWS), representing the degree of proximity of a destination from an origin, following a walking path within open space that is attractive, pleasant, comfortable and safe. The component terms are defined as follows:

1. Origin – a pedestrian residence;
2. Destination – the service areas grouped under the seven categories indicated in Table 1 of the preceding literature review;

3. Path – the route between origin and destination with least restrictions, conceptualized in terms of the types of surfaces travelled by pedestrians through the relative open spaces;
4. Attractiveness, comfort, pleasantness and safety – the factors listed in Table 2 of the preceding literature review, represented by the selection of independent and observable variables explaining the relative factor.

$$TWS_n = \sum K_m * \delta_m \quad (1) \qquad TWS_n \in \{0,1\}$$

$$\begin{cases} \delta_m = 1 \rightarrow p_n \in \Omega_m \\ \delta_m = 0 \not\rightarrow p_n \in \Omega_m \end{cases}$$

$$\begin{cases} p_n \in \Omega_m \rightarrow t_{mn} \leq 15min \\ t_{mn} = \sum (W_i * v) * l_i \end{cases}$$

p_n= n-th origin
Ω_m= Service area of typology of the m-th service
t_{mn}= Time from n to m
W_i= Walkability index of the i-th component
v: 5 km/h
l_i= I-th segment length

(1)

The TWS represents the sum of the weights K_m of each service category that can be accessed in a maximum time of 15 min, considered as the maximum time that each pedestrian is willing to walk. δ_m represents is a Kronecker delta, which assumes the value 1 when the destination is reachable within the selected threshold and 0 if not. Equation 1 is used to calculate the TWS of the segment n though the weighted sum of the values of each variable.

The Walkability Index (W_i) is integrated within the measurement in the calculation of the time needed to reach the proximity service. This measure is multiplied by the average pedestrian speed that is assumed equal to 5 km/h according with previous literature [43, 44] and by the length of each stretch travelled, which varies from section to section. The W_i measures the suitability of the pedestrian paths inside the open spaces. It can be analytically computed using Eq. 2, so that it represents the weighted sum of four indices (Safety Index (*Is*), Attractiveness Index (*Ia*), Comfort and Efficiency Index (*Ic*) and Pleasantness Index (*Ip*)) that represent factors not directly measurable, but which are explained by 14 qualitative and quantitative variables. The *K* represents the weight of each factor.

$$\begin{aligned} &W_i = K_s \cdot Is_i + K_c \cdot Ic_i + K_a \cdot Ia_i + K_p \cdot Ip_i \\ &K_s + K_c + K_a + K_p = 1 \\ &W_i \in \{0, 1\} \end{aligned} \quad (2)$$

4 Conclusions

Walkability is a concept that extends beyond mere accessibility, considering not just the proximity of destinations but also the crucial quality of pedestrian paths and the overall user experience. While accessibility is traditionally defined as the potential for interaction

within urban space, focusing on quantifiable factors like time, cost, and distance [54], walkability delves deeper. It considers the spatial quality of the environment and how it actively encourages or discourages pedestrian mobility [46].

A review of the literature reveals that accessibility and walkability are often conflated, leading to knowledge gaps in urban planning practices. Many studies prioritize quantitative accessibility metrics without sufficiently incorporating the qualitative aspects vital to walkability, such as perceived safety, comfort, and aesthetic appeal. This narrow focus can result in planning strategies that, while providing accessible environments, fail to create genuinely walkable ones, thereby discouraging pedestrian activity even when destinations are nearby. For instance, a neighbourhood may feature well-distributed amenities, but poor sidewalk conditions or unsafe street crossings can significantly deter walking.

Our study addresses this critical gap by proposing a novel hybrid methodology that integrates both quantitative and qualitative approaches to assess walkability comprehensively. This methodology builds upon existing literature but significantly extends it by focusing on a holistic evaluation of urban features that influence people's willingness to walk. Unlike previous models that primarily consider impediments such as time, cost, and distance, our approach also meticulously assesses the qualitative dimensions of the walking experience.

The methodology utilizes two interconnected components: a Walkability Index (Wi) to evaluate the quality of individual pedestrian paths and a Total Walkability Score (TWS) to account for the broader network structure and service locations. Specifically, the Walkability Index (Wi) evaluates the quality of pedestrian paths within the open space network by considering four key factors: safety, comfort, attractiveness, and pleasantness. Each factor is further broken down into measurable variables, with weights assigned based on a targeted survey of pedestrian preferences. The Total Walkability Score (TWS) then combines the Wi with data on network structure and the location of origins (e.g., residences) and destinations (e.g., proximity services). It reflects pedestrian accessibility to services while critically considering the quality of the walking experience required to reach them. The TWS is calculated by identifying services reachable within a 15-min walk along suitable paths, factoring in the service type's weight derived from another user survey.

This GIS-based methodology is designed to provide effective support for decision-making in policy and planning, offering a comprehensive assessment of the multifaceted concept of walkability. It moves beyond traditional accessibility measures by systematically integrating the quality of pedestrian paths with service proximity, utilizing both objective open-source data and resident preference data collected via questionnaires. Combining the results of Wi and TWS with population density data can guide decision-makers towards prioritising interventions in areas with the most significant need for improvement. To further substantiate its practical application and demonstrate its added value, future developments of this study will involve a rigorous comparison of our proposed indicators (Wi and TWS) with established walkability and accessibility measures. This comparative analysis will ideally be tested across diverse urban case studies, aiming to validate the enhanced insights and practical benefits our comprehensive framework offers to urban planners and policymakers.

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