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Chapter 22

Perceived Walkability Measurement: A Comprehensive Bibliometric Review (2003-2023)

Ozge Ceylin Yıldırım *, Prof. Dr. Aslı Sungur and Assoc. Prof. Dr. Derya Güleç Özer

Introduction

Walking is an action that offers the possibility of experiencing the city for a wide range of purposes, such as enjoyment, leisure, physical exercise, and transport (Hatamzadeh & Hosseinzadeh, 2020). Walking is also defined as a mode of experience of place, a multifaceted action, and a temporal and rhythmic praxis (Wunderlich, 2008). As Lefebvre (2004) puts it, walking in urban space is the 'automatism of repetitions' of the individual, a temporal and physical reproduction, and a rhythmic experience. In the city, it is an active mode of perception of urban space with all the senses, an activity that nourishes and supports ephemeral perceptions and repetitive interactions (Ettema & Smajic, 2015; Wunderlich, 2008). Furthermore, walking can enhance one's understanding of the city's cultural and social dimensions, as it provides opportunities for spontaneous interactions and encounters. In this way, walking integrates physical, psychological, and social benefits, making it a vital component of urban life.
Walkability is defined as the extent to which the urban environment is pedestrian friendly, typically quantifying multiple attributes of the built environment at different scales (Fonseca et al., 2022; Forsyth & Southworth, 2008). In addition, that term aims to improve the walking experience for pedestrians and promote sustainable transport, and is essential for sustainable, liveable and equitable urban development (Hussein, 2018; Liu et al., 2023). The complex nature of walkability in urban environments has been studied through different methods, providing valuable insights into what helps or barriers walking. However, this approach has mostly looked at measurable factors, missing out on the individual, perceived dimension of walkability (Hassan & Elkhateeb, 2021). Recent research indicates a positive association between perceived walkability and walking behavior (Mondschein, 2023; Syafriharti et al., 2021). The decision to walk is affected by perceived walkability, which includes factors such as safety, accessibility, physical activity, wellbeing, comfort, urban ambiance, pedestrian infrastructure, and street connectivity (Kang et al., 2023; Kim et al., 2023). Walking behavior is shaped not only by the physical attributes of the walkable environment but also by social norms, personal attitudes, and individual capabilities (Jun & Hur, 2015; Sami & Galal, 2021; Tarek et al., 2021). Recent studies have deepened understanding by examining how people perceive the quality of walking environments and their access to various activities (De Vos et al., 2023; Saadi et al., 2022). These findings show that assessments need to consider personal experiences and interactions with the urban environment. This research seeks to bridge this gap by delving into the perceptual of walkability, exploring how personal experiences, preferences, and constraints shape an individual's interaction with and walkability through urban environment.
While there are numerous review articles on walkability and physical activity (Sundquist et al., 2011; Tobin et al., 2022), health (Barnett et al., 2023; Bird et al., 2018; IgeElegbede et al., 2022), age-related aspects of walkability(Hilland et al., 2020; Hwang, 2017; Malacarne et al., 2022), neighborhood scale walkability research (Almeida et al., 2021; Wang & Yang, 2019), built environment characteristics (Saelens & Handy, 2008; Wan Mohammad et al., 2021; Westenhöfer et al., 2023), research trends (Hijriyah et al., 2024; Shields et al., 2023) and specific indices such as Walk Score(Brown et al., 2023; Hall & Ram, 2018), these studies have specific focuses on field. This paper addresses the limitations of perceived walkability research, providing a comprehensive review of various types of walkability research. This article provides a thorough review of a wide range of studies from different research fields on perceived walkability, making a significant contribution to the existing literature. Furthermore, an innovative bibliometric analysis is used to highlight different research directions and provide a structured framework for critical review. The review includes 348 papers and presents guidelines for measuring perceived walkability and insights for future studies in this area. The methodology section outlines the research

Corresponding Author: * Ozge Ceylin Yildirim
Department of Architecture, Faculty of Architecture, Omer Halisdemir University, Nigde, Turkiye
e-mail: ozgeceylinyildirim@gmail.com
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approach, followed by a detailed analysis including both bibliometric analysis and critical review. The discussion section presents the findings of the review, while the conclusion section considers the implications for future directions of research.

Materials and Methods

This methodology is one of the well-known and commonly applied methodologies nowadays to effectively search, evaluate and interpret the available literature in a specific scientific research field (De Vos et al., 2023; Lame, 2019). A systematic literature review aims to comprehensively analyse a limited number of articles by focusing on specific research questions (Barn et al., 2017; Jacob, 2023). It also allows for a more thorough examination and understanding of a topic. In this context, a systematic review method was employed to understand the gaps in perceived walkability issues and to extract the main themes of previous studies in this area. This research aims to systematically evaluate the scope of the literature on perceived walkability and the methods used to measure this. The goals are to: (i) quantitatively identify the spread of literature across specific and relevant categories, and (ii) identify research gaps that can inform future researchers.

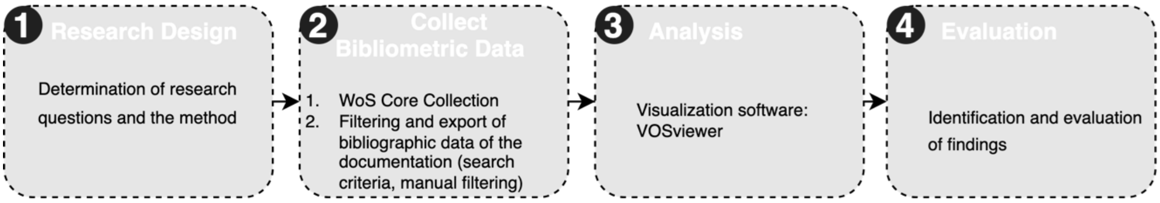

Figure 1. Flowchart of the Study

The figure outlines a systematic four step research process used in the study (Figure 1). The first step, Research Design, involves determining the research questions and the methodology to be used. In the second step, Collect Bibliometric Data, data is gathered from the Web of Science (WoS) Core Collection. This data is then filtered and exported based on specific search criteria and manual filtering to ensure relevance. The third step, Analysis, utilizes VOSviewer, a visualization software, to analyze the bibliometric data. Finally, the Evaluation step focuses on identifying and evaluating the findings from the analysis. This structured approach allows for a comprehensive examination of the literature on perceived walkability and its measurement methods

Search Strategies

ALL= ("assessment" OR "tool" OR "measurement" OR "audit tool" OR "measure*"). The inclusion of the asterisk (*) acted as a wildcard, facilitating the capture of terms with derivative meanings such as 'perceive', 'perception', and 'perceptional', enhancing the breadth of the search (Grames et al., 2019). The primary focus of this paper is on perceived walkability, which influenced the selection of search terms. The terms 'measurement' and 'assessment' are closely related; therefore, 'audit tool' was also included to capture a broader spectrum of methodologies. This strategy was intentionally chosen to avoid limiting the search to specific measurement tools or methods, thereby aiming to access a diverse array of research studies. These terms were utilized as the Topic Search criterion in the Web of Science (WoS) Core Collection database, spanning the period from 2003 to 2023. The Clarivate Analytics WoS Core Collection has been selected to study the scientific literature, obtaining systematic data, and providing general conclusions from the collected data. This selection has been due to inclusion of the WoS Core Collection, which is the most frequently used database for bibliometric studies (Zupic & Čater, 2015) and high-quality scientific publications (Budler et al., 2021).

This scholarly literature review aims to synthesize current and relevant research within the field. As the review is confined to journals indexed in the Social Sciences Citation Index (SSCI), Science Citation Index Expanded (SCI-Expanded), Emerging Sources Citation Index (ESCI), and Arts & Humanities Citation Index (AHCI), it specifically targets perceived walkability within the disciplines of urbanism, architecture, planning, and environmental studies. This deliberate focus ensures the exclusion of topics not directly related to these fields, maintaining a clear and relevant thematic boundary for the research. According to the search criteria, 604 articles from 94 journals were identified. This data was filtered and exported based on manual filtering to ensure relevance. After reviewing individual abstracts, 348 articles were selected for further review. Finally, a total of 72 articles were identified for in-depth analysis, focusing primarily on perceived walkability measurement research.

Bibliometric Analysis

Bibliometric analysis includes various mathematical and statistical methods to analyse publication patterns in a particular field (Shi et al., 2020; Zhong et al., 2016). It reflects the research field, reveals its strengths and

weaknesses, and summarises the current situation. It is used to measure the productivity of authors, citation and content analyses and the impact of research (Zupic & Čater, 2015). The analysis reveals research trends, exploration of popular topics, and potentials for future studies, from micro-scale to macro-scale. These methods surpass traditional literature reviews by providing a more extensive examination of patterns within the literature. Capable of analysing thousands of studies, bibliometric methods visually map out a research area and offer greater objectivity in literature assessments (Zupic & Čater, 2015). This research utilised three main bibliometric analyses: co-occurrence of the keywords, country, and their changes according to years.
VOSviewer was utilized to elucidate specific relationships by creating networks and maps from the data exported from the WoS Core Collection. VOSviewer, a free software program developed by van Eck and Waltman (Arifin et al., 2021), is widely used for literature analysis. Additionally, tables and figures were employed to offer more detailed information for the analysis.

Results

Overview

In general, the number of papers published over the years is a key indicator for measuring scientific progress and importance. Publications on "walkability and perception", which refers to the walkability of the literature, have increased since 2003, as shown in Figure 2. For this reason, a review of the literature has been carried out since 2003, prior to which there was insufficient research activity specifically focused on walkability, its perception and measurement. In subsequent years, the number of publications on walkability increased exponentially, with yearly growth rates indicating a rapidly increasing interest in this research field.

A total of 348 records were classified under 44 different research themes in the WoS category analysis. This analysis showed that the searched keywords were used in different disciplines and fields. Table 1 shows the top 10 of the WoS categories with the highest level of strength. Since 2003, research on walkability has highlighted its important links with health issues such as physical activity, obesity and noncommunicable diseases, and has focused primarily on public, environmental and occupational health. The diversity of academic fields involved, including transportation, environment, urban development, urban planning, sustainable technology, geography and physiology, illustrates the complex nature of walkability studies. The significant increase in research articles in fields including mobility, environmental science, urban planning and geography indicates a broadening interest in exploring different dimensions of walkability.

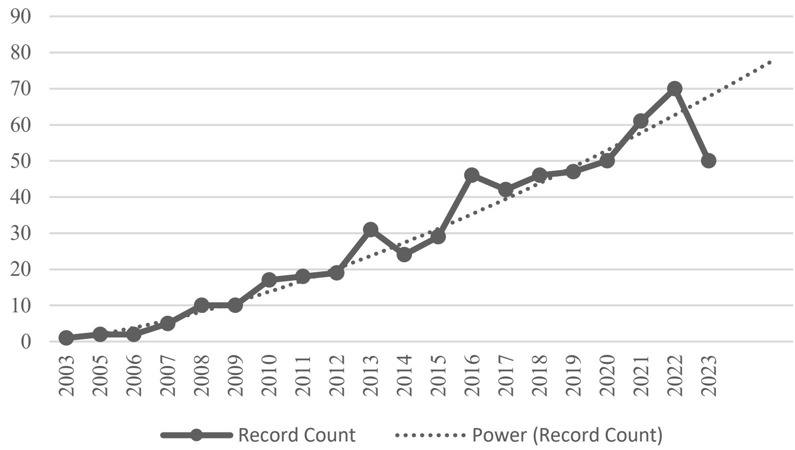

Figure 2. Annual publication output showing the total number of articles published from 2003 to 2013

The ten leading journals in walkability research shows Table 2. These journals highlight that are most engaged in the discourse on walkability, emphasizing the field's interdisciplinary nature, with inputs from public health, urban planning, architecture, sustainability, transport and health studies. Although it is difficult to rank one journal above another due to the diversity of disciplines within the top 10 journals, these findings can help researchers identify suitable journals for submission of their work.

Table 1. Top 10 results based on research fields on WoS categories

Web of Science Categories	Record Count	% of 348
Public Environmental Occupational Health	275	79%
Environmental Sciences	80	23%

Environmental Studies	74	21%
Urban Studies	57	16%
Transportation	53	15%
Geography	37	11%
Regional Urban Planning	35	10%
Green Sustainable Science Technology	25	7%
Physiology	24	7%
Geography Physical	23	7%

Table 2. Top 10 results based on publication titles

Publication Titles	Record Count	% of 348
International Journal of Environmental Research And Public Health	47	13.5%
Bmc Public Health	24	6.8%
International Journal of Behavioral Nutrition And Physical Activity	23	6.6%
Health Place	20	5.7%
Journal Of Transport Health Landscape and Urban Planning	19	5.4%
Journal Of Physical Activity Health	19	5.4%
Sustainability	17	4.4%
Environment And Behavior	13	3.7%
Cities	11	3%
Bmc Open	10	3%

The final dataset consists of 348 research articles extracted from the WoS databases as a RIS file. This dataset was subjected to keyword cooccurrence analysis using the VOSviewer software with the LinLog/modularity normalisation method. A minimum threshold of eight keywords was set. In addition, a thesaurus file was used to remove irrelevant keywords and to consolidate repeating terms (e.g. "walk score", "walkscorer", "GIS", "elderly", "older", "adults", "adult"). Of the 2,083 keywords, 103 items the established occurrence criterion and formed seven distinct cluster groups. These groups were delineated using a mixture of VOSviewer's automated clustering algorithms and manual review to maintain semantic consistency and relevance within each cluster. In the network visualization created with the provided data, each keyword appears as a node, and connections between nodes are determined by the frequency with which they cooccur in the collected literature (Figure 3). This network visualization, along with its clustered layout, simplifies the overall structure of the literature, making it easier to discern major research themes, emerging trends, and areas of research interest.

The commonly mentioned keywords indicated that research on walkability is often associated with aspects of the urban built environment, physical activities and health status. This link is further supported by the keyword cooccurrence matrix shown in Figure 3. The cooccurrence matrix shows how the main keywords related to walkability are connected, while the density plot shows the key research areas most closely associated with walkability. Together, these visual tools effectively illustrate the links between different themes in walkability research. The 103 keywords were collected and based on how closely their characteristics, application areas and connections to VOSviewer match, were grouped into 7 clusters. Each keyword in the network is part of only one cluster. The cluster of a keyword is the reason for its colour.

The 19 items in Cluster 1 include physical indicators of walkability and concepts relating to the perceptual dimension of walkability. Physical walkability indicators focus on the structural characteristics of the urban area, such as density, design, diversity, land use, urban design, urban form, scale of walkability, street connectivity and public transport. These factors are concrete characteristics that determine whether an area is walkable or not. In contrast, terms such as independent mobility, mode choice, subjective criteria and satisfaction refer to the perceptual dimension of walkability. These terms focus on how individuals experience walkability and how this experience influences personal preferences and social interactions. Furthermore, this cluster mentions the methodology of "space syntax" to measure walkability. Space syntax is a theoretical and methodological approach that helps us to understand how accessible and walkable an area is by analysing the impact of spatial arrangements on social interactions. The content of Cluster 2 provides a rich perspective on both individual characteristics and environmental factors. Terms such as obesity, overweight and body mass index refer to the health status of individuals and potential barriers to walking. These health indicators highlight not only the importance of walkable areas, but also the need to develop such areas for public health. Factors such as ageing and physical inactivity demonstrate the importance of creating walkable environments and promoting physical activity, especially for the older population. The need to consider the needs and behaviours of people of different ages and the importance of safe and accessible urban design for all is highlighted. Income, poverty and socioeconomic status are socioeconomic factors that affect the ability of different segments of society to access and benefit from walkable environments. Low income and high poverty levels are often associated with neighbourhoods that lack adequate walkable infrastructure. Terms such as environmental design, urban form and urban sprawl refer to the direct influence of the configuration of the physical environment on walking behaviour. This cluster provides a comprehensive examination of both micro (individual) and macro (environmental) factors that influence individuals' walking behaviour.

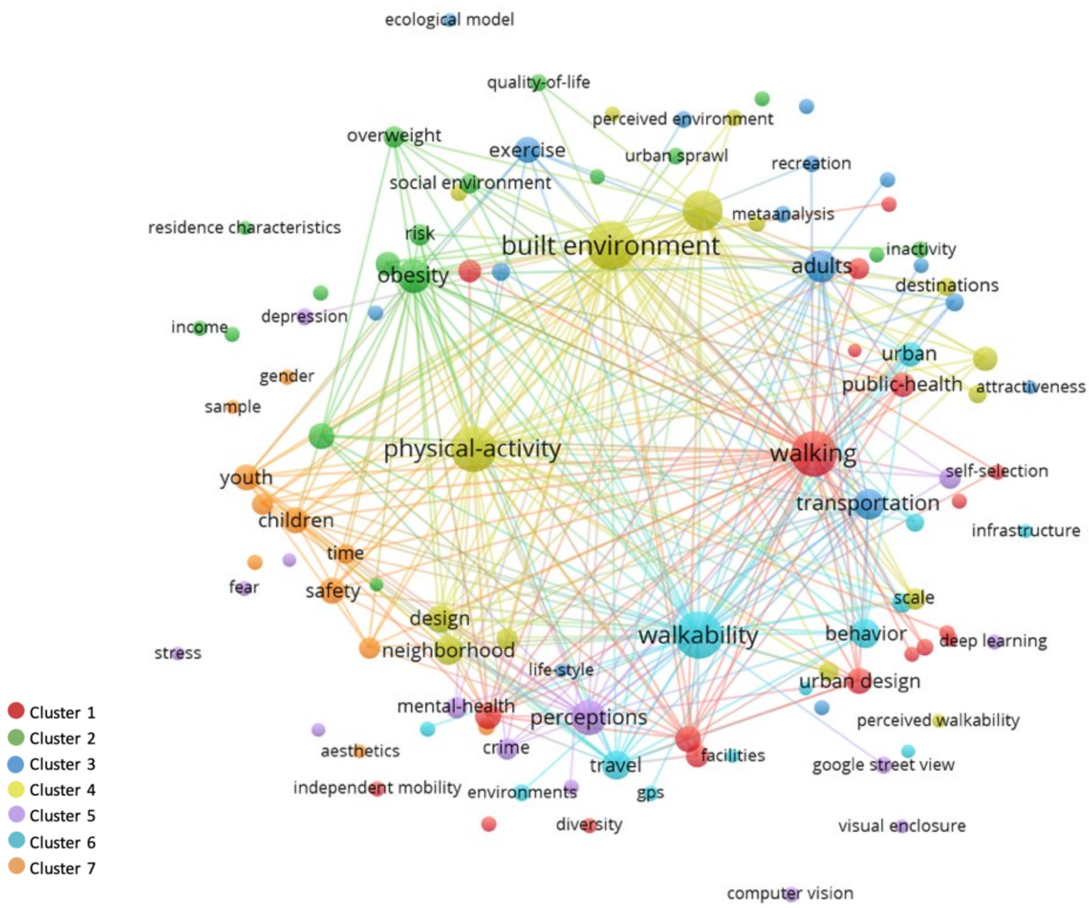

Figure 3. Keyword cooccurrence analysis network visualization and clusters

In Cluster 3, 'adults' is the highest-ranking term, followed by attractiveness, barriers, distance, proximity and ecomodel. This shows that walkability research focuses on the behaviour and needs of adults and the importance of physical and perceptual factors that influence individual behaviour. The quality of the environment, the existence of green spaces, transport alternatives, distance to destinations, physical or psychological barriers are criteria that influence the propensity to walk. Perceptual factors concern how individuals perceive their environment and how this perception affects their walking behaviour. The role of perceived environment on walking behaviour demonstrates the importance of walkability in an urban area in terms of personal experience and preferences. Finally, methods such as metanalysis and GIS provide important tools for measuring and analysing such factors and behaviours. By integrating findings from a variety of studies, these assessment methods allow us to develop a comprehensive understanding and help us to make strategic, data driven decisions for designing and improving walkable areas.

Cluster 4 contains 16 items including accessibility, age, built environment, design, destinations, health, environment and scale. This may indicate that this study focuses on how environmental features affect walkability and how to measure walkability, as environment and features are the most important terms in this cluster. Different factors that influence walkability have been investigated in previous studies. Research has also examined the different effects of objective and subjective environmental measures on walkability. In addition, demographic factors create important differences in walking habits, and these differences provide insights into how urban design can be made more inclusive for all.

Cluster 5 contains elements related to the psychological and safety dimensions of walkability. It demonstrates how this research integrates objective measurements of environmental factors with individuals' subjective perceptions and psychological responses. Advanced technologies, such as computer vision and deep learning techniques, offer the opportunity to comprehensively and evidence based analyse the effects of both physical and perceptual components of walkability in environmental research through Google Street View, audit. The terms 'crime', 'fear' and 'violent crime' illustrate the prevalence of research into psychological factors that have a negative impact on the walkability of the area. Perception of safety and visual closure underline the need to ensure that urban spaces are designed to make people feel safe and comfortable. These comprehensive approaches allow for the development of multidimensional strategies to ensure that walkability works become safer and more attractive.

Cluster 6 focuses on the synergy between human behaviour, technology and policy, and includes a term of 13 interrelated terms crucial to sustainable urban development. The cluster addresses the critical integration of machine learning and GPS technologies as key assets for advancing urban planning and improving mobility systems. This integrative approach facilitates the development of urban environments by using the analysis of behavioural patterns and travel data to propose methods for increasing walkability and promoting healthier living conditions. The individual behavioural aspects of walkability, combined with environmental characteristics, emphasise the multidimensional nature of walkability.

In Cluster 7, the interrelation of adolescents, children, and gender dynamics plays a crucial role in the fabric of urban walkability culture, particularly in low-income areas where access to walkable environments can be limited. The aesthetics of a city's walking infrastructure can significantly influence school commute times and the likelihood of walking behavior being adopted by younger populations. Studies have focused that when the travel environment is inviting and considers the needs of diverse groups, including school age children and adolescents from various gender and socioeconomic backgrounds

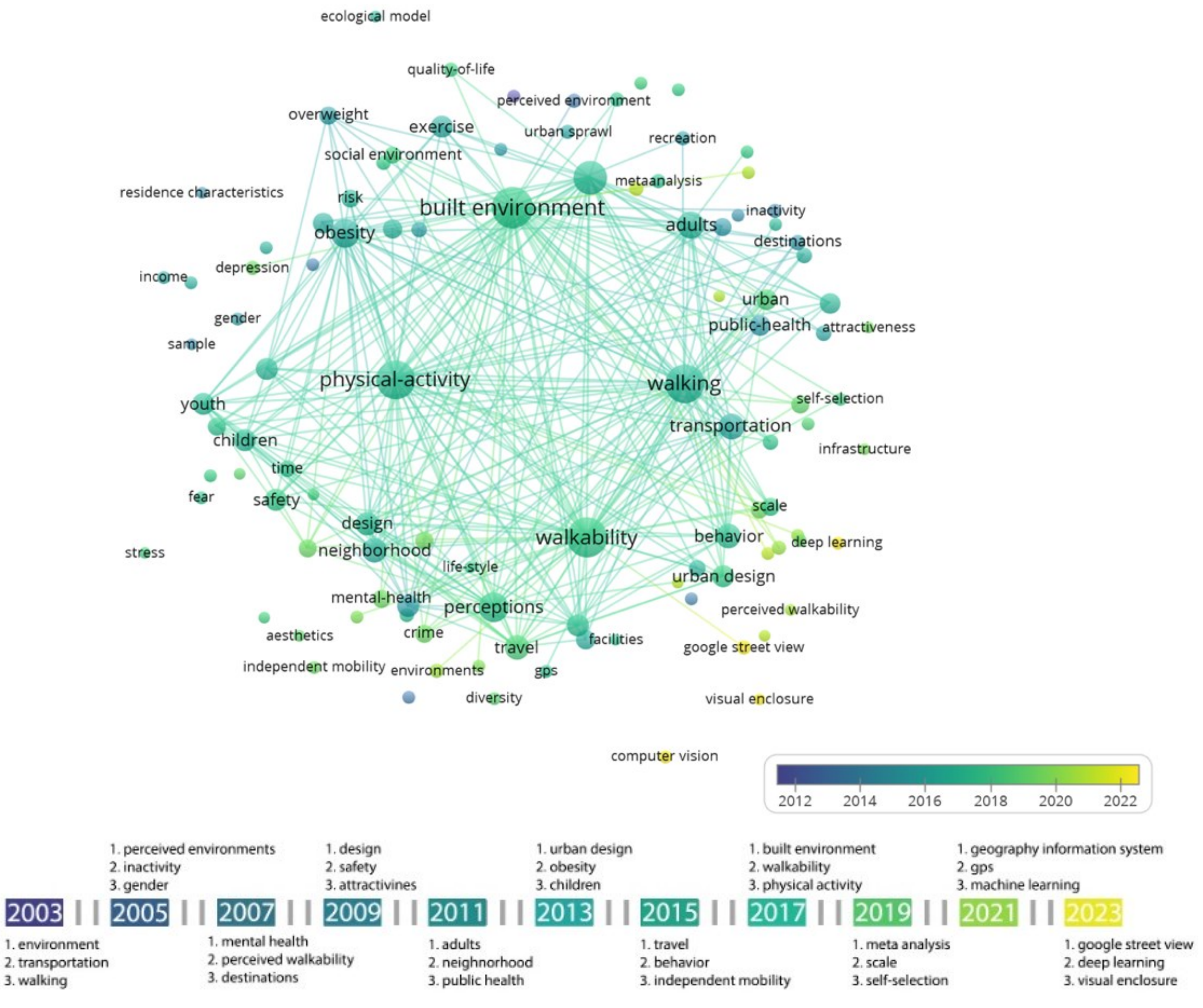

Figure 5. Network map of the cooperating countries (occurrences of country ≥ 5)

Figure 5 analyses collaboration between countries and institutions in the perceived walkability research process since 2003. The connectivity between the nodes indicates collaboration between other countries or organisations, while the size of the nodes reflects the strong collaboration with other countries or organisations. The network diagram of collaboration between 34 countries, including 2 clusters, is shown in Figure 5. In addition, the colour change in the timeline shows how this work evolved over time and new links were formed. According to the ranking of the strength of cooperation with other countries, the USA has the highest index of collaboration between countries. It is followed in terms of interaction by Canada, Australia, Belgium and England. This indicates that these countries prioritise research highlighting the importance of walkability for urban planning, public health and transport policy. As the colour scale reflects trends over time, India and Poland, where the yellow links dominate, show a more recent increase in walkability research. Countries with green links, such as the Netherlands, Portugal, Chile and Norway, then demonstrate that research has intensified and continue beyond 2020. This situation highlights how walkability has become a changing priority in different countries over time.

Critical review

The seven clusters illustrated in Figure 3 show the components of environmental attributes for assessing both perceptual and physical walkability, including the data collection tools, research methods, and scales utilized for these measurements. Through a detailed review of abstracts, 72 articles were selected based on prior bibliometric analysis and article content. Methodological advantages and disadvantages, scopes, and results of these studies were broadly categorized. Figure 6 presents a roadmap for this critical review. Most of the selected studies focused on the relationship between walkability components and measurement methods, categorized into GIS, audit tools, and advanced techniques, considering the tools used.

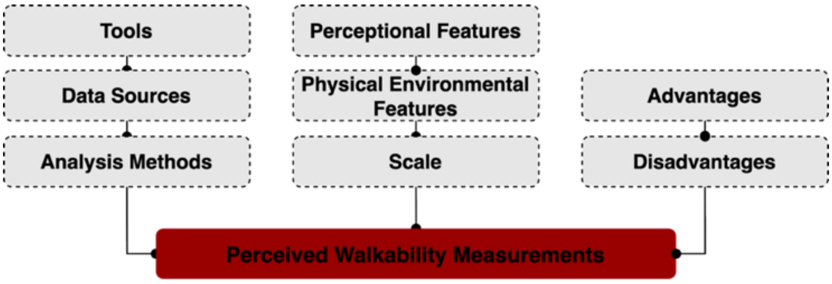

Figure 6. Roadmap for critical review on perceived walkability measurements

In the last two decades, studies on perceived walkability have gained increasing attention in the fields of urban planning, design, and health environments. These studies aim to better understand individuals' walking habits and urban space utilization by integrating both objective and subjective data in the measurement of urban walkability. It is widely accepted that walkability is influenced by the design and features of the built environment. These studies have already provided significant insights into the factors that impact walkability (Leslie et al., 2005; Qureshi et al., 2018). Walkability, which refers to the features of an urban space that promote walking, can be measured using a geospatial method based on physical and perceptional indicators that can be integrated into a GIS system (Al Shammas & Escobar, 2019; Alyasari et al., 2020; Grasser et al., 2017). GIS has proven to be highly effective in gathering information, visualizing field data, and integrating data to comprehend the spatial differences in walkability and its impact on individual walking behavior in urban environments (D'Orso & Migliore, 2020). A GIS-based multicriteria approach has been created to assess walkability levels in a pedestrian network, demonstrating its efficiency in mapping walkability and distinguishing varying levels of walkability within urban areas (Telega et al., 2021).

Table 3 shows that these studies used survey data, walkability indices (NEWS, MAPSmini), body mass index (BMI) and data from step counting devices such as Accelerometers in combination with GIS methodology and used various analytical techniques such as correlations, sensitivity analyses and comparative analyses to investigate factors related to walkability. These studies' physical environment characteristics commonly analysed include housing density, land use diversity and street connectivity. Participants are assessed on factors such as safety, comfort and motivation. These studies are predominantly conducted at macro or mesoscales and provide researchers with comprehensive information on the perception of walkability and its relationship with behavioural patterns. Despite their contributions, walkability studies face challenges such as potential biases in perception measurements, limited generalisability and insufficient consideration of safety aspects. However, these studies have proven valuable in validating survey instruments, improving the understanding of walkability, and providing methodological insights that contribute to the broader field of urban planning and public health.

Table 3. Walkability Assessments Using GIS Tools: Findings of Selected Studies

References	Tools	Data sources	Analysis	Physical Environmental Features	Perceptual Features	Scale	Advantages	Disadvantages
Adams et al., 2009; Gebel et al., 2011; Leslie et al., 2005; Qureshi et al., 2018)	**NEWS** **NEWS-A**	-Survey data -GIS data -BMI data	-Correlational Analysis -Sensitivity Analysis -Comparative Analysis	-Residential Density -Land-Use Mix -Connectivity	-Safety -Comfort	Macro Meso	-Insight into Perception and Behavior Link - Validation of Survey Instruments -Enhanced Understanding of Walkability - Insightful Methodological Approach	-Potential Bias in Perception Measurement -Limitation in Generalizability - Limited Scope on Safety Aspects
Annear et al., 2024; Pocock et al., 2020	**MAPS-mini**	-Systematic Walking Audits -GIS data - Photography data	-Reliability Analysis -Spatial Analysis	-Sidewalks - Road Types -Pedestrian-Friendly Attributes - Residential Density -Land Use Mix	-Safety -Comfort -Motivation	Meso Micro	-Modified Audit Tool Efficiency -Comprehensive Methodology	-Infrastructure-Centric Challenges -Limited scope
Hajna et al., 2016; Kim et al., 2023	**Accelerometers** **Pedometers**	-GIS Data -Survey Data -Accelerometer data - Pedometers data	- Self-Reported And Objectively Measured Walking Times - Socio-Demographic And Physical Activity Adjustment - Comparative Analysis -Bayesian Longitudinal Hierarchical Linear Regression Models	-Residential Density -Connectivity -Land-Use Mix -Pedestrian Safety - Traffic Density - Accesibility	-Safety -Aesthetics -Comfort -Motivation	Macro Meso	-Detailed Environmental and Activity Data - Holistic Measurement Approach	-Variable Measure Sensitivity -Limited Generalizability - Potential Bias in Self-reported Data
Gong et al., 2023	**-Computer Vision (CV)** **-Machine Learning Algorithms**	-Street View Images data -Survey data	-Machine Learning Prediction - Comparative Analysis	-Infrastructure -Urban form -Public Spaces	Imageability - Enclosure -Human scale -Complexity -Safety	Macro	-Comprehensive Tool Integration -Focus on Gender Differences - Advanced Data Collection Techniques	-Complexity of Data Processing

The reviewed studies emphasise the use of auditbased approaches to improve pedestrianfriendly environments. Audit tools allow for a comprehensive and systematic assessment of walkability. By taking into account both physical environmental characteristics and individual perceptions, these tools contribute to the creation of more walkable and healthy urban areas (Table 4). One of these audit tools, NEWS, is used to assess the walkability of the neighbourhood environment (Cerin et al., 2013). It measures physical environmental characteristics such as housing density, land use diversity, street connectivity, pedestrian safety, aesthetics and accessibility (Figueiredo et al., 2022). Respondents indicate their perception of the walkability of their neighbourhood. Multilevel confirmatory factor analyses were used to test the generalisability of neighbourhood walkability across different cities (Adlakha et al., 2016; Consoli et al., 2020). The NEWS index was developed by each researcher with different language and geographical locationspecific details (Oyeyemi et al., 2016; Pelclova et al., 2014). Another audit tool, the Microscale Audit of Pedestrian Streets (MAPS) index, is a quantitative, theorybased method to understand and evaluate pedestrian behavior in urban spaces (Zaleckis et al., 2022). It examines the impact of physical features on pedestrian interactions at the microscale, considering the relationships between social and built environments. Tools like MAPS-Mini and MAPS-A bridged address contextspecific features. Using mixed methods of analysis, including GIS, space syntax, and GSV, along with field research and observation, the MAPS index identifies strategies for a safe, accessible, and aesthetically pleasing pedestrian experience (Annear et al., 2024; Cain et al., 2018). Another commonly used audit tool is the WalkScore. WalkScore is a theorybased measurement tool that assesses how easy it is to walk from a given location to surrounding amenities on a 10 point scale (Hajna et al., 2016; Kelly et al., 2015). It combines three main elements: shortest distance to predetermined destinations, block size, and intersection density. WalkScore explores the relationship between the built and social environments and allows for analysis from macro to meso scales in different urban spaces (E. J. Kim & Jin, 2023). It has also been used to study the walking behavior of different user profiles (Horak et al., 2022). Similarly, the Walkability Index measures walkability by assessing connectivity, mixed-use, shopping areas, and residential density (PoklewskiKoziell et al., 2023). The Leyden Walkability Instrument (LWI), PANES, Perceptions Index (PPI), SPACES and other indices such as the Street Walkability and Thermal Comfort Index (SWTCI) are used to assess pedestrian environments. LWI analyses audit and GIS data (Bias et al., 2010), PANES and PPI analyses pedestrian comfort, aesthetics and safety (McCormack et al., 2020) factors at different levels in a comprehensive approach.

The data sources used are mostly survey data, GIS data, physical activity data and data from participatory studies such as walking interviews. Using a variety of analytical methods, the studies have assessed the relationships between physical environmental characteristics, particularly housing density, land use diversity, infrastructure accessibility and proximity, and perceptual characteristics such as comfort, motivation, quality of life, aesthetics, sense of community and environmental stressors. The main advantages of these studies are that they combine objective and subjective measures, make comprehensive assessments and use mixed methods. However, there are also limitations such as seasonal and socioeconomic variables, potential biases in perception measurements, and incomplete consideration of variables that may affect walkability.

Table 4. Walkability Assessments Using Audit Tools: Findings of Selected Studies

References	Tools	Data sources	Analysis	Physical Environmental Features	Perceptual Features	Scale	Advantages	Disadvantages
Cerin et al., 2013; Figueiredo et al., 2022; Leslie et al., 2005; Scheller & Bachner, 2024	**NEWS** **NEWS-A** **NEWS-India** **NEWS-Y-G**	-Survey Data - Physical Activity Data - Participatory Workshops(Walking Interviews and Mapping) - GIS Data - BMI Data	-Confirmatory Factor Analysis -Correlation and Standardized Difference Analysis - Statistical Analysis - Decision Tree Analysis -Spatial Analysis	-Residential Density -Land Use Mix-Diversity -Street Connectivity -Infrastructure -Accesibility - Proximity	-Comfort -motivation, -Quality of Life -Safety -Aesthetics -Sense of Community - Social Cohesion -Environmental Stressors	Macro Meso Micro	-Combination of Subjective and Objective Measures -Comprehensive Assessment -Use of Mixed Methods -Focus on Lifestyle Factors -Youth-Centric Approach	-Seasonal and Socioeconomic Variations -Limitations in Subjective Reporting - Potential Bias in Perception Data -Limited capacity to consider variables contributing to walkability
Annear et al., 2024; Pocock et al., 2020; Ussery et al., 2019	**MAPS Global-SN** **MAPS mini**	-Audit Data -GIS Data - Publicly Available Census Data - Photography Data - Street Segment Data	-Two-Stage Sampling Method - Reliability Assessment -Spatial Analysis	-Sidewalks - Road Types -Pedestrian Infrastructure - Residential Density -Land Use Mix	-Safety -Comfort -Motivation	Meso Micro	-Holistic Assessment -Purpose-Specific Insights -Modified Audit Tool Efficiency	-Dependence on Volunteer Auditors -Limited scope -Potential Bias in Subjective Measures
Bias et al., 2010; Labdaoui et al., 2021; McCormack et al., 2020; Samarasekara et al., 2011; Zhu et al., 2023	**Leyden Walkability Instrument (LWI)** **PANES** **Perceptions Index (PPI)** **SPACES** **Street Walkability and Thermal Comfort Index (SWTCI)**	- Streetscape Photos -Audit data -GIS data Demographics Data	-Factor Analysis -Statistical Analysis -Linear Regression and Mediation Analyses -Landis-Koch Rating System -Inductive and Deductive Approaches	-Pedestrian Comfort -Temperature -Humidity -Wind -Sidewalk Availability -Public Transport Access	-Aesthetic -Comfort -Motivation -Willingness -Satisfaction -Safety	Macro Meso Micro	-Comprehensive Approach -Focused on Underrepresented Populations - Holistic Assessment - Actionable Outputs	-Complexity of Data Collection and Analysis - Limited Generalizability - Potential Bias in Self-Reporting
(Hajna et al., 2016; Kelley et al., 2016; Kelly et al., 2015; Poklewski-Koziell et al., 2023)	**Walkscore** **Walkability Index**	-Audit data -survey data -GIS data -Real Estate Listing -PA Diaries -Interview Data	-AHP-SWOT -statistical analysis -Urban Design Review - Comparative Analysis -Spatial Environment Modeling - Semantic Segmentation	-Connectivity Of Streets - Availability Of Crosswalks - Integration Of Urban Features - Accessibility - Proximity -Infrastructure	Engagement -Acceptance -Comfort - Aesthetic -Motivation -Socioeconomic perceptions	Macro Meso	-Link between walkability and practical daily activities -Tailored Walkability Enhancements, Holistic Approach -Detailed Behavioral Tracking	-Limits the ability to infer causality between walkability and walking habits -Complexity in Data Collection and Analysis -Generalization of Findings -Limited Expansion Possibilities
Brookfield & Tilley, 2016	**Streetscape Audit Tool Google Street View**	-Field Observations -Survey data	-Spatial Analysis -Comparative Analysis	-Sidewalks -Street Furniture - Pedestrian Zones -Wayfinding -Lighting Conditions	-Legibility -Safety -Comfort	Macro	-Targeted Urban Improvements -Innovative Methodology	-Limited Impact of Some Factors - Subjectivity in Perceptions

Over the last two decades, innovative technologies used in perceived walkability measurement research have been the focus of scientific scrutiny. These studies include technologies such as Google Street View, Accelerometers, Pedometers, Computer Vision (CV), Machine Learning Algorithms, OpenStreetMap and Virtual Reality Technology, which provide comprehensive analyses of physical and perceptual characteristics related to walkability (Table 6). Data collected using Accelerometers and Pedometers were used to collect both self-reported and objectively measured data of walking times on the elderly population. These data allowed for a comprehensive assessment of walkability factors and the examination of the relationships between sociodemographic variables and physical activity (Hunter et al., 2022; Kim et al., 2023). Technologies such as Google Street View and Computer Vision have enabled visual analyses of urban spaces to examine physical features related to walkability such as sidewalks, road types, pedestrian friendly features in detail (Gong et al., 2023; Huang et al., 2023). Open Street Mapping and Machine Learning Algorithms have been used to quantify the infrastructure and accessibility characteristics of walkways. These technologies have demonstrated the potential to improve walkability by enabling the analysis of urban design elements and green space facilities (Pilgram & West, 2023; Ye et al., 2024). Virtual Reality Technology has provided in-depth information on walkability perceptions by allowing users to experience walkability scenarios in a virtual environment (Huang et al., 2023; Liao et al., 2022). This technology has also enabled a detailed assessment of the effects on users' sense of safety, aesthetics and functionality.

The use of these technologies has greatly contributed to the development of walkability measurement methodologies and more comprehensive, objective data collection techniques. However, challenges have also been identified, such as the complexity of data collection and analysis, and the impact of seasonal and socio-economic variables. These innovative tools play an important role in moving walkability studies forward, and the advantages and challenges of these technologies are important factors that will shape the future direction of walkability research.

Table 5. Walkability Assessments Using Innovative Methodology: Findings of Selected Studies

References	Tools	Data sources	Analysis	Physical Environmental Features	Perceptual Features	Scale	Advantages	Disadvantages
Hunter et al., 2022; Kim et al., 2023; Marquet & Hipp, 2019	Accelerometer Pedometers	-Adult Changes in Thought Activity Monitor -GIS Data -Accelerometer Data -Pedometer data -Survey Data - Physical Activity Data	-Self-reported and Objectively Measured Walking Times - Socio-Demographic and Physical Activity Adjustment -Regression Analysis with Interaction Terms -Multiple Imputation -Spatial Analysis	-Residential Density -Connectivity -Land-use Mix -Greeness -Accesibility -Pedestrian facilities -Proximity	-Safety -Comfort -Motivation -Aesthetic - Personal Importance	Macro Meso Mico	-Comprehensive Data Collection - Focus on Elderly Population -Holistic Measurement Approach	-Variable Measure Sensitivity -Limited Generalizability -Seasonal and Socioeconomic Variations -Potential Bias in Self-reported Data
Brookfield & Tilley, 2016; Gong et al., 2023; Huang et al., 2023	Google Street View Computer Vision (CV) Machine Learning Algorithms	- Field Observations Data -Survey data -Street View Images Data -Semantic Data	-Spatial analysis -Comparative Analysis -Machine Learning Prediction -Semantic Difference Method -Correlation and Regression Analyses	-Sidewalks - Road Types -Pedestrian-Friendly Attributes - Residential Density -Land Use Mix -Traffic Density -Natural Landscape	- Imageability -Enclosure -Human scale -Complexity -Safety -Comfort - Aesthetic -Motivation	Macro Micro	-Innovative Methodology -Comprehensive Tool Integration -Focus on Gender Differences -Comprehensive Environmental Analysis	-Limited Impact of Social Environmental Factors -Subjectivity in Perceptions -Complexity of Data Processing
Pilgram & West, 2023; Ye et al., 2024	-OpenStreetMap -Machine Learning and Algorithms -Big Data	-Open streetmap Data -Population-Weighted Land Use Analysis -Street View Images Data -Survey Data -Spatial Data	-Spatial Analysis -Comparative Validation -Machine Learning Prediction -Regression Analysis	-Land-Use Mix -Infrastructure -Accessibility -Urban Design Elements -Green Street Facilities -Parks -Separation from Vehicle Traffic -Connectivity	-Attractiveness -Comfort - Aesthetic -Motivation	Macro Micro	-Scalability and Recomputability -Focus on Pedestrian Experience -Objective and Detailed Combination of Objective and Subjective Measures	-Data Reliability and Bias -Limited Generalizability
Huang et al., 2023; Liao et al., 2022	Virtual Reality Technology	-Experimental Data -Semantic Data -GSVP Images Data	-Statistical Analysis -Conjoint Analysis -Semantic Difference (SD) Method -Correlation And Regression Analyses	-Land Use Mix -Connectivity -Road Size -Open Space -Green Areas -Traffic Density	-Feelings of Comfort -Sense of Security -Aesthetics -Functionality	Micro	-Detailed Emotional Insights -Innovative Assessment Techniques -Comprehensive Environmental Analysis	-Potential Bias in Virtual Settings -Complexity of Analysis Methods -Complexity of Technology Implementation

In summary, over the past few years, the number of scientific publications on walkability and its perceptions has increased significantly. This increase shows that walkability is increasingly being studied across disciplines including public health, environmental studies, urban planning and geography. A variety of methods have been used in studies to assess the physical and perceptual aspects of the pedestrian environment. These methods include GIS-based analyses, streetscape photographs, audit data, surveys and high-tech tools. The physical environmental attributes analysed included housing density, land use diversity, street connectivity and pedestrian-friendly infrastructure. Perceptual attributes include safety, comfort, aesthetics and motivation. These studies have revealed links between walkability and health issues such as physical activity, obesity and chronic diseases. Innovative technologies used in walkability research have made data collection and analysis processes more comprehensive and objective. However, there are also challenges such as the complexity of data collection and analysis and the effects of seasonal and socioeconomic variables. The advantages of these technologies are important factors that will shape the direction of future walkability research.

Discussions

The purpose of this review is to provide a summary of the peer-reviewed literature on the measurement and evaluation methods of perceived walkability research in urban development. The reviewed literature clearly demonstrates the importance and growing scientific interest in walkability in various disciplines, using a wide range of methods that assess physical and perceptual aspects of pedestrian environments.

Most studies have examined the influence of the physical components of urban space to measure the perception of walkability at the micro and meso scale. These results are consistent with previous findings that they influence individuals' walking experience in terms of both safety, comfort and motivation, as well as perceptions of walkability (E. J. Kim & Kim, 2020; Zhu et al., 2023). However, although these studies recognised the importance of environmental and thermal factors, socio-demographic, cultural, individual and psychosocial factors, they did not adequately focus on these specific factors (Fonseca et al., 2022; Saadi et al., 2022; Ye et al., 2024). Lack of knowledge on how to collect adequate and accurate data is another limitation. When some studies use participants' perceptual data from self-reported walking experiences, such as questionnaires or interviews, measurement errors and biases may appear in the results. This may negatively affect the reliability and validity of walkability research. In addition, there is limited research on measuring and analysing these data with neuroscience devices such as EEG, EDA, fMRI (Li et al., 2021; Mavros et al., 2022). To comprehensively measure perceived walkability, future research should consider more potential factors influencing walkability listed in Table 6 and investigate the interactions between various factors. Since perceived walkability may be correlated with some perceptual factors such as people's emotions, attention and satisfaction, the interactions between these factors should be examined to clarify the independent influence of a single factor on walkability. To improve the reliability of walkability assessments, future research should collect more accurate data. GIS is widely used in walkability research to obtain objective data, and IT technologies such as Google Street View, VR technologies, big data and crowdsourcing facilitate the objective data collection process. Combining objective data with subjective data obtained through surveys and neuroscientific methods can provide objective measurement of perceptual data and deeper insights into walkability. The integration of these technologies allows for more comprehensive and accurate data to be obtained in walkability research. In the future, it is emphasised in research that walkability should be measured comprehensively and accurately using both objective and subjective data and the relationship between the two types of data should be examined (Wang & Yang, 2019).

Table 6. Potential Factors Affecting Perceived Walkability

Category	Factors
Demographic	Age, Gender, Education Level, Income Level, Socioeconomic Status etc.
Environmental	Air Quality, Noise Levels, Availability of Green Spaces, Pedestrian-Friendly Infrastructure etc.
Thermal	Temperature, Humidity, Wind
Economic	Housing Prices, Cost of Living, Access to Shopping and Services etc.
Individual	Physical Activity Level, Health Status, Daily Walking Habits etc.
Psychosocial	Perception of Safety, Social Support, Community Ties, Stress Levels etc.
Cultural	Local Cultural Norms, Walking Tradition, Social Expectations etc.
Perceptual	Emotion, Attention, Satisfaction, Aesthetic Perception, Motivation etc.
Infrastructure	Condition of Roads and Sidewalks, Street Lighting, Public Transport Accessibility etc.
Social	Neighborhood Relationships, Community Participation, Access to Local Events etc.

Walking is a fundamental human activity, and it is widely recognised that promoting walkability has significant benefits at both the individual and collective level. Walkability indices such as NEWS, Walkscore, Walkability Index, MAPS and Leyden are not measures of walking or walkability directly, but of the interaction between the built environment and the individual (Forsyth, 2015; Hall & Ram, 2018). The results of this review show that a complex approach to analysing the relationship between walkability perceptions and walkability indices produces results. Considering the tools, study topics and geographical differences, the links between walkability perception and these indices are diverse and multidimensional. While these indices generally provide objective measures of walkability (Horak et al., 2022; Lee et al., 2020), it is important to integrate these measures with individual perceptions. There is a need for innovative approaches to accurately measure perceived walkability, such as mixed methods integrated with walkability indices and subjective measurements. Mixed methods integrated with walkability indices and subjective measures show that there is an urgent need for innovative approaches to accurately assess perceived walkability. In this context, future research should contribute to an in-depth understanding of this field by focusing more on the relationships between walkability indices and individuals' subjective perceptions.

Advances in technology have significantly improved walkability assessment methodologies with a focus on obtaining comprehensive and objective data. Technologies such as Google Street View, accelerometers and pedometers, machine learning algorithms, OpenStreetMap and virtual reality are effective in providing detailed information on both physical and perceptual characteristics related to walkability. For example, accelerometers and pedometers allow the collection of detailed data on walking times, especially in older populations, facilitating the analysis of walkability factors and their relationships with sociodemographic variables and physical activity (Hunter et al., 2022; Stappers et al., 2021). However, these methods are insufficient to measure individuals' walking behaviours, attitudes and interactions with urban space. Similarly, Google Street View and computer vision technologies allow for visual analysis of urban areas, helping to assess physical features such as sidewalks and pedestrian-friendly features(Gong, 2023). However, these assessments alone are not sufficient to reveal the physical characteristics of urban space. In addition to physical features, individuals' perceptual experiences and satisfaction levels should also be considered. Therefore, technologies such as virtual reality and augmented reality can provide more comprehensive and multidimensional walkability analysis by allowing users to experience urban spaces. In addition, by analysing large datasets, machine learning algorithms can help to understand the relationships between walking behaviours and urban areas. Therefore, there is a need for further research to develop innovative approaches using mixed research methods to better understand the relationships between perceived walkability and built environment characteristics. Mixed research methods make it possible to comprehensively analyse both individuals' perceptions of walkability and objective measures of the physical environment by combining qualitative and quantitative data collection techniques (Schmidt et al., 2019; Tilley et al., 2017; Yıldırım et al.,2023). These methods can include various data collection techniques such as surveys, in-depth interviews, observation and GIS. Digital platforms such as social media and mobile applications can also be used to collect real-time data from a wide range of users. This data can be analysed to understand individuals' walking behaviour and perceptions.

Limitations in applying perceived walkability include that few studies have applied walkability to research areas other than built environment and health, and existing applications have not been fully validated with more case studies. Future research should focus on testing the applicability of perceived walkability in different countries and across different age groups to further validate and extend the application of perceived walkability. By conducting more case studies in different contexts, the universal validity of perceived walkability can be ensured. In addition, other areas of research, such as economic and social perspectives, can be added to the potential applications of perceived walkability. Perceived walkability can be utilized as an indicaton to address socio-economic issues such as poverty, inequality and discrimination.

Conclusions

This paper provides a comprehensive review of prominent research topics related to perceived walkability. It begins with a detailed bibliometric analysis using visualisation techniques to provide deeper insights into recent developments in walkability research. This analysis sets the stage for a critical review of the measurement of perceived walkability. Most studies highlight the connection between the walkability of the spatial environment and individual perceptual aspects.

The papers reviewed are discussed from three perspectives. These include the use of GIS, walking indices and innovative technological tools. While most studies address the objective dimensions of walkability in detail, they have limitations in analysing the subjective dimensions. In view of the limitations of the recent studies under discussion, future studies could reach more reliable conclusions based on more accurate and appropriate data and consider both subjective and objective analyses. Future studies should go beyond perceptual factors such as comfort, safety and motivation to focus on other specific factors such as sensations, emotions and behaviours and their interactions. This more comprehensive approach may help to better understand the relationship between perceptions of walkability and the built environment. As there are still no clear and consistent results on the relationship between the walkability of the built environment and perceived walkability, more detailed studies are needed to examine the relationship and differences in the context of different countries. In conclusion, this review can be used as a road map for future research with a focus on perceptions of walkability.

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Conflict of Interests

The author declares no conflict of interest.

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