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"The Pedestrian Network Concept: A Systematic Literature Review"

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ABSTRACT

The design of urban spaces that foster sustainable practices requires new analytical and structural approaches to spatial planning. An appropriate pedestrian network could significantly contribute to sustainable urban development goals, particularly by promoting sustainable mobility and pedestrian friendliness. With such goals, several attempts have been made to develop suitable models for pedestrian networks. However, something that is missing from the current literature is a framework that incorporates the main findings of the various studies as an integrated concise concept of the pedestrian network. To address this knowledge gap, this paper reviews studies on pedestrian networks and evaluates this concept based on the systematic 3W1H analysis method, which asks where, what, who, and how. In essence, the following questions are thus analyzed: Where is the pedestrian network located, What criteria play a role in the pedestrian network's performance, Who uses the pedestrian network, and How can the pedestrian network be analyzed? In this context, a systematic literature review is carried out by investigating studies conducted during the period 2001 to 2023 that appear in the Scopus database. The paper presents the results of the review of a selection of 67 papers dealing with pedestrian networks. Findings show that different models have been developed based on particular characteristics. Overall, researchers aimed to identify the most suitable network based on specific criteria for optimizing the walking experience in urban areas. By synthesizing the findings reported in these papers, this paper arguably contributes to a more comprehensive understanding of pedestrian networks, provides insights into the prioritization of design phases, facilitates the use of pedestrian network assessment models for future research, and creates a bigger picture for urban planners with a multidimensional view to a new sustainable urban structure.

1. Introduction

Walking is considered to be one of the most important non-motorized modes of transport (Jabbari, Ahmadi, & Ramos, 2022). Pedestrian mobility, or the act of traveling on foot, is indeed the oldest form of mobility. Before the invention of wheeled vehicles, animals for transportation, or even boats, humans had to rely solely on their own two feet to get from one place to another. As civilizations began to evolve, pedestrian mobility remained an important mode of transportation. Ancient Greeks, Persians, and Romans, built networks of roads and footpaths to facilitate travel by foot, and even today, some of these ancient routes are still in use (Amato, 2004; Habibi, 1996; Hodza & Butler, 2022; Lay, 1999). In many parts of the world, a pedestrian network continued to be an essential means of transportation. The primary function of the pedestrian network is to provide mobility for pedestrians, allowing them to travel from one location to another on foot. The pedestrian network in Iranian cities worked as a city skeleton and there were main urban elements and activities included the bazaar complex, school, and neighborhood centers (Farkisch, Ahmadi, & Che-Ani, 2015; Jabbari, Fonseca, & Ramos, 2021). The concept of the pedestrian network originated in 1797 when the French army occupied Venice and attempted to build a structure to connect the island groups by waterways (Vivo, 2016). They worked to transform the amphibious city into a homogeneous pedestrian network by creating canals, building bridges, and creating paths. De Vivo (2016) believes that walking was a daily habit and formed the pedestrian network in sixteenth-century Venice.

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Despite being replaced by faster modes of transport for longer journeys, walking continues to be an essential means of transportation for shorter trips, and for changing between modes. The Personal, social, economic, and environmental benefits of walking are well documented: Walking reduces traffic congestion, air pollution, and noise; it is beneficial for individual health and well-being; it provides economic benefits; it affects property prices; and it improves the sociability and vitality of urban spaces (Bahrainy & Khosravi, 2013; H.-Y. Chan, Xu, Chen, & Liu, 2022; Kim, Park, & Lee, 2014; P. Zhao & Li, 2017). For these reasons, the promotion of walking and walkability has become a focus of various urban policies, especially since the rise of the green mobility debate. Green mobility has gained popularity in recent years due to growing concerns about the impact of transportation on the environment, climate change, and the public health issues associated with air pollution. Green mobility represents a shift towards more sustainable modes of transportation (Delso, Martín, Ortega, & Van De Weghe, 2019; Pamucar et al., 2022; Zamparini, Domènech, Miravet, & Gutiérrez, 2022). In addition, the COVID-19 pandemic has highlighted the importance of pedestrian networks in creating safe and healthy cities. In many cities around the world, there has been a shift toward prioritizing pedestrian infrastructure in response to the pandemic (Sainz-Santamaria et al., 2023).

Accordingly, the quality of the pedestrian network is arguably one of the most important parameters for sustainable urban development and sustainable mobility (Forsyth, Oakes, Lee, & Schmitz, 2009; Lilasathapornkit, Rey, Liu, & Saberi, 2022). A pedestrian network can be understood as a structure within an urban space, which consists of interconnected streets with elements of accessibility and connectivity (Fonseca, Fernandes, & Ramos, 2022; Gaglione, Cottrill, & Gargiulo, 2021; Jabbari et al., 2021; Pearce, Matsunaka, & Oba, 2021). More recently, two well-known pedestrian network projects were implemented in Hong Kong and Toronto. In Hong Kong, the at-grade pedestrian network was created in the 1970s, linking the different outdoor and indoor pedestrian areas into a continuous experience of movement and creating a collective urban identity (Z. Tan & Q.L. Xue, 2014; Z. Tan & Xue, 2015; Zhou, Zhang, & Jf Chiaradia, 2022). Toronto's pedestrian network is a largely underground downtown pedestrian network that spans more than 30 kms of restaurants, shopping, services, and entertainment and opened in 1987 (Bélanger, 2007; Cui, 2021).

Despite the many opportunities to study and implement pedestrian networks, there is limited research, both on technical and practical application issues (Kelly, Tight, Hodgson, & Page, 2011). Much of the work on pedestrian networks has been presented in processes that involve multiple stages with few components that did not consider a unit structure (Gaglione et al., 2021; Mitchell & MacGregor Smith, 2001; Xue X. Yang, Stewart, Fang, & Tang, 2022). To overcome this weakness, Hall and Ram (2018) pioneered the simplification of pedestrian network models using the well-documented Walk Score measure. However, it focused only on individual and independent variables of walking and not on the correlation of these variables in the context of urban planning. The literature review showed that the current models are complex, they are still not very application-oriented, they may be too articulate for urban planning, and they maybe not consider the pedestrian network assessment as an urban structure.

To address these knowledge gaps, the aim of this study is to review and synthesize the extant knowledge on pedestrian networks. To do this, the paper take stock of papers published on PNs between 2001 and 2023 and utilizes the 3W1H method (Malik, Chandra, Rao, & Arora, 2020) to analyze these. As such, it analyzes *where* (W) is the pedestrian network located?, *what* (W) criteria play a role in the pedestrian network's performance?, *who*(W) uses the pedestrian network? and *how*(H) can the pedestrian network be analyzed?

The rest of this paper is structured as follows. After explaining the applied method in Section 2, Section 3 outlines the results from the literature review. The discussion, including a conceptual model that arguably contributes to a more comprehensive understanding of PNs, is then presented in Section 4. Lastly, a few concluding remarks are provided in the fifth and final section.

2. Method

The aim of this study is to review the current pedestrian network models and simplify their processes and components in the context of urban planning using the 3W1H method. This method is a rational thought process and a well-documented method for decision-making (Chi, Lin, & Liu, 2008; Jagarajan et al., 2017; Malik et al., 2020; Y. Tan, Liu, Zhang, Shuai, & Shen, 2018), which has previously been successfully applied in other cases (Jagarajan et al., 2017; Y. Tan et al., 2018; J. Zhao, Sun, & Webster, 2020).The information processed by the 3W1H method identifies the relationship between the purpose and the components of a given model. The method includes three main questions: where, what, who, and how? The method provides a complete perspective for the construction of the assessment model. It consists of a set of concepts, relationships and their scope (Johannessen, Flak, & Sæbø, 2012).

Studying pedestrian networks involves a reflection on the theoretical and practical implications of the concept. This systematic literature review follows a four-step procedure that corresponds to the methodological approach used by Motomura et al. (2022), which is illustrated in Fig. 2. First, in step 1, the so-called identification step, the sources and procedures for the literature search are determined on the basis of the Scopus database. It focused on papers published since 2001 that appeared in the Scopus database. All studies are recent, with one-third of the total papers (24 out of 67) published since 2020. Step 2 is then to define the scope, which includes the objectives and a review protocol for the systematic review. The process consists in searching the expression "pedestrian network" in articles published in journals with more than four occurrences in the title, abstract, text, and keywords. This ensures that "pedestrian network" is a relevant expression used in the searched papers. The following step 3 is about the eligibility and identification of concepts through a focused synthesis of the results according to the 3W1H method. Finally, Step 4 is the evaluation and includes a comprehensive summary of the main processes and components in theory and practice in terms of where, what, who, and how to influence the process of the pedestrian network.

3. Results

According to the described literature review method, 67 papers containing the expression "pedestrian network" were identified (Table 1). From these, 28% are within the scientific field of mathematics, 47% are related with urban planning, and 26% with remote sensing. The majority of these papers come from Asian research centers (Diagram 1). They include mathematical approaches that focus on developing algorithms to automatically identify the geometry of pedestrian routes; urban planning approaches that often focus on identifying and assessing the capacity of urban space for pedestrians including by conducting surveys to target groups; remote sensing approaches, on the other hand, typically focus on tracking the pedestrian environment using high quality imagery by satellite imagery and open data sources to identify patterns of pedestrian behavior.

Based on 677 papers found in the Scopus databases, 31 papers related to urban planning are considered in order to analyze more (Abass & Tucker, 2018; Arroyo, Mars, & T., 2018; Azad, Abdelqader, Taboada, & Cherry, 2021; D'Orso & Migliore, 2020; Delso, Martín, & Ortega, 2018; Fonseca et al., 2020; Garip, Þalgamcýoðlu, & Cimþit Koþ, 2015; Q. Guo, Xu, Pei, Wong, & Yao, 2017; Hajrasouliha & Yin, 2015; J. He et al., 2016; Jabbari et al., 2022 M. Jabbari, Fonseca, & Ramos, 2018; Kwon, Kim, & Lee, 2017; Lunecke & Mora, 2018; Oswald Beiler, McGoff, & McLaughlin, 2017; Özbil, Yeþiltepe, & Argýn, 2015; Pearce et al., 2021; Tal & Handy, 2012; Z. Tan & Q.L. Xue, 2014; Z. Tan & Xue, 2015; Ujang, 2016; X. Yang, Sun, Huang, & Fang, 2022; Zhou et al., 2022). This paper seeks to answer the following questions: (1) Where is the

Table 1
References and topics of the references containing pedestrian network on Scopus database.

	Authors	Approach	Purpose	Local
1	Zhou et al. (2022)	Urban planning	Estimating wider economic impacts of transport infrastructure Investment: Evidence from accessibility disparity in Hong Kong	Hong Kong
2	Łaszkiewicz et al. (2022)	Mathematical	Valuing access to urban greenspace using non-linear distance decay in hedonic property pricing	Poland
3	Gaglione et al. (2022)	Urban planning	Where can the elderly walk? A spatial multi-criteria method to increase urban pedestrian accessibility	Italy
4	H.-Y. Chan et al. (2022)	Mathematical	Impacts of the walking environment on mode and departure time shifts in response to travel time change: Case study in the multi-layered Hong Kong metropolis	Hong Kong
5	Fonseca et al. (2022)	Urban planning	Walkable Cities: Using the Smart Pedestrian Net Method for Evaluating a Pedestrian Network in Guimarães, Portugal	Portugal
6	X. Yang et al. (2022)	Urban planning	A Framework of Community Pedestrian Network Design Based on Urban Network Analysis	China
7	H.-Y. Chan et al. (2022)	Urban planning	Pedestrian route choice with respect to new lift-only entrances to underground space: Case study of a metro station area in hilly terrain in Hong Kong	Hong Kong
8	Jabbari et al. (2022)	Urban planning	Defining a Digital System for the Pedestrian Network as a Conceptual Implementation Framework	Sweden
9	Gholami, Torreggiani, Tassinari, and Barbaresi (2022)	Remote sensing	Developing a 3D City Digital Twin: Enhancing Walkability through a Green Pedestrian Network (GPN) in the City of Imola, Italy	Italy
10	X. Yang et al. (2022)	Remote sensing	Attributing pedestrian networks with semantic information based on multi-source spatial data	China
11	Azad et al. (2021)	Urban planning	Walk-to-transit demand estimation methods applied at the parcel level to improve pedestrian infrastructure investment	USA
12	Gaglione et al. (2021)	Urban planning	Urban services, pedestrian networks and behaviors to measure elderly accessibility	Italy
13	Cui (2021)	Urban planning	Building three-dimensional pedestrian networks in cities	Australia
14	Georgiou, Skoufas, and Basbas (2021)	Urban planning	Perceived pedestrian level of service in an urban central network: The case of a medium size Greek city	Greece
15	Carroll, Caulfield, and Ahern (2021)	Mathematical	Appraising an incentive only approach to encourage a sustainable reduction in private car trips in Dublin, Ireland	Ireland
16	Moustaid and Flötteröd (2021)	Mathematical	Macroscopic model of multidirectional pedestrian network flows	Sweden
17	Pearce et al. (2021)	Urban planning	Comparing accessibility & connectivity metrics derived from dedicated pedestrian networks and street networks in the context of Asian cities	Japan
18	Zhao et al. (2020)	Remote sensing	Walkability scoring: Why and how does a three-dimensional pedestrian network matter?	Hong Kong
19	Yang et al. (2020)	Remote sensing	Pedestrian network generation based on crowdsourced tracking data	China
20	Vo, Qian, Lam, and Sumalee (2020)	Remote sensing	Modeling joint activity-travel patterns in pedestrian networks with use of Wi-Fi data	Hong Kong
21	D'Orso and Migliore (2020)	Urban planning	A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments	Italy
22	Zuo et al. (2020)	Urban planning	First-and-last mile solution via bicycling to improving transit accessibility and advancing transportation equity	USA
23	Fonseca et al. (2020)	Urban planning	Smart Pedestrian Network: An Integrated Conceptual Model for Improving Walkability	Portugal
24	Sun, Wallace, and Webster (2020)	mathematical	unraveling the impact of street network structure and gated community layout in development-oriented transit design	Hong Kong
25	Higgins (2019)	Mathematical	A 4D spatio-temporal approach to modeling land value uplift from rapid transit in high density and topographically-rich cities	Hong Kong
26	Bhattacharjee, Roy, and Das Bit (2019)	Remote sensing	Constructing digital pedestrian maps of the disaster affected areas	India
27	Lesani and Miranda-Moreno (2019)	Remote sensing	To estimate travel times (speeds), to classify bicycle-pedestrian WiFi signals, and to extrapolate pedestrian MAC counts.	Canada
28	Itu, Cerbu, and Galatanu (2019)	Remote sensing	Modeling and Testing of the Sandwich Composite Manhole Cover Designed for Pedestrian Networks	Romania
29	Oyama and Hato (2018)	Remote sensing	To estimate the route choice parameters with the fewer personal approach	Switzerland
30	M. Jabbari et al. (2018)	Urban planning	Integrated approach to assess a pedestrian network by combining multi-criteria and space syntax.	Portugal
31	Delso et al. (2018)	Urban planning	To provide a procedure to evaluate the impact of obstacles to pedestrian mobility and walkability	Spain
32	Lunecke and Mora (2018)	Urban planning	Understanding the impact of downtown Santiago's three-scale pedestrian network on walkability	USA
33	He et al. (2018)	Urban planning	To explore the influences of various morphological features of non-uniform and orthogonal breezeway networks on pedestrian ventilation in high-density urban environments under Singapore's climatic conditions.	Singapore
34	Arroyo et al. (2018)	Urban planning	To identify factors that influence the decision to walk and cycle.	Spain
35	Yao, Wang, Fang, and Wu (2018)	Remote sensing	To identify Vehicle-Pedestrian Collision Hotspots at the Micro-Level	China
36	Hoogendoorn, Daamen, Knoop, Steenbakkers, and Sarvi (2018)	Mathematical	To analyze relations between density network and speed pedestrian	Netherlands
37	Jung and Hong (2017)	Remote sensing	Guiding network for pedestrian detection	Korea
38	Zhu, Liao, Lei, and Li (2017)	Remote sensing	To predict multiple attributes together in a unified framework	China

(continued on next page)

Table 1 (*continued*)

	Authors	Approach	Purpose	Local
39	Osama and Sayed (2017)	Mathematical	To assess the impact of network connectivity, directness, and topography on pedestrian safety	Canada
40	Ki-Ho and Kang (2017)	Remote sensing	Aggregating Channel Features (ACF) and rich Deep Convolutional Neural Network (DCNN) features for efficient and effective pedestrian detection in complex scenes	China
41	Hänseler, Lam, Bierlaire, Lederrey, and Nikolić (2017)	Mathematical	To describe this interaction, a stream-based pedestrian fundamental diagram	China
42	Guo et al. (2017)	Urban planning	Focused on the role of different road network patterns on the occurrence of crashes involving pedestrians.	China
43	Kwon et al. (2017)	Urban planning	Locating Automated External Defibrillators in a Complicated Urban Environment Considering a Pedestrian-Accessible Network that Focuses on Out-of-Hospital Cardiac Arrests	Korea
44	Zheng and Elefteriadou (2017)	Mathematical	Estimating pedestrian delay at unsignalized intersections in urban networks	USA
45	Oswald Beiler et al. (2017)	Urban planning	Trail network accessibility: Analyzing collector pathways to support pedestrian and cycling mobility	USA
46	Qu and Lim (2016)	Mathematical	Detecting pedestrian using neural network with a weighted fuzzy membership function	South Korea
47	Ujang (2016)	Urban planning	Studying tourists' expectations on the spatial characteristics of walkways in terms of accessibility, connectivity and continuity	Malaysia
48	Xin and Wu (2016)	Mathematical	To improve traffic safety and protect pedestrians	China
49	Dai and Jaworski (2016)	Remote sensing	Investigating the influence of built environment on pedestrian crashes	USA
50	Roshandeh, Li, Zhang, Levinson, and Lu (2016)	Remote sensing	Simultaneously assess the overall impacts of vehicle & pedestrian crashes caused by signal timing optimization in dense urban street networks.	USA
51	Hong, Shankar, and Venkataraman (2016)	Remote sensing	To derive a modeling framework for characterizing the space-time exposure of pedestrians in crosswalks,	USA
52	Rashidi, Parsafard, Medal, and Li (2016)	Mathematical	To minimize the safety hazard for pedestrians and the total transportation cost of the network	USA
53	Z. Tan and Xue (2015)	Urban planning	To track the evolving concept of grade-separated pedestrian networks in Hong Kong, revisiting the critical actions from 1965 to 1997.	Hong Kong
54	Tiplica (2015)	Mathematical	Studying the behavior of drivers interacting with pedestrians and what might be the cause of their decisions of legitimate transgressions	France
55	Yu, Ma, Lo, and Yang (2015)	Remote sensing	Optimizing mid-block pedestrian crossing network with discrete demands	China
56	Hajrasouliha and Yin (2015)	Urban planning	Investigating the impact of street network connectivity on pedestrian volume	USA
57	Garip et al. (2015)	Urban planning	Studying the influence of architectural configuration on the pedestrian network	Turkey
58	Özbil et al. (2015)	Urban planning	Understanding street-level urban design qualities and objectively measured street network configuration are related to pedestrian movement, controlling for land use	Turkey
59	Z. Tan and Q.L. Xue (2014)	Urban planning	Elevating pedestrian systems of Hong Kong in the context of planning regulation and land finance	Hong Kong
60	Zhang and Chang (2014)	Mathematical	Defining model to evacuate pedestrian–vehicle mixed-flow networks	USA
61	Raghuram Kadali, Rathi, and Perumal (2014)	Mathematical	Evaluating the pedestrian mid-block road crossing behavior using artificial neural network	India
62	Kasemsuppakorn and Karimi (2013)	Mathematical	A pedestrian network construction algorithm based on multiple GPS traces	USA
63	Tal and Handy (2012)	Urban planning	Measuring nonmotorized accessibility and connectivity in a robust pedestrian network	USA
64	Chin et al. (2008)	Urban planning	Accessibility and connectivity in physical activity studies: The impact of missing pedestrian data	Australia
65	Bélanger (2007)	Urban planning	Underground landscape: The urbanism and infrastructure of Toronto's downtown pedestrian network	Canada
66	Trépanier, Chapleau, and Allard (2002)	Mathematical	Transit Itinerary Calculation on the Web: Based on a Transit User Information System	USA
67	Mitchell and MacGregor Smith (2001)	Mathematical	Topological network design of pedestrian networks	USA

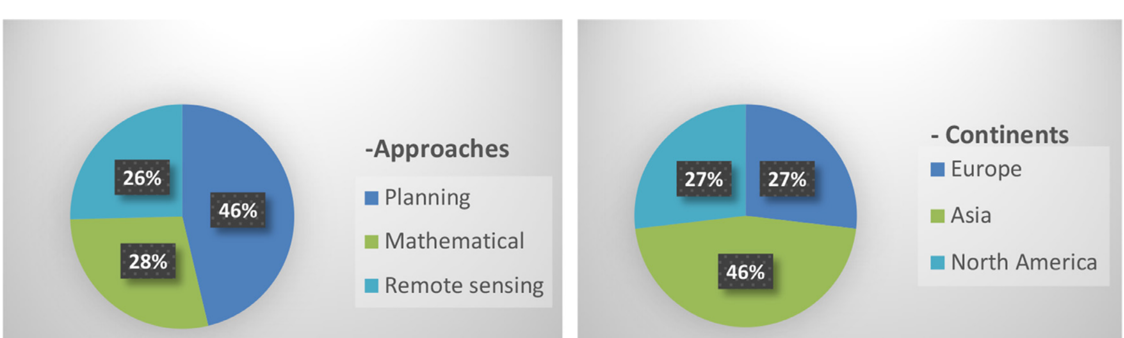

Diagram 1. Division of the papers into approaches and continents.

pedestrian network located? (2) What criteria play a role in the pedestrian network's performance? (3) Who uses the pedestrian network? and (4) How can the pedestrian network be analyzed? Fig. 2 shows the relationship between these questions based on the 3W1H method.

3.1. Where is the pedestrian network located?

The question "Where is the pedestrian network located?" identifies the place for which the model was designed at the site. In fact, the pedestrian network is closely related to the practical context in which the work is carried out. In order to understand the practical context, researchers have pursued a variety of objectives. The main objectives of this research, which addresses the concept of the pedestrian network, are: to promote social interactions at the neighborhood level; to increase urban vitality in the city center; to find the potential urban space for the pedestrian network in the city center; and to improve the conditions for visiting and promoting trade in city centers (J. He et al., 2016; M. Jabbari et al., 2018; Lunecke & Mora, 2018; Tal & Handy, 2012; Z. Tan & Q.L. Xue, 2014).

The models analyzed different geographical scales including urban space, street network, and urban structure. As such, the research arguably included micro-scale, macro-scale, and even multi-scale approaches (J. He et al., 2016; M. Jabbari et al., 2018; Kwon et al., 2017; Lunecke & Mora, 2018; Tal & Handy, 2012; Z. Tan & Q.L. Xue, 2014). Some researchers are currently using the specific scale of the pedestrian network model in the urban planning processes based on limited data (J. He et al., 2016; Tal & Handy, 2012; Z. Tan & Xue, 2015). Indeed, the pedestrian network model is applied at multiple scales based on the spatial hierarchical theory (M. Jabbari et al., 2018; Lunecke & Mora, 2018). This theory contains an integrated dataset at multiple scales and links planning, analysis and data to the hierarchical urban structure (Bereitschaft, 2018; Buckley, Stangl, & Guinn, 2017; Cheng & Masser, 2003; Girling, Zheng, Monti, & Ebneshahidi, 2019).

The COVID-19 pandemic has had a significant impact on the pedestrian network. In many cities around the world, there has been a shift towards prioritizing pedestrian infrastructure in response to the pandemic. This has been driven by the need for physical distancing and the recognition of walking as a safe and healthy mode of transportation during the pandemic to provide safe and accessible routes for people to walk from one point to another. The primary function of pedestrian infrastructure is to provide mobility for pedestrians, allowing them to travel from one location to another on foot. The pandemic has highlighted the importance of the pedestrian network in creating safe and healthy cities. The changes made to the pedestrian infrastructure during the pandemic have the potential to create lasting improvements (Sainz-Santamaria et al., 2023) and redesign pedestrian networks as main urban structure.

3.2. What criteria play a role in the pedestrian network's performance?

Pedestrian network models have a wide range of applications as they not only address physical environmental aspects but also consider some macro-level street network analyses (J. He et al., 2016; M. Jabbari et al., 2018; Lunecke & Mora, 2018; Tal & Handy, 2012; Z. Tan & Q.L. Xue, 2014). In order to qualify and evaluate the different dimensions, this paper considers two main contexts. First, some pedestrian network models identified criteria related to the characteristics of each street suitable for walking (J. He et al., 2016; M. Jabbari et al., 2018; Lunecke & Mora, 2018; Tal & Handy, 2012; Z. Tan & Q.L. Xue, 2014). Second, some other pedestrian network models assessed the position of the street in the network by using urban structure criteria such as connectivity, integration and distribution (Hajrasouliha & Yin, 2015; J. He et al., 2016; M. Jabbari et al., 2018; Özbil et al., 2015; Tal & Handy, 2012).

The studies on criteria related to the characteristics of streets show that they are very complex. By understanding what a pedestrian considers an attractive route, planners can build more pedestrian-friendly and liveable cities. In the beginning, it focuses on the majority criteria that most influence the definition of the street that the literature review revealed a large number of research findings and related attributes associated with walkability. The main criteria considered can be divided into four groups: built environment, urban function, accessibility, and natural environment.

Built environment includes several perceptual qualities that can affect the walking environment (Bahrainy & Khosravi, 2013; Garcia & Lara, 2015; Kim et al., 2014; Wey & Chiu, 2013). Some researchers have proposed six sub-criteria in this context: image, enclosure, human scale, transparency, complexity, and slope(Ewing & Handy, 2009; Lundberg & Weber, 2014). These criteria have been used to create urban design quality indices to capture aspects of the built environment that are related to people's emotional responses to aesthetics in urban areas (Ferrer, Ruiz, & Mars, 2015; Garip et al., 2015; M. Jabbari et al., 2018; Lunecke & Mora, 2018).

Urban function affects spatial activity. Land use as one of the sub-criteria of urban function affecting pedestrian satisfaction and distribution in urban space (Bahrainy & Khosravi, 2013; Bélanger, 2007; Lamíquiz & López-Domínguez, 2015; Lerman & Omer, 2016). Population density is another sub-criterion most often used in this topic (M. Jabbari, Fonseca, & Ramos, 2018; Tal & Handy, 2012). Above all, population density correlates residential areas with pedestrian movements (Lerman & Omer, 2016; Peiravian, Derrible, & Ijaz, 2014). To be safe in a pedestrian network should consider the traffic condition because pedestrians are especially vulnerable on the roadway in the case of collisions and personal security (Fonseca et al., 2022). In fact, the urban function classifies three sub-criteria, including land use, population density and safety.

Accessibility is another criterion analysed by several authors that can improve pedestrians' quick access to a given location. This includes public transport and intelligent transport systems (ITS) as a sustainable method of urban mobility (Grecu & Morar, 2013). Accessibility is a facilitating criterion that strongly links urban function to the built environment. For example, to connect suburban areas that are largely car-dependent, considering the accessibility criterion can promote the pedestrian network through transport purposes as intermodal transportation (Gilderbloom, Riggs, & Meares, 2015b; Lamíquiz & López-Domínguez, 2015; Oswald Beiler et al., 2017).

Natural environment of streets and urban areas is also an important criterion, influencing walking and making a comfort zone (Panagopoulos, Duque, & Dan, 2016), pleasant conditions, by temperature control with artificial solutions (Peiravian et al., 2014) green spaces, sunlight, shade and wind are important for walking (Koh & Wong, 2013). Some authors have developed approaches to improve the walkability in green spaces of urban areas (Lwin & Murayama, 2011).

Another group of studies assessed the position of the street in the pedestrian network at the macro-level. Some structural criteria were assessed to get a better understanding of the spatial configuration of the streets, the road network and the location of economic activities (Chin, Van Niel, Giles-Corti, & Knuiman, 2008; Gilderbloom et al., 2015b; Kim et al., 2014; Lerman & Omer, 2016; Millward, Spinney, & Scott, 2013; Peiravian et al., 2014). The degree of connectivity in the street network is the most important parameter for any movement in urban space (Carpio-Pinedo, Martínez-Conde, & Daudén, 2014). The connectivity criterion joins places with people and defines how streets are networked (Azmi & Ahmad, 2015; Bahrainy & Khosravi, 2013; Pearce et al., 2021). Furthermore, the urban structure defines how the streets are arranged and interconnected and how they connect the different urban areas with their surroundings. A well-functioning urban structure has coherent neighborhoods where the centers of activities are within easy walking distance. In this context, walking creates economic value and social vibrancy (Gallimore, Brown, & Werner, 2011; Lindelöw, Svensson, Brundell-Freij, & Winslott Hiselius, 2017; Loo, Mahendran, Katagiri, & Lam, 2017). The integration of the road network is also a morphological parameter with implications for pedestrian movement (Carpio-Pinedo et al., 2014; Koh & Wong, 2013). Additionally, Z. Tan and Q.L. Xue (2014) examined the distribution of pedestrian mobility in the street network, as another parameter. He, Tablada, and Wong (2018) consider that the distribution of pedestrian flows characterizes these multi-level pedestrian systems.

3.3. Who uses the pedestrian network?

The organization of the pedestrian network based on the habits, pedestrian behavior and lifestyles of users living in cities has been discussed by many authors (Borst et al., 2009; Stevenson et al., 2017; X. Yang et al., 2022. However, it is only in recent years that attention has been focused on 'vulnerable' populations (children, older people, people with disabilities) in relation to the accessibility (Abass & Tucker, 2018). Gradients, pavement widths, obstacles on sidewalks, sidewalks in poor condition, traffic characteristics, etc. represent barriers for users walking in the city, especially for vulnerable populations. This is particularly important for users who require a wider space, such as pushchair and wheelchair users (H.-Y. Chan, Ip, Mansoor, & Chen, 2022; Fonseca et al., 2022; Gaglione et al., 2021; Šurdonja, Otković, Deluka-Tibljaš, & Campisi, 2023).

In addition, some studies have developed level of service (LOS) measurement to assess and compare the quality of urban services for different user modes (i.e. car, pedestrian, bicycle and transit). Several factors contribute to the LOS: pedestrian satisfaction with the route to the stop, satisfaction of waiting passengers, and satisfaction of passengers using the pedestrian network as part of intermodal transport. Traditional cost-benefit analysis is usually applied in an evaluation context to capture direct benefits to users, such as savings in travel time and improved quality of transport services sought by the municipality (urban manager). In order to realize the potential of systematic use of urban space, it is necessary to learn lessons from existing cases and understand user (pedestrian) behavior and concerns (Azad et al., 2021; Jabbari et al., 2022 Zhou et al., 2022; Zuo, Wei, Chen, & Zhang, 2020).

3.4. How can the pedestrian network be analyzed?

The urban planning process to provide a pedestrian network model is a complex task. The physical structure of the city as well as economic, social and environmental factors of different scales must be taken into account in the planning process. However, 79% of the walk score studies conducted by Hall and Ram (2018) were based on independent variables, only once as a mediating-moderating variable (Abass & Tucker, 2018) and on no occasion as a dependent variable. Also, in a few papers a bivariate correlation model was applied (Duncan et al., 2016; Hall & Ram, 2018; Towne et al., 2016). Therefore, the urban information model about pedestrian network should integrate the multidimensional urban aspects of economy, society, and environment. In fact, bonding among different criteria through different models determine the relationships between the potential of urban space and pedestrian.

Furthermore, pedestrian network, including multifunctional spaces, is used by different users with often conflicting interests and pedestrian network models reflect aspects of the users (Herrmann, 2016). Elderly, children and disabled people are vulnerable users that should not be forgotten in pedestrian network planning in urban public spaces (Šurdonja et al., 2023; Wijayanti & Pandelaki, 2012). Some studies look at pedestrian flows and behavior, while others use surveys to collect pedestrian data(Arroyo et al., 2018; Cui, 2021; Duncan et al., 2016; Hall & Ram, 2018; Towne et al., 2016; Ujang, 2016). However, more work is needed on classifying users and combining the results from their feedback in the pedestrian network model.

An attempt is made to classify urban spaces in order to propose a new typology of public space based on the way public space is managed, the so-called urban space typology (Carmona, 2010). The typology approach was applied in the city center and classified into pedestrian zones based on the characteristics of the public space. These pedestrian zones provided a short design document to manage the PEDESTRIAN NETWORK based on specific characteristics (Z. Tan & Xue, 2015). In the 1960s, pedestrian zones emerged in Europe, especially in city centers, and spread rapidly. For example, in 1966 there were only 63 pedestrian zones in Germany, but by 1972 there were 182 and by 1977 there were 370 pedestrian zones (Kostof, 2004; Lunecke & Mora, 2018). Lunecke and Mora (2018) have shown that the high volume of pedestrians in the street network occurred at specific street sections. These areas were usually located near the pedestrian zones.

The pedestrian network requires full consideration of the spatial continuity of the city (Yücel, 1979). The connectivity of the street network has an important impact on walking and how streets are interconnected (Azmi & Ahmad, 2015; Bahrainy & Khosravi, 2013). Therefore, a convenient design of pedestrian network should be provided to encourage walking and minimize obstacles. The connectivity of the street network can be defined as the number of intersecting streets per unit area (Azmi & Ahmad, 2015; Garcia & Lara, 2015). Space syntax was used to assess street network connectivity because it has several advantages over simpler measures of road network connectivity, such as passive graphical terms. By using axial lines, the space syntax is better suited to calculate movements in networked settlements and functional connectivity in networks (Gilderbloom, Riggs, & Meares, 2015a; M. Jabbari et al., 2018; Lerman & Omer, 2016; Tianxiang, Dong, & Shoubing, 2015).

In turn, the urban configuration is the most important factor in shaping pedestrian movement patterns. Peponis, Ross, and Rashid (1997) presented some findings on the morphology of Greek cities and their patterns of pedestrian movement. In their study, patterns of pedestrian movement and urban configuration were compared using the typological model of urban layouts. Different measures of urban configuration are related to aspects of social life. Accessibility is based on the relationships that each space has with the others in an urban system (Girling et al., 2019; Jabbari et al., 2022 Jeong & Banyn 2016). As a result, the use of integration analysis in urban studies has increased in recent years and the pedestrian network model has been developed (J. He et al., 2016). For instance, Li, Xiao, Ye, Xu, and Law (2016) measured the spatial configuration of street networks in the Chinese city of Gulangyu using integration analysis to guide urban planning and tourism management policies and tourist preferences. Cutini (2016) also used space syntax to analyze the relationship between movement and the urban structure of Florence to examine how movement patterns have changed over time as the metropolitan area has grown and its network has been progressively reshaped. In this sense, this method should be useful for further comparison with another model supporting pedestrian network, as it takes into account both spatial and functional aspects of urban form.

In the urban planning literature, numerous studies have focused on the relationships between walking and all these criteria. These factors are usually composed of multiple criteria and sub-criteria that are interrelated but weighted differently (MiMillward et al., 2013). The multi-criteria analysis (MCA) approach was used in the pedestrian network model to address the complexity of urban mobility issues reflected in the multiplicity of sustainability indicators (M. Jabbari et al., 2018). The MCA enabled through the structured prioritization of a number of nested variables of urban space in relation to pedestrians. These approaches were inspired by the study of Frank, Schmid, Sallis, Chapman, and Saelens (2005) which created a combined walkability index from three urban criteria to analyze their influence on physical activity. The MCA is also a commonly used tool, especially in spatial planning. The MCA evaluates decision problems and different options based on specific criteria or the preferences of decision makers, using a set of qualitative and/or quantitative criteria with different weights (Durmuş & Turk, 2014). Furthermore, H.-Y. Chan et al. (2022) based on a face-to-face questionnaire survey conducted in a new station area of a hilly neighborhood, developed a binary mixed logit model to estimate the effect of route attributes, trip characteristics, socio-demographics, and walking preferences on the decision to use alternative underground walking routes.

Table 2
Models Evaluation for Pedestrian Network.

What: Goal	Where: Place-Scale	Who: User	How: Model Content	Method	Strength Model	Author
To bring more walk-in shop visiting; purchasing opportunities; characteristics of an target group-friendly pedestrian network	Some streets, Urban spaces/Micro-scale	Citizen/ Tourist	Static built environment data, dynamic environmental behavior data and Street network	Survey maps, GIS and Space Syntax software	Considering three main dimensions sociology, economic and urban planning; Improving understanding of service proximity and user behavior	He et al. (2018); Hajrasouliha and Yin (2015); Delso et al. (2018); Oswald Beiler et al. (2017); Garip et al. (2015); Gaglione et al. (2022),
To bring more walk-in shop visiting and purchasing opportunities; to improve wider economic impacts in transport infrastructure	Neighbourhood, City center/ Macro-scale	Citizen/ Commuters	Standard, Guideline, Survey & Design code, Strategic plan, Represent the distributional equity of transit accessibility among social groups.	Processed to design pedestrian network zone and regulation, Survey	Creating standard document related to the pedestrian network; Place-based policies in a dense city require improvement in the pedestrian network;	Chin et al. (2008); Arroyo et al. (2018); Tan et al. (2015); Ujang (2016); Zuo et al. (2020); Cui (2021); Zhou et al. (2022)
To increase urban vitality	Urban areas, Suburban/Multi-scale	Citizen/ Tourist/ Commuters	Public space typologies, pedestrian flows and retail uses	Survey, Typology, Using Open Street Map data	Interconnecting the pedestrian network in order to develop the well-function	Lunecke and Mora (2018); Osama and Sayed (2017); Pearce et al. (2021);
To find the potential urban space for the pedestrian network	Urban areas, Suburban/Multi-scale	Citizen/ Tourist/ Commuters	Static built environment data and Street network	Survey, GIS, Space Syntax, Rhino software	Developing model as a service in transportation system; Considering Multi-scale in model;	Bélanger (2007); Tal and Handy (2012); Özbil et al. (2015) ; Kwon et al. (2017) ; M. Jabbari et al. (2018); Fonseca et al. (2022); X. Yang et al. (2022); Azad et al. (2022); Zuo et al. (2020)

The increasing availability of spatial data with greater disaggregation promoted the use of Geographic Information Systems (GIS) in pedestrian network models. GIS has been used by many authors for various tasks, such as identifying high and low walkability, providing information on the walkability characteristics of a given region, and creating a standardized benchmark to compare different environments in terms of the characteristics shown to create the pedestrian network (Badland et al., 2013; Kim et al., 2014; Tal & Handy, 2012). Indeed, many pedestrian network attributes, namely density, land use mix, road network and accessibility, can be analyzed in GIS (Azad et al., 2021; Z. Guo & Loo, 2013; Tal & Handy, 2012). For these authors, the combination of GIS data and an environmental audit has proven to be a valid tool for assessing pedestrian network. GIS has been used in spatial analysis to assess the connectivity of the road network for cyclists and pedestrians (Lundberg & Weber, 2014). The GIS techniques are often used in combination with other approaches, namely: agent-based simulations, where GIS provides geographical data to model the walkability of neighborhoods (Badland et al., 2013; D'Orso & Migliore, 2020).

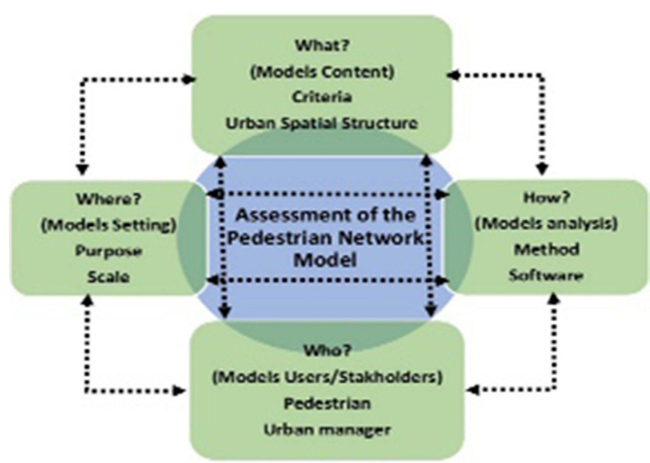

Fig. 1. Correlation among questions in the pedestrian network.

4. Discussion - Future directions for pedestrian network models

The review focuses on pedestrian network approaches in the field of urban planning. These studies rely on different data sources to achieve different objectives at different scales and areas. It can be concluded that the identification and assessment of a pedestrian network is a challenging process; especially since there are various contexts and levels of application, associated to the multi-functionality, mixed spaces, and natural features found in urban areas (Table 2). The results show that the majority of the studies focused on how to assess pedestrian network and on what criteria should be used in the evaluations of pedestrian network. Researchers mainly examined criteria related to the built environment, urban functions, accessibility, and the natural environment of pedestrian networks. Finally, these criteria were assessed using analytical tools and methods at the micro and macro level. In this context, GIS was increasingly used as a tool to analyze urban spatial attributes. Moreover, space syntax is applied to assess urban configuration and street connectivity. Less studies have been focused on where is the pedestrian network and who use the pedestrian network.

There is little evidence of where will be located the pedestrian network characteristics at site and area scale how to impact on the urban planning process. It raises up the question when the considering the pedestrian network in the urban structure how to make relationship with path segments that will be well-connected in the transportation network and have specific destinations along them. In addition, some researches were limited to city centers and neighborhoods in terms of the pedestrian network place-making and could be extended to suburban or even a large area. Other researches have taken micro, macro and even multi-scale approaches, mainly focusing on policy and guide-

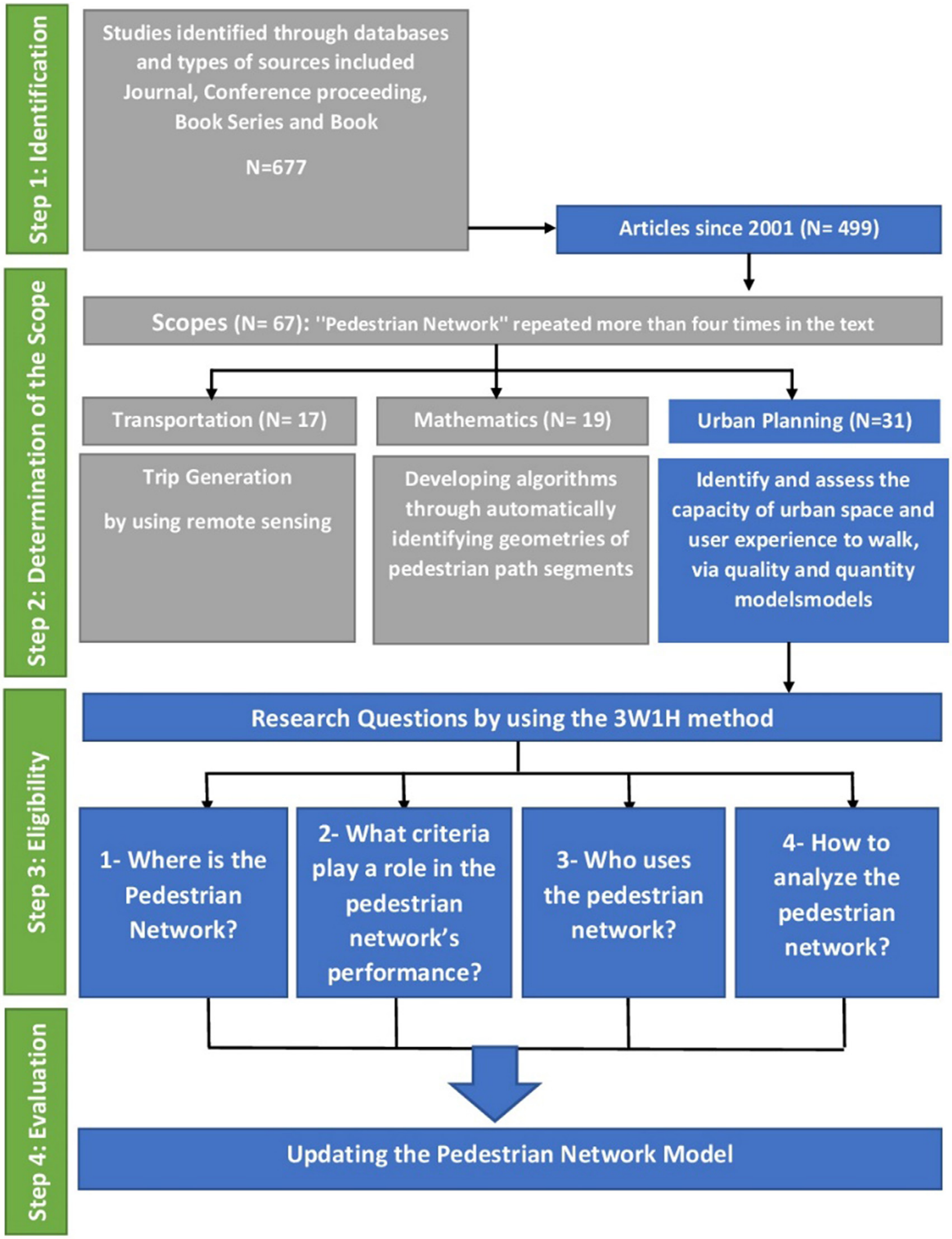

Fig. 2. Flow diagram of the selection process and final studies included in the systematic review.

line making. Pedestrians cross the current road network and there are various cars and other modes of transport. It seems that the pedestrian network should consider an independent urban structure and the urban transport system should support it as a main priority. However, since the role of conceptual research is to open more debate on where the pedestrian network is located and how to provide urban transport needs in the particular urban context, with a view to creating more sustainable urban transport.

Another question that would be highlighted for future studies is who uses the pedestrian network. Since the pedestrian network would be making attractive modes to a much wider range of people, not yet perceived: in particular paths are safer and pedestrian environments are more pleasant and such facilities are the norm in urban areas. Few researchers focused on pedestrians' needs; especially vulnerable pedestrians and disabled people. Vulnerable pedestrian groups may include children, elderly individuals, and people with disabilities, as well as individuals who are under the influence of drugs or alcohol. Understanding the behavior of these groups is important for designing and implementing effective safety interventions to reduce pedestrian injuries and fatalities. Research has shown that vulnerable pedestrian groups may exhibit different behaviors and risk-taking tendencies as compared to the general population (Gaglione et al., 2021). For example, children may have limited cognitive and perceptual abilities that affect their capability to accurately judge distances and speeds of oncoming vehicles. Elderly individuals may have physical impairments that affect their gait and balance, making them more susceptible to falls and collisions. People with disabilities may have limited mobility or sensory impairments that affect their capability to navigate their environment safely. It is important to consider these differences in behavior when developing interventions to improve pedestrian safety. For example, interventions may need to be tailored to the specific needs and abilities of different vulnerable groups, such as improving crosswalk markings and signal timing for elderly individuals, or providing extra supervision and education for children. Overall, understanding the behavior of vulnerable pedestrian groups is an important component of improving pedestrian safety and reducing pedestrian injuries and fatalities. The pedestrian network should provide inclusive environments for all users, encouraging people to walk and offering vibrant walking experiences.

Additionally, when designing a pedestrian network as an urban structure, it is significant to consider the element of a sufficient capacity of the transportation system. Parking often takes up valuable space that could be used to improve the pedestrian infrastructure. This can lead to conflicts between pedestrians and vehicles, making it unsafe for people to walk and increasing the risk for accidents. To address these issues, it is important for urban planners and policymakers to prioritize the pedestrian infrastructure in transportation plans and policymaking. This may involve reallocating space currently used for vehicle parking for the pedestrian infrastructure, such as wider sidewalks, improved lighting, and more accessible crosswalks. It may also involve developing and enforcing policies that prioritize pedestrian safety and convenience over vehicular traffic, such as reducing speed limits, creating more pedestrian-only zones, and installing more traffic calming measures. Overall, improving the pedestrian network infrastructure is critical for promoting safe and convenient pedestrian movement and creating more livable and sustainable urban environments.

Likewise, it seems to define a combined system involves an urban planning process and also the opinions of residents, which can be useful to strengthen the robustness of the assessment approach based on Sustainable Urban Mobility Plans (SUMPs). In addition, the physical environment is expressed through the structural characteristic of the space, which influences the overall perception of walkability. For this reason, many pedestrian studies in the literature refer to behavioral experiences related to the physical environment (Bahrainy & Khosravi, 2013; Forsyth et al., 2009; Gaglione, Gargiulo, & Zucaro, 2022; Gilderbloom et al., 2015b; Lamíquiz & López-Domínguez, 2015; Nasir, Lim, Nahavandi, & Creighton, 2014). It is important to check the results of the pedestrian models and compare them with real pedestrian behavior. Such a comparison is useful to identify the discrepancy between the pedestrian requirements and the results of the model defined by urban planners, providing additional support for the creation of the pedestrian network.

5. Conclusion

This paper examines the pedestrian network concept through a systematic literature review. The aim of this paper is to evaluate the theoretical and practical questions about pedestrian networks in an urban planning approach in order to support the development of future models/plans for pedestrian networks. Hence, the analysis of the literature review was carried out using the 3W1H method by answering the following questions: (1) Where is the pedestrian network located? (2) What criteria play a role in the pedestrian network's performance?, (3) Who uses the pedestrian network? and (4) How can the pedestrian network be analyzed?

Given the ever-increasing complexity of cities and the increasing focus on sustainability, urban structures may be undergoing major changes (S. Hong, Hui, & Lin, 2022). This paper has conducted a comprehensive systematic literature review focused on the concept of Pedestrian Network studies by applying 3W1H analysis method. The review showed that there is a significant body of research that emphasizes the importance of well-designed and connected pedestrian networks in promoting walking, active transportation system, and improving the overall livability of cities. It was found that connecting the pedestrian network to the transportation system requires a comprehensive and integrated approach that considers the needs and safety of pedestrians in transportation master plans and policy-making. This will support the creation o a more accessible, safe, and efficient transportation system for all users. Although, many research projects on the topic have been conducted over more than a decade, and some of them even predict and conceptualize the future, there is not yet a systematic and coherent study that synthesizes the full range of knowledge concerning ''pedestrian network''. In addition, there is a need for further research on the topic, particularly in the areas of network analysis, design guidelines, and implementation strategies to effectively promote pedestrian active mobility and safety.

Hence, it is crucial to shed light on the existing and new concepts underlying the vision of the future urban fabric and to capture and analyze the perceptions, insights and expectations of relevant scholars and practitioners. Addressed to analyze the condition of pedestrian networks is still a challenge due to the diverse urban environments and the different attributes that influence the decision to walk. However, considering the pedestrian network as a new urban structure in the urban planning process include global overview to where, what, who, and how that will provide good conditions for walking, encourage people to walk and change cities towards more sustainable urban development is a crucial goal. (Fig. 1)

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abass, Z. I., & Tucker, R. (2018). Residential satisfaction in low-density Australian suburbs: The impact of social and physical context on neighbourhood contentment. *Journal of Environmental Psychology, 56*, 36–45. 10.1016/j.jenvp.2018.02.005.

Amato, J. (2004). *On foot: a history of walking*. UK: NYU Press.

Arroyo, R., Mars, L., & T., R.. (2018). Perceptions of pedestrian and cyclist environments, travel behaviors, and social networks. Sustainability, 10((9),).

Azad, M., Abdelqader, D., Taboada, L. M., & Cherry, C. R. (2021). Walk-to-transit demand estimation methods applied at the parcel level to improve pedestrian infrastructure investment. *Journal of Transport Geography, 92*, Article 103019. 10.1016/j.jtrangeo.2021.103019.

Azmi, D., & Ahmad, P. (2015). A GIS approach: Determinant of neighbourhood environment indices in influencing walkability between two precincts in Putrajaya. *Procedia - Social and Behavioral Sciences, 170*, 557–566.

Badland, H., White., M., MacAulay, G., Eagleson, S., Mavoa, S., Pettit, C. et al. (2013). Using simple agent-based modeling to inform and enhance neighborhood walkability. International Journal of Health Geographics, 12–58.

Bahrainy, H., & Khosravi, H. (2013). The impact of urban design features and qualities on walkability and health in under-construction environments: The case of Hashtgerd New Town in Iran. *Cities Journal, 31*, 17–28.

Bélanger, P. (2007). Underground landscape: The urbanism and infrastructure of Toronto's downtown pedestrian network. *Tunnelling and Underground Space Technology, 22*(3), 272–292. 10.1016/j.tust.2006.07.005.

Bereitschaft, B. (2018). Walk Score® versus residents' perceptions of walkability in Omaha, NE. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 11*(4), 412–435. 10.1080/17549175.2018.1484795.

Bhattacharjee, S., Roy, S., & Das Bit, S. (2019). Post-disaster map builder: Crowdsensed digital pedestrian map construction of the disaster affected areas through smartphone based DTN. *Computer Communications, 134*, 96–113. 10.1016/j.comcom.2018.11.010.

Borst, H. C., de Vries, S. I., Graham, J. M. A., van Dongen, J. E. F., Bakker, I., & Miedema, H. M. E. (2009). Influence of environmental street characteristics on walking route choice of elderly people. *Journal of Environmental Psychology, 29*(4), 477–484. 10.1016/j.jenvp.2009.08.002.

Buckley, P., Stangl, P., & Guinn, J. (2017). Why people walk: Modeling foundational and higher order needs based on latent structure. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 10*(2), 129–149. 10.1080/17549175.2016.1223738.

Carmona, M. (2010). Contemporary public space: Critique and classification, part one: Critique. *Journal of Urban Design, 15*(1), 123–148. 10.1080/13574800903435651.

Carpio-Pinedo, J., Martínez-Conde, J. A., & Daudén, F. L. (2014). Mobility and urban planning integration at city-regional level in the design of urban transport interchanges (EC FP7 NODES Project–Task 3.2.1.). *Procedia - Social and Behavioral Sciences, 160*, 224–233. 10.1016/j.sbspro.2014.12.134.

Carroll, P., Caulfield, B., & Ahern, A. (2021). Appraising an incentive only approach to encourage a sustainable reduction in private car trips in Dublin, Ireland. *International Journal of Sustainable Transportation, 15*(6), 474–485. 10.1080/15568318.2020.1765054.

Chan, H.-. Y., Ip, L.-. C., Mansoor, U., & Chen, A. (2022). Pedestrian route choice with respect to new lift-only entrances to underground space: Case study of a metro station area in hilly terrain in Hong Kong. *Tunnelling and Underground Space Technology, 129*, Article 104678. 10.1016/j.tust.2022.104678.

Chan, H.-. Y., Xu, Y., Chen, A., & Liu, X. (2022). Impacts of the walking environment on mode and departure time shifts in response to travel time change: Case study in the multi-layered Hong Kong metropolis. *Travel Behaviour and Society, 28*, 288–299. 10.1016/j.tbs.2022.04.010.

Cheng, J., & Masser, I. (2003). Modelling urban growth patterns: A multiscale perspective. *Environment and Planning A: Economy and Space, 35*(4), 679–704. 10.1068/a35118.

Chi, T. L., Lin, L., & Liu, G. (2008). Application of FMEA and KT method on fab daily management. *Journal of Quality, 15*(6).

Chin, G. K. W., Van Niel, K. P., Giles-Corti, B., & Knuiman, M. (2008). Accessibility and connectivity in physical activity studies: The impact of missing pedestrian data. *Preventive Medicine, 46*(1), 41–45. 10.1016/j.ypmed.2007.08.004.

Cui, J. (2021). Building three-dimensional pedestrian networks in cities. *Underground Space, 6*(2), 217–224. 10.1016/j.undsp.2020.02.008.

Cutini, V. (2016). Motorways in metropolitan areas: The northwestern growth of florence and the urban use of motorway A1. *ISPRS International Journal of Geo-Information, 5*(6). 10.3390/ijgi5060077.

Dai, D., & Jaworski, D. (2016). Influence of built environment on pedestrian crashes: A network-based GIS analysis. *Applied Geography, 73*, 53–61. 10.1016/j.apgeog.2016.06.005.

De Vivo, F. (2016). Walking in Sixteenth-Century Venice: Mobilizing the Early Modern City. *I Tatti Studies in the Italian Renaissance, 19*(1), 115–141. 10.1086/685830.

Delso, J., Martín, B., & Ortega, E. (2018). A new procedure using network analysis and kernel density estimations to evaluate the effect of urban configurations on pedestrian mobility. The case study of Vitoria –Gasteiz. *Journal of Transport Geography, 67*, 61–72. 10.1016/j.jtrangeo.2018.02.001.

Delso, J., Martín, B., Ortega, E., & Van De Weghe, N. (2019). Integrating pedestrian-habitat models and network kernel density estimations to measure street pedestrian suitability. *Sustainable Cities and Society, 51*, Article 101736. 10.1016/j.scs.2019.101736.

D'Orso, G., & Migliore, M. (2020). A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments. *Journal of Transport Geography, 82*, Article 102555. 10.1016/j.jtrangeo.2019.102555.

Duncan, D., Méline, J., Kestens, Y., Day, K., Elbel, B., Trasande, L., et al., (2016). Walk Score, transportation mode choice, and walking among french adults: A GPS, accelerometer, and mobility survey study. *International Journal of Environmental Research and Public Health, 13*(6), 611.

Durmuş, A., & Turk, S. (2014). Factors influencing location selection of warehouses at the intra-urban level: Istanbul case. *European Planning Studies, 22*(2), 268–292.

Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. *Journal of Urban Design, 14*(1), 65–84.

Farkisch, H., Ahmadi, V., & Che-Ani, A. I. (2015). Evaluation of neighborhood center attributes on resident's territoriality and sense of belonging a case study in Boshrooyeh, Iran. *Habitat International, 49*, 56–64. 10.1016/j.habitatint.2015.05.012.

Ferrer, S., Ruiz, T., & Mars, L. (2015). A qualitative study on the role of the built environment for short walking trips. *Transportation Research Part F, 33*, 141–160.

Fonseca, F., Fernandes, E., & Ramos, R. (2022). Walkable cities: Using the smart pedestrian net method for evaluating a pedestrian network in guimarães, Portugal. *Sustainability, 14*(16). 10.3390/su141610306.

Fonseca, F., Ribeiro, P., Jabbari, M., Petrova, E., Papageorgiou, G., Conticelli, E., et al., (2020). *Smart pedestrian network: an integrated conceptual model for improving walkability* 2020//) Paper presented at the Society with Future: Smart and Liveable Cities, Cham.

Forsyth, A., Oakes, M., Lee, B., & Schmitz, K. (2009). The built environment, walking, and physical activity: Is the environment more important to some people than others? *Transportation Research Part D: Transport and Environment, 14*(1), 42–49.

Frank, L., Schmid, T., Sallis, J., Chapman, J., & Saelens, B. (2005). Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. 28(2), 117–125.

Gaglione, F., Cottrill, C., & Gargiulo, C. (2021). Urban services, pedestrian networks and behaviors to measure elderly accessibility. *Transportation Research Part D: Transport and Environment, 90*, Article 102687. 10.1016/j.trd.2020.102687.

Gaglione, F., Gargiulo, C., & Zucaro, F. (2022). Where can the elderly walk? A spatial multi-criteria method to increase urban pedestrian accessibility. *Cities, 127*, Article 103724. 10.1016/j.cities.2022.103724.

Gallimore, J. M., Brown, B. B., & Werner, C. M. (2011). Walking routes to school in new urban and suburban neighborhoods: An environmental walkability analysis of blocks and routes. *Journal of Environmental Psychology, 31*(2), 184–191. 10.1016/j.jenvp.2011.01.001.

Garcia, R., & Lara, J. (2015). Q-PLOS, developing an alternative walking index. A method based on urban design quality. *Cities, 45*, 7–17.

Garip, E., Þalgamcýoðlu, M. E., & Cimþit Koþ, F. (2015). The influence of architectural configuration on the pedestrian network in Büyük Beþiktaþ market. *A|Z ITU Journal of the Faculty of Architecture, 12*(3), 105–113.

Georgiou, A., Skoufas, A., & Basbas, S. (2021). Perceived pedestrian level of service in an urban central network: The case of a medium size Greek city. *Case Studies on Transport Policy, 9*(2), 889–905. 10.1016/j.cstp.2021.04.009.

Gholami, M., Torreggiani, D., Tassinari, P., & Barbaresi, A. (2022). Developing a 3D city digital twin: Enhancing walkability through a green pedestrian network (GPN) in the City of Imola, Italy. *Land, 11*(11). 10.3390/land11111917.

Gilderbloom, J., Riggs, W., & Meares, W. (2015a). Does walkability matter? An examination of walkability's impact on housing values, foreclosures and crim. *Cities, 42*, 13–24.

Gilderbloom, J., Riggs, W., & Meares, W. (2015b). Does walkability matter? An examination of walkability's impact on housing values, foreclosures and crime. *Cities, 42*, 13–24.

Girling, C., Zheng, K., Monti, A., & Ebneshahidi, M. (2019). Walkability vs. walking: Assessing outcomes of walkability at Southeast False Creek, Vancouver, Canada. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 12*(4), 456–475. 10.1080/17549175.2019.1626269.

Grecu, V., & Morar, T. (2013). A Decision support system for improving pedestrian accessibility in neighborhoods. *Procedia Social and Behavioral Sciences, 92*, 588–593.

Guo, Q., Xu, P., Pei, X., Wong, S. C., & Yao, D. (2017). The effect of road network patterns on pedestrian safety: A zone-based Bayesian spatial modeling approach. *Accident Analysis and Prevention, 99*, 114–124.

Guo, Z., & Loo, B. (2013). Pedestrian environment and route choice: Evidence from New York City and Hong Kong. *Journal of Transport Geography, 28*, 124–136.

Habibi, S. M. (1996). *de la cité à la ville_ analyse historique de la conception urbaine et son aspect physique*. Iran: University of Tehran Press.

Hajrasouliha, A., & Yin, L. (2015). The impact of street network connectivity on pedestrian volume. *Urban Studies Journal, 52*(13), 2483–2497. http://journals.sagepub.com/doi/pdf/10.1177/0042098014544763.

Hall, C. M., & Ram, Y. (2018). Walk score® and its potential contribution to the study of active transport and walkability: A critical and systematic review. *Transportation Research Part D: Transport and Environment*. 10.1016/j.trd.2017.12.018.

Hänseler, F. S., Lam, W. H. K., Bierlaire, M., Lederrey, G., & Nikolić, M. (2017). A dynamic network loading model for anisotropic and congested pedestrian flows. *Transportation Research Part B: Methodological, 95*, 149–168. 10.1016/j.trb.2016.10.017.

He, J., Zacharias, J., Geng, J., Liu, Y., Huang, Y., & Ma, W. (2016). Underground pedestrian network for urban commercial development in Tsim Sha Tsui of Hong Kong. *Procedia Engineering, 165*, 193–204. 10.1016/j.proeng.2016.11.791.

He, Y., Tablada, A., & Wong, N. H. (2018). Effects of non-uniform and orthogonal breezeway networks on pedestrian ventilation in Singapore's high-density urban environments. *Urban Climate, 24*, 460–484. 10.1016/j.uclim.2017.03.005.

Herrmann, G. (2016). nstrumentos de planifcación y diseño urbano para promover al peatón en las ciudades. Un estudio comparado entre Chile y Alemania [Planning instruments and urban design tools to promote pedestrians: A comparative study between Chile and Germany]. *Revista Urbano, 19*, 48–57 1022320/07183607.2016.19.34.5.

Higgins, C. D. (2019). A 4D spatio-temporal approach to modelling land value uplift from rapid transit in high density and topographically-rich cities. *Landscape and Urban Planning, 185*, 68–82. 10.1016/j.landurbplan.2018.12.011.

Hodza, P., & Butler, K. A. (2022). Juxtaposing GIS and archaeologically mapped ancient road routes. *Geographies, 2*(1), 48–67.

Hong, J., Shankar, V. N., & Venkataraman, N. (2016). A spatially autoregressive and heteroskedastic space-time pedestrian exposure modeling framework with spatial lags and endogenous network topologies. *Analytic Methods in Accident Research, 10*, 26–46. 10.1016/j.amar.2016.05.001.

Hong, S., Hui, E. C.-m., & Lin, Y. (2022). Relationship between urban spatial structure and carbon emissions: A literature review. *Ecological Indicators, 144*, Article 109456. 10.1016/j.ecolind.2022.109456.

Hoogendoorn, S. P., Daamen, W., Knoop, V. L., Steenbakkers, J., & Sarvi, M. (2018). Macroscopic fundamental diagram for pedestrian networks: Theory and applications. *Transportation Research Part C: Emerging Technologies, 94*, 172–184. 10.1016/j.trc.2017.09.003.

Itu, C., Cerbu, C., & Galatanu, T.-. F. (2019). Modeling and testing of the sandwich composite manhole cover designed for pedestrian networks. *Materials (Basel, Switzerland), 12*(7), 1114. 10.3390/ma12071114.

Jabbari, M., Ahmadi, Z., & Ramos, R. (2022). Defining a digital system for the pedestrian network as a conceptual implementation framework. *Sustainability, 14*(5). 10.3390/su14052528.

Jabbari, M., Fonseca, F., & Ramos, R. (2018a). Combining multi-criteria and space syntax analysis to assess a pedestrian network: The case of Oporto. *Journal of Urban Design, 23*(1), 23–41. 10.1080/13574809.2017.1343087.

Jabbari, M., Fonseca, F., & Ramos, R. (2018b). Combining multi-criteria and space syntax analysis to assess a pedestrian network: The case of Oporto. *Journal of Urban Design*, 1–19. 10.1080/13574809.2017.1343087.

Jabbari, M., Fonseca, F., & Ramos, R. (2021). Accessibility and connectivity criteria for assessing walkability: An application in Qazvin, Iran. *Sustainability, 13*(7), 3648.

Jagarajan, R., Abdullah Mohd Asmoni, M. N., Mohammed, A. H., Jaafar, M. N., Lee Yim Mei, J., & Baba, M. (2017). Green retrofitting – A review of current status, implementations and challenges. *Renewable and Sustainable Energy Reviews, 67*, 1360–1368. 10.1016/j.rser.2016.09.091.

Jeong, S. K., & Banyn, Y. U. (2016). A point-based angular analysis model for identifying attributes of spaces at nodes in street networks. *Physica A: Statistical Mechanics and its Application, 450*, 71–84.

Johannessen, M. R., Flak, L. S., & Sæbø, Ø. (2012). *Choosing the right medium for municipal eParticipation based on stakeholder expectations* 2012// Paper presented at the Electronic Participation, Berlin, Heidelberg.

Jung, S.-. I., & Hong, K.-. S. (2017). Deep network aided by guiding network for pedestrian detection. *Pattern Recognition Letters, 90*, 43–49. 10.1016/j.patrec.2017.02.018.

Kasemsuppakorn, P., & Karimi, H. (2013). A pedestrian network construction algorithm based on multiple GPS traces. *Transportation Research Part C, 26*, 285–300.

Kelly, C. E., Tight, M. R., Hodgson, F. C., & Page, M. W. (2011). A comparison of three methods for assessing the walkability of the pedestrian environment. *Journal of Transport Geography, 19*(6), 1500–1508. 10.1016/j.jtrangeo.2010.08.001.

Ki-Ho, K., & Kang, D.-. S. (2017). A study of pedestrian detection using a deep neural network and mixed-LGP. *Advanced Science Letters, 23*(10), 10289–10292. 10.1166/asl.2017.10437.

Kim, S., Park, S., & Lee, S. (2014). Meso- or micro-scale? Environmental factors influencing pedestrian satisfaction. *Transportation Research Part D, 30*, 10–20.

Koh, P., & Wong, Y. (2013). Influence of infrastructural compatibility factors on walking and cycling route choices. *Journal of Environmental Psychology, 36*, 202–213.

Kostof, S. (2004). *the city assembled*. London: Thames and Hudson.

Kwon, P., Kim, M.-. J., & Lee, Y. Y. K. (2017). Locating automated external defibrillators in a complicated urban environment considering a pedestrian-accessible network that focuses on out-of-hospital cardiac arrests. *ISPRS International Journal of Geo-Information, 6*(39).

Lamíquiz, P. J., & López-Domínguez, J. (2015). Effects of built environment on walking at the neighbourhood scale. A new role for street networks by modelling their configurational accessibility? *Transportation Research Part A, 74*, 148–163.

Łaszkiewicz, E., Heyman, A., Chen, X., Cimburova, Z., Nowell, M., & Barton, D. N. (2022). Valuing access to urban greenspace using non-linear distance decay in hedonic property pricing. *Ecosystem Services, 53*, Article 101394. 10.1016/j.ecoser.2021.101394.

Lay, M. G. (1999). *Ways of the world: a history of the world's roads and of the vehicles that used them*. Italy: Rutgers University Press.

Lerman, Y., & Omer, I. (2016). Urban area types and spatial distribution of pedestrians: Lessons from Tel Aviv. *Computers, Environment and Urban Systems, 55*, 11–23.

Lesani, A., & Miranda-Moreno, L. (2019). Development and testing of a real-time Wifi-bluetooth system for pedestrian network monitoring, classification, and data extrapolation. *IEEE Transactions on Intelligent Transportation Systems, 20*(4), 1484–1496. 10.1109/TITS.2018.2854895.

Li, Y., Xiao, L., Ye, Y., Xu, W., & Law, A. (2016). Understanding tourist space at a historic site through space syntax analysis: The case of Gulan gyu, China. *Journal of Tourism Management, 52*, 30–43.

Lilasathapornkit, T., Rey, D., Liu, W., & Saberi, M. (2022). Traffic assignment problem for footpath networks with bidirectional links. *Transportation Research Part C: Emerging Technologies, 144*, Article 103905. 10.1016/j.trc.2022.103905.

Lindelöw, D., Svensson, Å., Brundell-Freij, K., & Winslott Hiselius, L. (2017). Satisfaction or compensation? The interaction between walking preferences and neighbourhood design. *Transportation Research Part D: Transport and Environment, 50*, 520–532. 10.1016/j.trd.2016.11.021.

Loo, B. P. Y., Mahendran, R., Katagiri, K., & Lam, W. W. Y. (2017). Walking, neighbourhood environment and quality of life among older people. *Current Opinion in Environmental Sustainability, 25*, 8–13. 10.1016/j.cosust.2017.02.005.

Lundberg, B., & Weber, J. (2014). Non-motorized transport and university populations: An analysis of connectivity and network perceptions. *Journal of Transport Geography, 39*, 165–178.

Lunecke, M. G. H., & Mora, R. (2018). The layered city: Pedestrian networks in downtown Santiago and their impact on urban vitality. *Journal of Urban Design, 23*(3), 336–353. 10.1080/13574809.2017.1369869.

Lwin, K. K., & Murayama, Y. (2011). Modelling of urban green space walkability: Ecofriendly walk score calculator. *Computers, Environment and Urban Systems, 35*, 408–420.

Malik, S., Chandra, G. M., Rao, A. C., & Arora, S. (2020). *3W1H Approach to understand the millennial generation I. R. L. (Ed.) (Ed.)* (pp. 330–346). 10.4018/978-1-7998-4543-0.ch017.

Millward, H., Spinney, J., & Scott, D. (2013). Active-transport walking behavior: Destinations, durations, distances. *Journal of Transport Geography, 28*, 101–110.

Mitchell, D. H., & MacGregor Smith, J. (2001). Topological network design of pedestrian networks. *Transportation Research Part B: Methodological, 35*(2), 107–135. 10.1016/S0191-2615(99)00039-9.

Motomura, M., Koohsari, M. J., Lin, C.-. Y., Ishii, K., Shibata, A., Nakaya, T., et al., (2022). Associations of public open space attributes with active and sedentary behaviors in dense urban areas: A systematic review of observational studies. *Health & Place, 75*, Article 102816. 10.1016/j.healthplace.2022.102816.

Moustaid, E., & Flötteröd, G. (2021). Macroscopic model of multidirectional pedestrian network flows. *Transportation Research Part B: Methodological, 145*, 1–23. 10.1016/j.trb.2020.12.004.

Nasir, M., Lim, C., Nahavandi, S., & Creighton, D. (2014). A genetic fuzzy system to model pedestrian walking path in a built environment. *Simulation Modelling Practice and Theory, 45*, 18–34.

Osama, A., & Sayed, T. (2017). Evaluating the impact of connectivity, continuity, and topography of sidewalk network on pedestrian safety. *Accident Analysis and Prevention, 107*, 117–125. 10.1016/j.aap.2017.08.001.

Oswald Beiler, M., McGoff, R., & McLaughlin, S. (2017). Trail network accessibility: Analyzing collector pathways to support pedestrian and cycling mobility. *Journal of Urban Planning and Development, 143*(1), Article 04016024. 10.1061/(ASCE)UP.1943-5444.0000351.

Oyama, Y., & Hato, E. (2018). Link-based measurement model to estimate route choice parameters in urban pedestrian networks. *Transportation Research Part C: Emerging Technologies, 93*, 62–78. 10.1016/j.trc.2018.05.013.

Özbil, A., Yeþiltepe, D., & Argýn, G. (2015). Modeling walkability: The effects of street design, street-network configuration and land-use on pedestrian movement. *A|Z ITU Journal of the Faculty of Architecture, 12*(3), 189–207.

Pamucar, D., Deveci, M., Stević, Ž., Gokasar, I., Isik, M., & Coffman, D. M. (2022). Green strategies in mobility planning towards climate change adaption of urban areas using fuzzy 2D algorithm. *Sustainable Cities and Society, 87*, Article 104159. 10.1016/j.scs.2022.104159.

Panagopoulos, T., Duque, J., & Dan, M. (2016). Urban planning with respect to environmental quality and human well-being. *Environmental Pollution, 208*, 137–144.

Pearce, D. M., Matsunaka, R., & Oba, T. (2021). Comparing accessibility and connectivity metrics derived from dedicated pedestrian networks and street networks in the context of Asian cities. *Asian Transport Studies, 7*, Article 100036. 10.1016/j.eastsj.2021.100036.

Peiravian, F., Derrible, S., & Ijaz, F. (2014). Development and application of the Pedestrian Environment Index (PEI). *Journal of Transport Geography*, (39), 73–84.

Peponis, J., Ross, C., & Rashid, M. (1997). The structure of urban space, movement and co-presence: The case of Atlanta. *Geoforum, 28*(3), 341–358. 10.1016/S0016-7185(97)00016-X.

Qu, L., & Lim, J. S. (2016). A novel way of pedestrian detection using neural network with a weighted fuzzy membership function. *Advanced Science Letters, 22*(11), 3516–3519. 10.1166/asl.2016.7866.

Raghuram Kadali, B., Rathi, N., & Perumal, V. (2014). Evaluation of pedestrian mid-block road crossing behaviour using artificial neural network. *Journal of Traffic and Transportation Engineering (English Edition), 1*(2), 111–119. 10.1016/S2095-7564(15)30095-7.

Rashidi, E., Parsafard, M., Medal, H., & Li, X. (2016). Optimal traffic calming: A mixed-integer bi-level programming model for locating sidewalks and crosswalks in a multimodal transportation network to maximize pedestrians' safety and network usability. *Transportation Research Part E: Logistics and Transportation Review, 91*, 33–50. 10.1016/j.tre.2016.03.016.

Roshandeh, A. M., Li, Z., Zhang, S., Levinson, H. S., & Lu, X. (2016). Vehicle and pedestrian safety impacts of signal timing optimization in a dense urban street network. *Journal of Traffic and Transportation Engineering (English Edition), 3*(1), 16–27. 10.1016/j.jtte.2016.01.001.

Sainz-Santamaria, J., Moctezuma, D., Martinez-Cruz, A. L., Téllez, E. S., Graff, M., & Miranda-Jiménez, S. (2023). Contesting views on mobility restrictions in urban green spaces amid COVID-19—Insights from Twitter in Latin America and Spain. *Cities, 132*, Article 104094. 10.1016/j.cities.2022.104094.

Stevenson, M., Thompson, J., de Sá, T. H., Ewing, R., Mohan, D., McClure, R., et al., (2017). Land use, transport, and population health: Estimating the health benefits of compact cities. *The Lancet, 388*(10062), 2925–2935. 10.1016/S0140-6736(16)30067-8.

Sun, G., Wallace, D., & Webster, C. (2020). Unravelling the impact of street network structure and gated community layout in development-oriented transit design. *Land Use Policy, 90*, Article 104328. 10.1016/j.landusepol.2019.104328.

Šurdonja, S., Otković, I. I., Deluka-Tibljaš, A., & Campisi, T. (2023). Simplified model of children-pedestrian crossing speed at signalized crosswalks. *Transportation Research Procedia, 69*, 560–567. 10.1016/j.trpro.2023.02.208.

Tal, G., & Handy, S. (2012). Measuring nonmotorized accessibility and connectivity in a robust pedestrian network. *Transportation Research Record: Journal of the Transportation Research Board, 2299*, 48–56. 10.3141/2299-06.

Tan, Y., Liu, G., Zhang, Y., Shuai, C., & Shen, G. Q. (2018). Green retrofit of aged residential buildings in Hong Kong: A preliminary study. *Building and Environment, 143*, 89–98. 10.1016/j.buildenv.2018.06.058.

Tan, Z., & Xue, C. Q. L. (2015). The evolution of an urban vision: The multilevel pedestrian networks in Hong Kong, 1965–1997. *Journal of Urban History, 42*(4), 688–708. 10.1177/0096144214566962.

Tan, Z., & Xue, C. Q. L. (2014). Walking as a planned activity: Elevated pedestrian network and urban design regulation in Hong Kong. *Journal of Urban Design, 19*(5), 722–744. 10.1080/13574809.2014.946895.

Tianxiang, Y., Dong, J., & Shoubing, W. (2015). Applying and exploring a new modeling approach of functional connectivity regarding ecological network: A case study on the dynamic lines of space syntax. *Ecological Modelling, 318*, 126–137.

Tiplica, T. (2015). Conditionality and risk for the pedestrian: Modelling with the Bayesian networks AU - Gaymard, Sandrine. *International Journal of Injury Control and Safety Promotion, 22*(4), 340–351. 10.1080/17457300.2014.909500.

Towne, S. D., Won, J., Lee, S., Ory, M. G., Forjuoh, S. N., Wang, S., et al., (2016). Using walk score^{TM} and neighborhood perceptions to assess walking among middle-aged and older adults. *Journal of Community Health, 41*(5), 977–988. 10.1007/s10900-016-0180-z.

Trépanier, M., Chapleau, R., & Allard, B. (2002). Transit itinerary calculation on the web: Based on a transit user information system. *Journal of Public Transportation, 5*(3), 13–32. 10.5038/2375-0901.5.3.2.

Ujang, N. (2016). Tourist' expectation and satisfaction towards pedestrian networks in the historical district of Kuala Lumpur, Malaysia AU - Mansouri, Mahsa. *Asian Geographer, 33*(1), 35–55. 10.1080/10225706.2016.1185639.

Vivo, F. (2016). *Walking in Sixteenth-Century Venice: Mobilizing the Early Modern City. I Tatti Studies in the Italian Renaissance, 19*(1), 115–141. 10.1086/685830.

Vo, K. D., Qian, K., Lam, W. H. K., & Sumalee, A. (2020). Modeling joint activity-travel patterns in pedestrian networks with use of Wi-Fi data. *Asian Transport Studies, 6*, Article 100007. 10.1016/j.eastsj.2020.100007.

Wey, W., & Chiu, Y. (2013). Assessing the walkability of pedestrian environment under the transit-oriented developmen. *Habitat International, 38*, 106–118.

Wijayanti, B. E., & Pandelaki, E. E. (2012). Places where the elderly meet friends at Banyumanik Public Housing. *Semarang, Indonesia. AcE-Bs Bangkok, Thailand, Procedia-Social and Behavioral Science*, 50.

Xin, D.-. R., & Wu, Y.-. H. (2016). Pedestrian detection for traffic safety based on Accumulate Binary Haar features and improved deep belief network algorithm AU - Zhang, Yang. *Transportation Planning and Technology, 39*(8), 791–800. 10.1080/03081060.2016.1231898.

Yang, X., Stewart, K., Fang, M., & Tang, L. (2022). Attributing pedestrian networks with semantic information based on multi-source spatial data. *International Journal of Geographical Information Science, 36*(1), 31–54. 10.1080/13658816.2021.1902530.

Yang, X., Sun, H., Huang, Y., & Fang, K. (2022). A framework of community pedestrian network design based on urban network analysis. *Buildings, 12*(6). 10.3390/buildings12060819.

Yang, X., Tang, L., Ren, C., Chen, Y., Xie, Z., & Li, Q. (2020). Pedestrian network generation based on crowdsourced tracking data. *International Journal of Geographical Information Science, 34*(5), 1051–1074. 10.1080/13658816.2019.1702197.

Yao, S., Wang, J., Fang, L., & Wu, J. (2018). Identification of vehicle-pedestrian collision hotspots at the micro-level using network kernel density estimation and random forests: A case study in Shanghai, China. *Sustainability, 10*.

Yu, C., Ma, W., Lo, H. K., & Yang, X. (2015). Optimization of mid-block pedestrian crossing network with discrete demands. *Transportation Research Part B: Methodological, 73*, 103–121. 10.1016/j.trb.2014.12.005.

Yücel, A. (1979). Mekan okuma araci olarak tipolojik çözümleme, çevre, (der: Pultar, M.). *Yapı ve Tasarım, Çevre ve Mimarlık Bilimleri Derneği, Ankara*.

Zamparini, L., Domènech, A., Miravet, D., & Gutiérrez, A. (2022). Green mobility at home, green mobility at tourism destinations: A cross-country study of transport modal choices of educated young adults. *Journal of Transport Geography, 103*, Article 103412. 10.1016/j.jtrangeo.2022.103412.

Zhang, X., & Chang, G.-l. (2014). A dynamic evacuation model for pedestrian–vehicle mixed-flow networks. *Transportation Research Part C: Emerging Technologies, 40*, 75–92. 10.1016/j.trc.2014.01.003.

Zhao, J., Sun, G., & Webster, C. (2020). Walkability scoring: Why and how does a three-dimensional pedestrian network matter? *Environment and Planning B: Urban Analytics and City Science, 48*(8), 2418–2435. 10.1177/2399808320977871.

Zhao, P., & Li, P. (2017). Rethinking the relationship between urban development, local health and global sustainability. *Current Opinion in Environmental Sustainability, 25*, 14–19. 10.1016/j.cosust.2017.02.009.

Zheng, Y., & Elefteriadou, L. (2017). A model of pedestrian delay at unsignalized intersections in urban networks. *Transportation Research Part B: Methodological, 100*, 138–155. 10.1016/j.trb.2017.01.018.

Zhou, Y., Zhang, L., & Jf Chiaradia, A. (2022). Estimating wider economic impacts of transport infrastructure Investment: Evidence from accessibility disparity in Hong Kong. *Transportation Research Part A: Policy and Practice, 162*, 220–235. 10.1016/j.tra.2022.05.014.

Zhu, J., Liao, S., Lei, Z., & Li, S. Z. (2017). Multi-label convolutional neural network based pedestrian attribute classification. *Image and Vision Computing, 58*, 224–229. 10.1016/j.imavis.2016.07.004.

Zuo, T., Wei, H., Chen, N., & Zhang, C. (2020). First-and-last mile solution via bicycling to improving transit accessibility and advancing transportation equity. *Cities, 99*, Article 102614. 10.1016/j.cities.2020.102614.