buildings

MDPI

Article

The Walkability Evaluation and Optimization Strategies of Metro Station Areas Taking Shanghai as an Example

Xiaoyan Chen [1,2], Zhengyan Shi [3] and Yanzhe Hu [1,2,*]

[1] College of Architecture and Urban Planning, Tongji University, Shanghai 200092, China; cxy9248@163.com
[2] Shanghai Key Laboratory of Urban Renewal and Spatial Optimization Technology, Shanghai 200092, China
[3] School of Mechanical Engineering, Tianjin University of Technology, Tianjin 300384, China; shizhengyan2025@163.com
* Correspondence: 10043@tongji.edu.cn

Abstract: Improving the pedestrian environment around metro stations and enhancing walkability are important for the daily travel and life quality of passengers. By reviewing existing studies, we summarized nine walkability elements and eventually refined them into 18 quantifiable research indicators. Walkability elements such as street enclosure, number of lanes, and tree canopy coverage were quantified through field surveys and passenger perception data. A stepwise regression analysis identified key influencing factors for nine walkability dimensions. Based on the correlation coefficients, factor assignments, and constants, a composite walkability index formula was established to evaluate pedestrian routes near four Shanghai metro stations. The results show that the proportion of sidewalks covered by a tree canopy, the number of lanes, street enclosures, and the transparency of the ground-floor building facade are the most important factors affecting the walkability of the pedestrian environment. In this study, we calculated the scores of each road section, compared the walking facilities and walking distance of different stations, and finally proposed relevant strategies for improving the walking environment.

Keywords: metro station area; walkability measurement; passenger perception evaluation; walkable environment quality

check for updates

Academic Editor: Jurgita Antucheviciene

Received: 3 April 2025
Revised: 11 May 2025
Accepted: 20 May 2025
Published: 21 May 2025

Citation: Chen, X.; Shi, Z.; Hu, Y. The Walkability Evaluation and Optimization Strategies of Metro Station Areas Taking Shanghai as an Example. *Buildings* **2025**, *15*, 1746. https://doi.org/10.3390/buildings15101746

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

1.1. Rapid Development of Urban Metro Transport Construction in China

In recent years, with the continuous expansion of Chinese cities, urban traffic congestion and transportation carbon emissions have become important issues for sustainable urban development [1]. Urban metro transit, as a large-capacity, convenient, efficient, and energy-saving urban public transportation mode, plays an important role in refining cities' spatial structure and layout, relieving traffic congestion, and improving people's quality of life [2]. Beijing, Shanghai, Guangzhou, Shenzhen, and other megacities have basically formed a networked metro transit operation system [3].

Shanghai has one of the largest urban metro transit systems in China. As of 2023, Shanghai's metro transit network had an operating mileage of 825 km, transporting a total of 3.659 billion passengers, ranking first in the world in terms of scale of operation. With the rapid construction of Shanghai's urban metro transit network, metro transit has taken up a large percentage of the public's trips, with the passenger sharing rate reaching 70% [4], playing a very obvious role in improving the level of Shanghai's public transport services. The significant increase in citizen participation in metro transport has led to the gathering

of urban elements in the metro station area. The metro station area, as a typical area of Shanghai's high-density city, is gradually becoming the core carrier of urban life.

1.2. Walkability of the Environment Connecting to Metro Stations Needs to Be Improved

Walking closely connects metro transit stations to other transportation modes, fulfilling the daily life and travel needs of the public [5]. Therefore, creating a safe and comfortable walking environment can not only reasonably integrate the functions and spaces around the station to effectively attract passenger flow, but also achieve the purpose of promoting green travel and building a humane city [6]. According to field research, the Shanghai metro station area's walking environment suffers from issues such as insufficient spatial attraction, poor organization of walking traffic, and a low degree of land composite use [7]. Therefore, perfecting the walking system and optimizing the walking environment are the keys to taking full advantage of the walking system's linking role.

Research on walkability has increased in recent years, and many urban design scholars have subjectively argued that improvements in the pedestrian environment can lead to more pedestrian trips [8,9]. However, as far as subway stations are concerned, most previous studies have focused on the application of the TOD model as well as the intrinsic relationship between land use characteristics and metro travel, but have not paid attention to the pedestrian environment of the station area [10,11]. Studies on walkability around stations have focused on the impact of macroscopic walking environment elements on station areas, with a greater emphasis on traffic engineering aspects [12], and have lacked a way to objectively define and quantify walkability [13,14]. While previous studies have addressed aspects of walkability, few have systematically combined subjective evaluations from passengers with quantifiable physical street indicators. Moreover, little research has been conducted in the context of high-density Chinese cities using a comprehensive, factor-weighted composite index.

This study aims to explore the following research questions:

(1) What physical and perceptual factors most influence walkability near metro stations?

(2) How can these factors be systematically quantified to assess walkability?

(3) How does walkability vary between core and edge metro station areas?

Therefore, this study takes the Shanghai station area as the research object, selects the physical environment elements that may affect walkability and derives the walkability index coefficients based on walking passengers' evaluation of the environment, and summarizes the formula of the comprehensive index of walkability so as to quantify the walkability. Based on the results, we compare the walkability of various metro station areas to learn how to enhance the walking environment, guide walking choices, and improve the perceived experience of metro passengers.

2. Literature Review

2.1. Walking Environment Around the Metro Station Area

The influence of the metro station area will decay to a critical value as the distance from the station increases. Many scholars have conducted a series of studies on the connection between metro transit and other transportation modes, focusing on improving the attractiveness of metro transit and expanding the impact range of metro stations [15]. However, they mainly focus on the connection with public transportation and less on the connection with non-motorized transportation and walking. According to the Shanghai 2021 comprehensive transportation survey, walking is the most common means of transportation used by metro passengers to reach and leave the station [16]. In 2024, Shanghai's metro transit accounted for more than 70% of the city's public transport trips [17]. More and more scholars are noticing the role of the walking environment in supporting walking

behavior [18–20]. Usually, the environment and walking facilities around metro transit stations have a great influence on whether people choose metro transportation to travel or not [21,22]. Therefore, it is of practical significance to expand the attractiveness of metro transit stations by improving the walking environment.

Saelens et al. [23] used the term "walkability" for the first time and proposed a theory of built environment factors influencing citizens' walking behavior. In recent years, many cities have begun to focus on improving the walkability of metro station areas to promote urban ecology, humanization, and urban vitality; these cities include London (2004), Chicago (2009), and Toronto (2009), which have developed design guidelines for walkable environments and continue to collect walkability data to make more targeted measurements. Many studies have explored relevant rubrics and conducted empirical research on the walking environment in different site areas [11,24,25], suggesting environmental factors that influence walking accessibility. However, the majority of these empirical studies took place in North American countries, raising questions about their applicability to Chinese cities.

2.2. Walkability Measurement and Quantification

Jesse Kocher et al. proposed the concept of "walk score" for walkability measurement in 2007 [26], which primarily considers the type of daily facilities and spatial layout, but also incorporates factors such as neighborhood edge length, walking distance decay, and intersection density to enhance the measurement's reliability. Liu [27] introduced the walkability score measurement method to China based on the relevant demand characteristics in China. Methods for measuring walkability have also come a long way. For example, the UK's transportation department uses the Pedestrian Environmental Rating System (PERS). Later researchers, like Gu [28] and Chen [29], have added to the quantitative evaluation methods of walkability by using wearable physiological sensors and multi-source data measurement. However, the aforementioned measurement methods primarily focus on measuring the built environment, with less attention given to the subjective feelings and needs of pedestrians. Many existing models rely on GIS-based indicators such as land use mix or intersection density, often neglecting the pedestrian's perspective [30]. Moreover, walkability indices in prior studies are usually not weighted based on pedestrian preferences, reducing their accuracy in guiding human-centered design [31]. According to Mateo-Babiano's [32] argument, pedestrians in Eastern countries tend to tolerate the walking environment more than those in Western countries. Therefore, the relevant international evaluation indicators and methods are not fully applicable to the actual situation in Shanghai and require further development and validation.

2.3. Walkability Elements

In order to better understand the impact of walkability on pedestrian perceptions and behaviours, Park Sungjin's study extrapolated walkability to connote five urban design domains: sense of safety, sense of public security, convenience, comfort, and visual interest [33]. Villaveces et al. [34] and Hussain et al. [35] emphasized the importance of crossing infrastructure and lane separation in shaping pedestrian comfort and perception of risk. The sense of public security, often tied to surveillance and visibility, has been widely examined in urban safety research [36–38]. Convenience of street crossing and facility accessibility have been consistently identified as key determinants of walkability [33,39]. These factors relate to the ease of navigating streets and reaching destinations, which is critical, especially in metro station areas. In terms of comfort-related factors, scholars such as Eboli et al. [40] and Majumdar et al. [41] highlighted the role of sidewalk continuity, cleanliness, and protection from negative environmental factors. The sense of street en-

closure, reflecting the spatial proportions between buildings and roadway widths, was identified by Ewing et al. [42] and Singh [43] as a predictor of psychological comfort and urban legibility. Finally, Nasar [44] and Li et al. [45] argue that street variety, diverse land uses, active surface interfaces, and aesthetic stimuli are critical to enhancing visual interest and keeping pedestrians engaged. These factors synthesize the widely cited and locally verified dimensions of walkability, providing a comprehensive framework for the passenger-based evaluation applied in this study.

When conducting walking-related research, researchers must deconstruct the quality components into more precise and quantifiable environmental elements that serve as fundamental indicators of their influence on people's perceptions and behaviors. First, many studies point out that the roadway elements within the curb line may affect the pedestrian's walking experience. Excessively wide streets contain more cars, thus reducing the feeling of safety and comfort while walking [46]. Additionally, the coverage of crosswalk facilities and the number of lanes have a close relationship with the safety of crossing the street [35,47]. Secondly, many studies have argued that buffers, including green belts, parking strips, and non-motorized lanes, are very important because they separate the space well and afford pedestrians a feeling of privacy on the sidewalk with little negative impact from motorized traffic [48]. Thirdly, the importance of sidewalk characteristics is mentioned as essential in almost all walking and sidewalk levels of service-related studies. The presence of sidewalks, as well as the width of sidewalks and the proportion of sidewalks covered by a tree canopy, are important features that have been focused on in studies [49]. Another influential factor is the length of sidewalks, which is considered to increase the degree of pedestrian detours by making intersections less dense and the connectivity of streets poorer when the block side length is too long. Sidewalk slope is likewise a very important element of walkability. Neighborhoods with better walkability have less topographic relief.

Furthermore, the degree of street enclosure reflects the relationship between street buildings and the street itself. Building height is also considered as a factor. The coordination of the ratio between the width of the street and the height of the buildings on either side is an essential factor in providing a sense of visual comfort [50]. Jacobs [51] considered the ratio of building height to block spacing to be very important and suggested that when the ratio is 1:3.3, the sense of enclosure is optimal. He also mentioned the concept of the "building line ratio" and believed that the smaller the distance between the street frontages, the greater the effect of limiting the street space. Many researchers also agree that facade transparency is a very important factor [52]. According to Basu et al. [53], pedestrians perceive a high degree of land use mix as beneficial, while open space or abandoned buildings create a negative experience. Commercial uses are generally considered pedestrian-friendly, and commercial facilities are detailed in Park's [33] study as being pedestrian-friendly and pedestrian-unfriendly.

These factors do not function independently; for example, tree canopy coverage improves both comfort and perceived safety [54], while ground-floor transparency enhances visual interest and security [55]. Therefore, understanding the interplay among these elements is crucial for building an effective walkability evaluation framework.

The above review reveals that there is no universal method for measuring walkability internationally, and different criteria exist for selecting variables and other influencing factors. Western countries have accumulated some experience from empirical studies on walkability, but their applicability to Chinese cities still requires further study. The cultural tolerance for environmental discomfort, such as uneven pavements or mixed-use sidewalks, is higher among Chinese pedestrians, which means traditional Western evaluation systems may overestimate negative perceptions. In Shanghai's peripheral

neighborhoods, gated communities are prevalent, which limits pedestrian connectivity, a factor that is not adequately captured by standard international indicators such as walk score. Additionally, some design features, such as narrow streets or street vendors that are negatively evaluated in Western contexts, are often considered positive or acceptable in Shanghai due to local habits. These local characteristics necessitate a tailored evaluation framework that reflects user perceptions and physical constraints in Chinese cities.

Currently, most people in China take metro transit connections on foot, so walkability impact indicators in metro transit station areas are important. The primary goal of this study is to identify the most important indicators and establish a walkability measurement method suitable for the region, or even Shanghai.

3. Methods

The authors selected walkability indicators by summarizing existing studies. The authors obtained walkability indicators for each street through ridership and street research. Finally, the authors performed a stepwise regression analysis of the walkability factors and the corresponding street indicators to obtain the indicators with the greatest influence on each factor.

3.1. Study Areas

We selected metro stations that existed for many years and had a relatively mature built environment in Shanghai to reflect the diverse environmental characteristics as much as possible. Four stations were selected from two categories representing different neighborhood characteristics, namely Changping Road Station and Linping Road Station, which are located in the core area of the old city, and Lianhua Road Station and Tonghe Xincun Station, which are located in the edge area of the central city (Figure 1). The classification follows the spatial typology proposed in the Shanghai Master Plan (2017–2035), where the Inner Ring encloses the historic urban core, and the zone between the Inner and Outer Rings serves as a transitional belt of suburbanized development. Core stations are situated in compact, mixed-use blocks with dense street grids. In contrast, edge stations are located in areas developed after the 1990s with large blocks, limited pedestrian permeability, and functionally segregated land use [56]. The study scope is a 1 km-radius area with the station as the center. The main factors for selecting these four stations were the variability in street characteristics related to the pedestrian environment in terms of neighborhood scale, development intensity and density, street width, and building uses along the street in the core and edge zone stations.

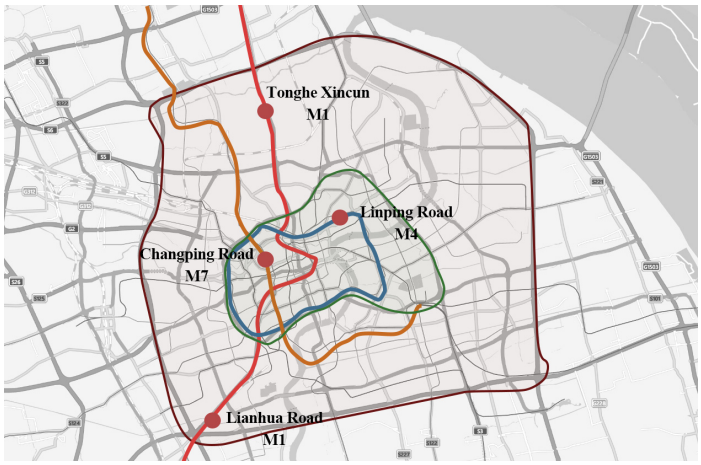


Figure 1. Station selection map.

There is an obvious difference between the core area stations and the edge area stations. Lianhua Road Station and Tonghe Xincun Station are situated in the peripheral area of the central city, primarily serving residential purposes. A small number of large commercial and office facilities supplement these residential functions, while public service facilities are relatively lacking. Overall, the neighborhood environment is homogeneous and spans a large area. The majority of the neighborhoods operate under closed management, with walls or greenery primarily separating them from the outside world. Changping Road Station and Linping Road Station are both located within the Inner Rim and belong to the old city area. Due to the early construction period, the neighborhood is highly mixed, forming a traditional commercial street atmosphere with all kinds of facilities. The building form is mainly low- and medium-rise. The neighborhood's architectural density is high, showing a small-scale mixed-block character, and the length of sidewalks in the street section is correspondingly small. Changping Road, for example, is adjacent to Jing'an Temple, and the neighborhood's function is primarily office and public facilities mixed with commercial. Small-scale street commerce, a few offices, and public functions dominate Linping Road, presenting a distinct neighborhood style. The density of the road network is also very different between the fringe sites and the core sites, with Lianhua Road and Tonghe Xincun being much sparser than Changping Road and Linping Road.

3.2. Walkability Factor Selection

Before performing regression analysis with the screened street indicators, we must decompose walkability into several quantifiable factors for the construction of a composite index of walkability. Park Sungjin's [33] study deduced five connotations: transportation connotations of safety and convenience, and urban design connotations of security, comfort, and visual interest. This study breaks down the five connotations into nine quantifiable walkability factors, serving as the fundamental components for assessing pedestrian perception scores (Table 1). We obtained the evaluation of the walkability factors for each street through a survey of metro transit passengers. The following tables substitute nine factors with M01–M09 to simplify the presentation.

Table 1. The 9 factors of walkability.

Sense of safety	M01	Street crossing safety
	M02	Safety on the sidewalk
Sense of public security	M03	Public security sense of personal safety
Convenience	M04	Convenience of street crossing
	M05	Accessibility of facilities
Comfort	M06	Sidewalk Features
	M07	Unaffected by negative environment
	M08	Sense of street dimensions
Visual Interest	M09	Street diversity

3.3. Passenger Research

We conducted this research in August 2021 using a questionnaire survey that is most commonly used to explore the walkability perception evaluation [57,58]. The research targeted metro passengers, and the data were collected by interviewing a random sample of passengers waiting for the metro on the platforms and using structured questionnaires and printed maps. A presurvey was carried out one week before the official survey, the questionnaire was revised to address the problems encountered in the survey, and the official survey plan was made (Figures A1 and A2). It was difficult to finish the

questionnaire at the Lianhua Road station because of the short departure interval. We sent out 130 copies and collected 105 valid questionnaires. For passengers who did not have enough time to finish the questionnaire, the investigator continued the survey with the bus after obtaining the passenger's consent and returned after completion. Later, we tried to send the questionnaire to the passengers for them to fill it in, and send back pictures of it via email. The other stations were issued 150 copies, with a recovery rate of more than 85% because of the appropriate departure interval. We collected 128 valid questionnaires from Tonghe Xincun, 127 from Changping Road, and 129 from Linping Road.

This research was divided into two parts. The first part involved gathering basic information from the passengers about their daily trips, including their mode, frequency, and purpose. Additionally, we asked them to prioritize the most important features of the walking environment and to assess the walkability factor from their perspective. The second part was a map of the station area. Passengers who walked to the station regularly or had walked before were asked to draw their walking paths on the map and to rate their chosen paths on various perceptions using a Likert scale below the map. The use of self-drawn paths allowed accurate tracking of perceived walking segments, allowing for the estimation of walking distances, and subsequent street research will be conducted for walkability indicators based on all of the segments involved in the map below (Figure 2).

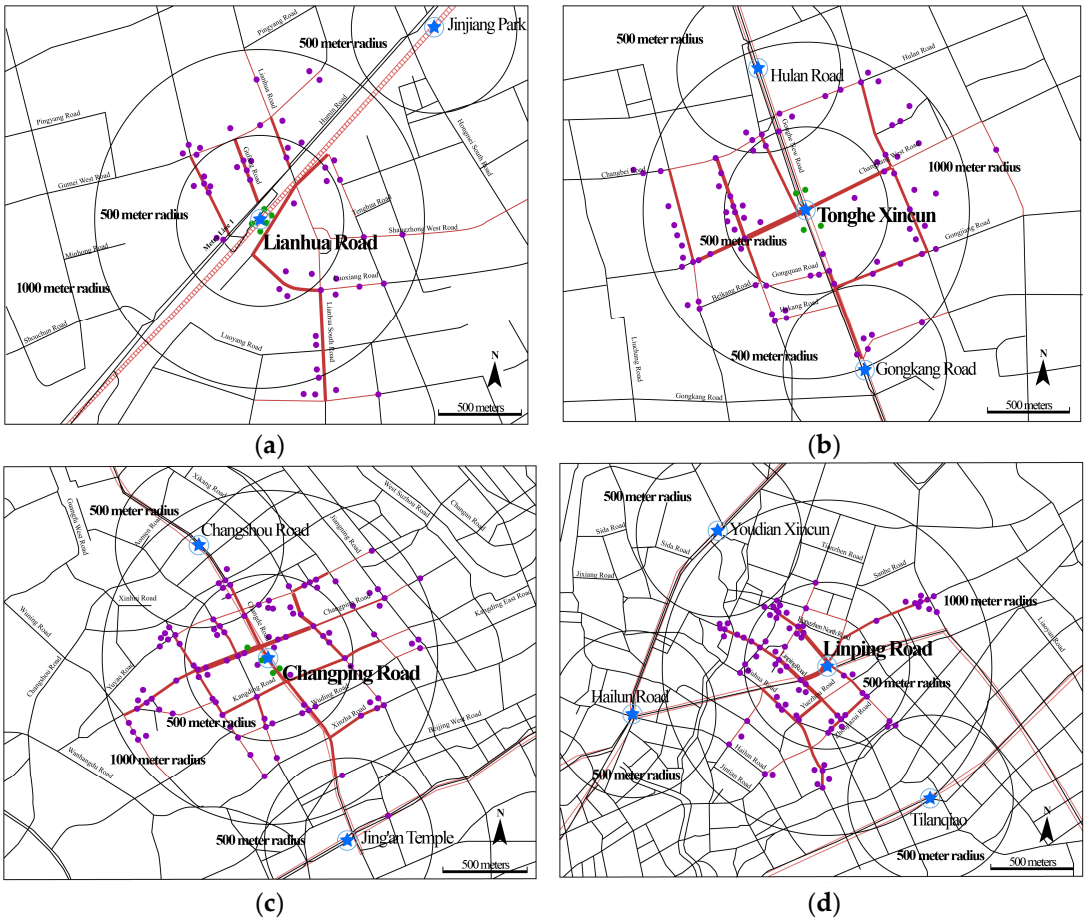


Figure 2. Starting point and walking path for passengers at each station. (**a**) Lianhua Road station; (**b**) Tonghe Xincun station; (**c**) Changping station. (**d**) Linping station.

3.4. Selection of Walkability Indicators

This study converted street elements into objectively measured walkability indicators and processed these indicators to ensure data comparability. Eighteen walkability indicators were eventually identified that not only covered pedestrian-scale design attributes but

also reflected the street's density and mixed land use. However, these indicators were subject to preliminary screening and correlation analysis before regression analysis with pedestrian perception evaluation, and those with too strong a correlation were screened again (Table 2).

Table 2. Walkability indicators.

Category	Walkability Indicators	Units	Quantification of Indicators
Indicators of walkability within the lanes	Number of lanes	Number	The number of lanes within a road, excluding left-turn lanes or traffic islands at flared intersections.
	Pedestrian crossing Facility coverage	%	Represents the percentage of pedestrian crossing facilities owned by each street segment.
Walkability indicators related to buffers	Buffer width	m	Average of the buffer zone widths on both sides of the street; this area is between the edge of the carriageway and the effective width of the sidewalk.
	Green belt width	m	The average value of the width of the green belt (including the municipal facility belt) on both sides of the street.
	Roadside parking	(1) Availability of roadside parking: 1 = at least one side; 0 = neither side	This is a dummy variable that counts as 1 when there is parking on at least one side of the street and 0 when there is none on either side.
Walkability indicators related to sidewalks and facilities	Effective width of sidewalk	m	The average of the net width of the sidewalk on both sides, counting only the width of the area used for human walking.
	Length of sidewalk	(m)	The average of the total length of sidewalks on both sides is equal to the block side length.
	Sidewalk coverage	%	If a street segment has sidewalks on both sides, then its coverage is 100%; if only one side has them, then the coverage is 50%.
	Proportion of sidewalks covered by tree canopy	%	The tree canopy referred to includes not only street trees but also the canopy in adjacent private spaces or green spaces, obtained by measuring the length of coverage on the sidewalk centerline.
Walkability indicators related to street scale and enclosure	Distance between adjacent buildings	m	The average distance between building facades on both sides of the street.
	Average building height	m	The average height of buildings within a street segment, but open space and green space do not count.
	Spatial enclosure	Height/Length	This indicator is the ratio of the average building height and the adjacent building distance; the larger the ratio, the higher the degree of the street enclosure. When this ratio is greater than 1, a greater sense of oppression will be formed.
	Building stick line rate	%	This indicator indicates the proportion of street segments with building facades.

Table 2. *Cont.*

Category	Walkability Indicators	Units	Quantification of Indicators
Walkability indicators related to buildings along the street	Ground floor facade transparency	facade/500 m sidewalk length	This indicator reflects the extent to which people walking on the sidewalk can see the interior of buildings along the street.
	Enclosure ratio	%	The study used fenestration above 1.5 m as the basis for the calculation, which is the ratio of the fence's length to the sidewalk.
	Proportion of ground-floor commercial uses (walkable)	%	Using Park's classification of walkable building uses and modified for the characteristics of Shanghai
	Proportion of ground-floor residential uses	%	Proportion of the width of ground-floor buildings used for residences to the total building length of the building along the street.
	Mixed use of buildings along the street	mixed = 1; not mixed = 0	Based on the pre-study, this paper defines a road section as mixed use if the proportion of buildings used for residence is greater than 25% and that used for commercial purposes is greater than 35%.

3.5. Regression Analysis

Due to the large number of independent variables in this study, we used multiple linear regression analysis through SPSS 20.0 software, applying stepwise regression to gradually eliminate irrelevant independent variables and finally arrive at the correlation coefficients of the variables screened in each model. We chose stepwise linear regression not only because it identifies key predictors from a larger pool of variables but also because it avoids multicollinearity. The 5-point Likert scale (1 = very dissatisfied, 5 = very satisfied), which is commonly used in perception-based urban design studies, was used for the evaluation, transforming subjective evaluations into semi-quantitative data [59]. Using the Likert scale method for walking passenger perception evaluation, the ratings were averaged from the participant ratings for each street segment, thus supporting the regression analysis treatment. This method has the disadvantage that the pedestrian satisfaction data obtained are discrete rather than continuous, and the linear regression model is only suitable for regression analysis of continuous variables. Therefore, in the subsequent section, we assigned the perception evaluation scores to each street block and used each of its perception factors as the dependent variable for the regression analysis between the perception scores and the walkability indicators.

3.6. Street Survey

After the passenger survey was completed and the road segments were compiled, the street segment survey within a 1 km radius was conducted at the end of September 2021. This phase involved investigating all the road sections where passengers walked and rated, resulting in 113 street sections: 19 on Lianhua Road, 23 on Tonghe Xincun, 40 on Changping Road, and 31 on Linping Road. The research was conducted with the help of Google Maps and 3D street view maps, but there were still some data points that could not be obtained in this way, so a table of field research was designed. The table consists of two parts. The first part is the data on sidewalks and lanes related to the research streets. The second part uses satellite images to investigate the characteristics of buildings along the street and their related indicators.

4. Result

4.1. Sample Feature Analysis and Walking Passenger Path Selection

4.1.1. Analysis of the Personal and Travel Characteristics of the Sample Passengers

The total number of valid questionnaires in the four stations was 499, of which 56% were males and 44% were females, with a slightly higher proportion of males than females, but the overall difference was not significant. The age range of the surveyed passengers at the four sites was between 14 and 69 years old, and the largest proportion was between 18 and 44 years old, accounting for 85.57% (Figure 3). In terms of work status, 76.3% of the passengers had full-time jobs; 15.8% were students or interns; and the proportion of retired or unemployed people and people with part-time jobs was low. In terms of household income, the income level refers to the 2021 Shanghai Statistical Yearbook, which shows that the per capita annual income in Shanghai in 2021 is RMB 78,000. Based on the number of people, the annual income is divided into three income categories: low, medium, and high. Lianhua Road and Tonghe Xincun are on par with the average income levels of the four stations, while Changping Road and Linping Road have a higher proportion of high-income passengers (14.3% and 17.6%). In Tonghe Xincun, the household car ownership rate is around 50%, with a higher proportion of passengers without a car (62.6%), and a slightly higher proportion of Lianhua Road passengers who usually use a car (9.7%) than that in the other stations.

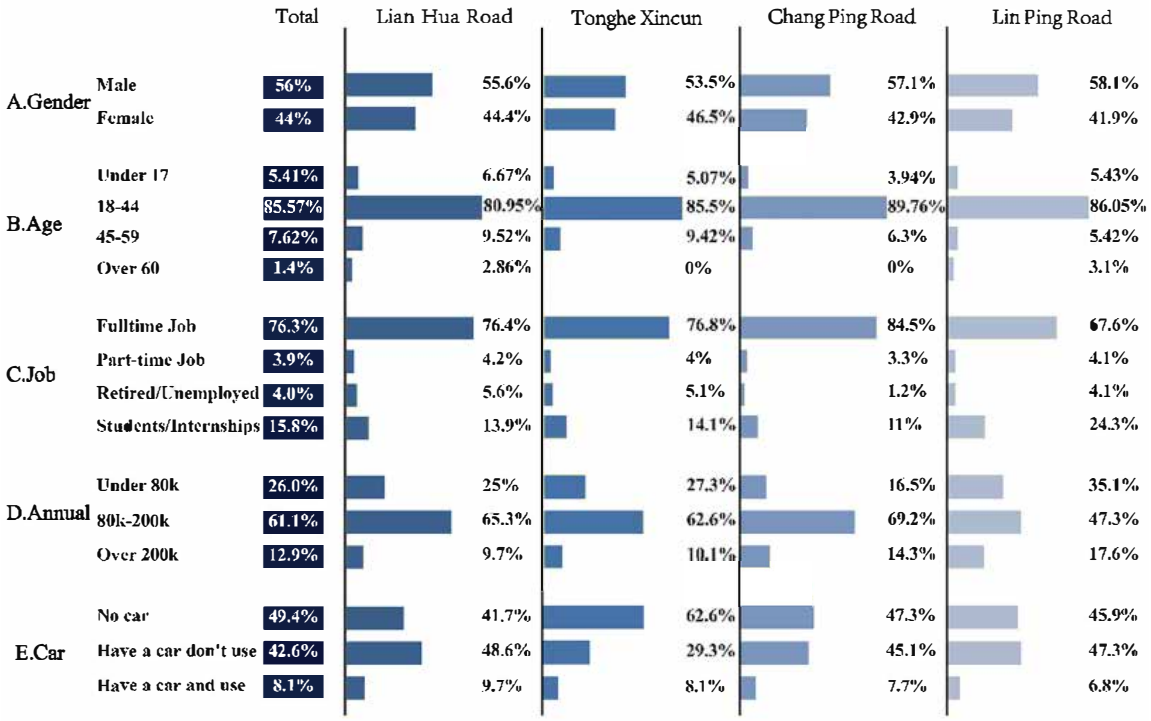


Figure 3. Passengers' personal characteristics and travel characteristics.

The survey results show that more than 70% of passengers use the case study stations more than three times a week, indicating that respondents are familiar with the station surroundings, which increases the reliability of the walking perception evaluation. The proportion of people using bus and bicycle transfers is significantly higher in the edge area sites than in the core area sites, with the highest proportion of 67.7% in Tonghe Xincun. The proportion of walking transfers is much higher in the core area sites than in the edge area sites, with the highest proportion of 92.3% in Changping Road.

4.1.2. Walking Detour Coefficient for Metro Transit Passengers

Passengers ranged in walking distance from 38 to 1690 m, with an average of 624.33 m. Comparing the stations, the walking distances of Lianhua Road and Tonghe Xincun (728.9 m and 749.8 m) were significantly farther than those of Changping Road and Linping Road (582.6 m and 485.3 m). By comparing the walking distance proportion of each site, it can be seen that the proportion of the core area sites with walking distance below 1000 m accounts for more than 90% of the total, while the most walking distance of the edge area sites is between 500 m and 1000 m (Figure 4).

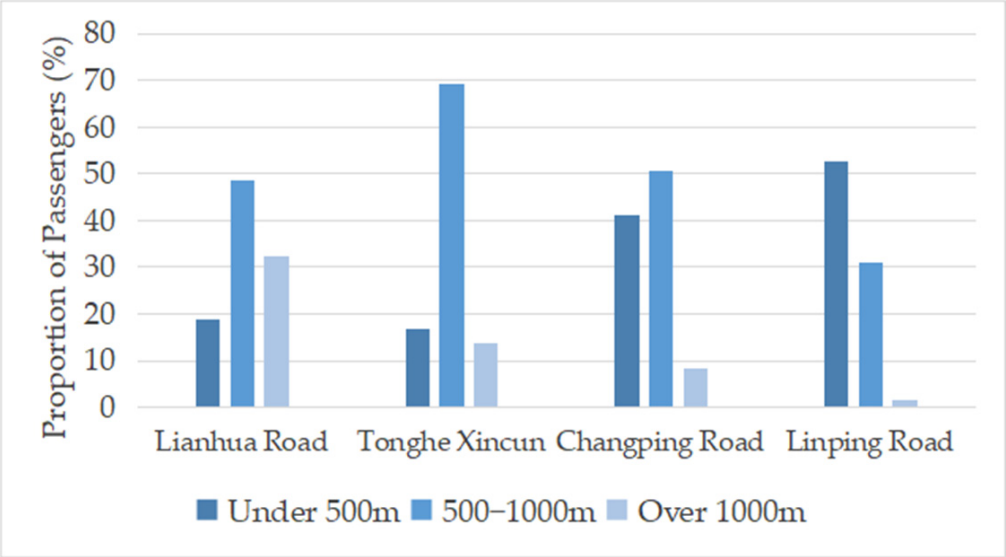


Figure 4. The proportion of different walking distances of the 4 stations.

Based on the path information obtained from the survey, the actual walking path distance (L) and the spatial straight distance (D) were calculated separately, the walking detour coefficient PRD (L/D) was calculated for each path, and the average value was calculated. The average detour coefficient was ranked as follows: Tonghe Xincun (1.39) > Lianhua Road (1.33) > Changping Road (1.22) > Linping Road (1.20). The results show that the PRD values of all four sites are between 1 and 2.2, and the detour phenomenon is more serious in the urban edge sites than in the core sites. The average block edge lengths are as follows: Tonghe Xincun, 397 m; Lianhua Road, 320 m; Changping Road, 199 m; and that of Linping Road is the smallest at 154 m. The comparison shows that the walking detour coefficient has a very strong positive correlation with the block edge length.

4.1.3. Perception Evaluation of Walking Passengers at Different Stations

In the walking passenger perception survey, a simplified five-level Likert scale was applied to the perceived evaluation of the walkability factor. Walkers' ratings of the factors were categorized into five levels of satisfaction, with 1 indicating very dissatisfied and 5 indicating very satisfied. Additionally, we calculated the average scores of passengers' perceptual evaluations of the M01–M09 elements at the four stations. In general, walkers rated core area stations higher than edge area stations, with facility accessibility being more prominent (Figure 5).

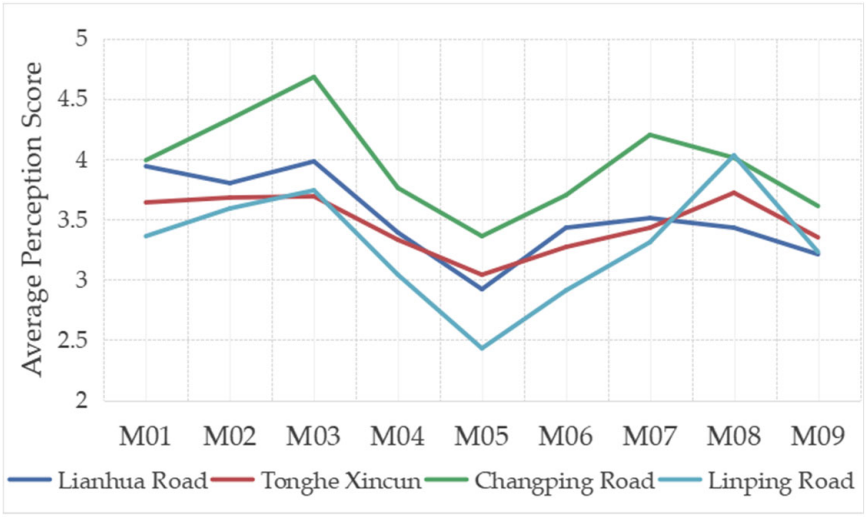


Figure 5. Passengers rated each factor of the block.

4.1.4. Analysis of Route Evaluation Scores by Passengers with Different Characteristics

Overall, passengers with middle and high incomes are more satisfied, whereas low-income passengers are only satisfied with accessibility to facilities, street diversity, and being unaffected by negative environmental influences. This indicates that high-income passengers have higher expectations for the quality and comfort of the walking environment, while low-income passengers are more concerned with safety, convenience, and street variety (Figure 6).

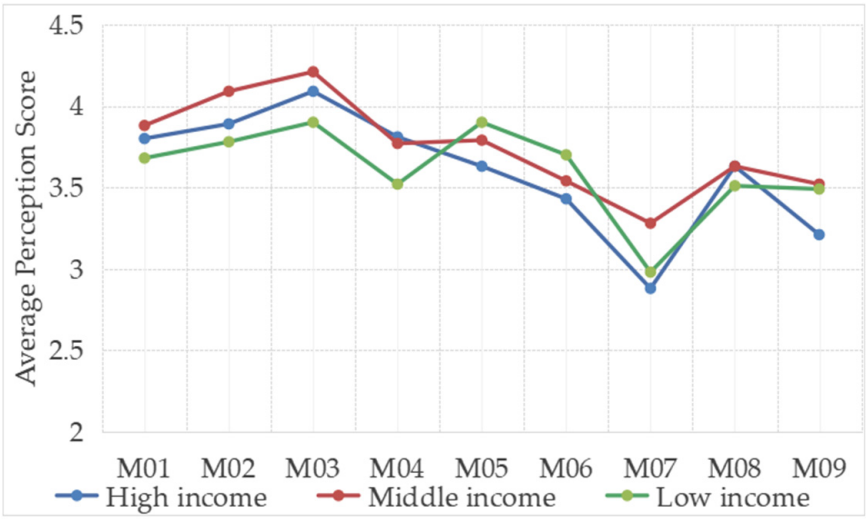


Figure 6. Comparison of route evaluation scores of passengers with different incomes.

The comparison revealed that there is a correlation between household car ownership and path evaluation scores. Passengers who owned a car at home had higher requirements for the walking environment and paid more attention to its quality, such as the availability of more facilities, the level of comfort, and the scale and enclosure of the street. In contrast, passengers who did not own a car placed more importance on the safety and convenience of the walking space, with poorer evaluations of elements such as the safety of crossing the street and walking on the sidewalk, while generally being more satisfied with the quality of the walking environment (Figure 7).

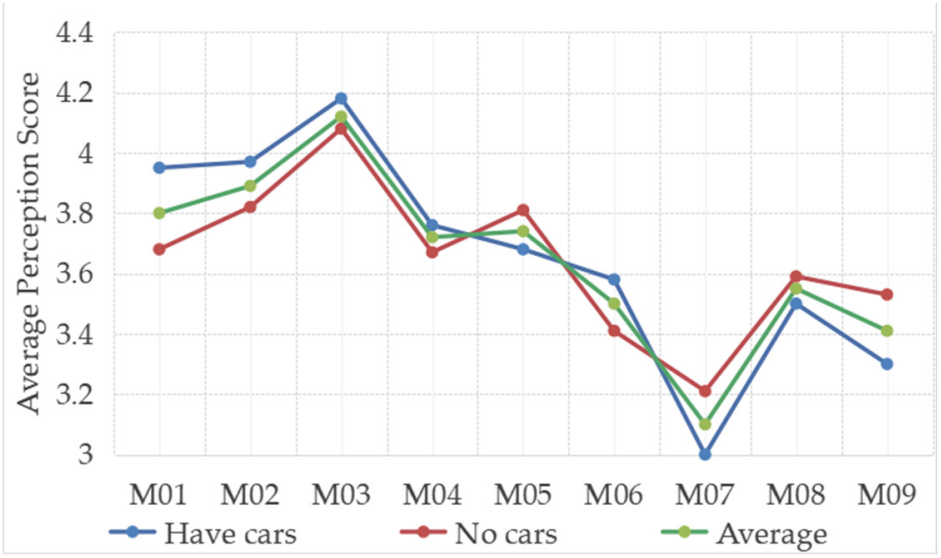


Figure 7. Comparison of car ownership and path evaluation scores.

4.2. Analysis of Walkability Impact Indicators at the Path Level and Construction of a Composite Index

4.2.1. Regression Analysis Between Walkability Factors and Indicators

The eighteen walkability indicators selected above were analyzed based on the results extracted from the passenger and street survey data, and five indicators with relatively strong correlations as well as insignificant differences were eliminated. For instance, the total width and the number of lanes had strong autocorrelation, so the total width of lanes was not included in the model. After the initial screening, 13 walkability indicators were subjected to Pearson correlation analysis as independent variables to identify variables with strong autocorrelation for further screening (Table 3). Following this, we eliminated three more indicators: building height, proportion of ground-floor residential buildings, and green belt width, leaving 10 indicators for the regression analysis (Table 4).

Table 3. Pearson correlation analysis of 13 independent variables.

		NL	GB	BW	SW	BH	SE	AG	FT	PC	PR	ER	TC	SL
Pearson's correlation	Number of lanes (NL)	1.000	0.056	0.240	0.294	−0.196	−0.434	0.116	−0.330	0.137	−0.132	0.478	0.090	0.207
	Green belt width (GB)	0.056	1.000	0.859	0.385	−0.039	−0.045	0.120	297	0.003	−0.088	−0.192	0.253	0.102
	Buffer width (BW)	0.240	0.859	1.000	0.364	0.001	0.075	0.067	214	0.090	−0.166	−0.058	0.277	0.150
	Effective width of sidewalk (SW)	0.294	0.385	0.364	1.000	−0.052	−0.170	−0.093	0.163	0.222	0.010	−0.030	0.178	0.208
	Average building height (BH)	−0.196	−0.039	0.001	−0.052	1.000	0.755	0.165	−0.018	−0.547	0.080	0.04	0.261	−0.496
	Street enclosure (SE)	−0.434	−0.045	−0.075	−0.170	0.755	1.000	0.271	0.364	−0.517	0.215	−0.367	−0.129	−0.398
	Building adherence rate (AG)	−0.116	0.120	0.067	−0.093	0.165	0.271	1.000	0.017	−0.053	−0.112	−0.173	0.063	0.050
	Ground floor facade transparency (FT)	−0.330	0.297	0.214	0.163	−0.018	0.364	0.017	1.000	0.084	0.284	−0.697	0.251	−0.014
	Proportion of ground-floor commercial uses (PC)	0.137	0.003	0.090	0.222	−0.547	−0.517	−0.053	0.084	1.000	−0.585	0.032	0.265	0.397
	Proportion of ground-floor residential uses (PR)	−0.132	−0.088	−0.166	0.010	0.080	0.215	−0.112	0.284	−0.585	1.000	−0.343	0.069	−0.174
	Enclosure ratio (ER)	0.478	−0.192	−0.058	0.030	0.041	−0.367	−0.173	−0.697	0.032	−0.343	1.000	−0.344	0.075
	Proportion of pavements covered by tree canopy (TC)	0.090	0.253	0.277	0.178	−0.26	−0.129	0.063	0.251	0.265	0.069	−0.344	1.000	0.120
	Length of sidewalk (SL)	0.207	0.102	0.150	0.208	−0.496	−0.398	−0.050	−0.014	0.397	−0.174	0.073	0.120	1.000

Through regression analysis, this study discovered an association between the scores of the walkability factors and the walkability indicators. Each of the nine walkability factors was used as the dependent variable, and the ten walkability indicators above were used as independent variables for the multiple linear regression analysis. Some studies have shown that some individual indicators, such as age and gender, also have an effect on the perceived evaluation of the walking environment. However, this study's assignment of individual ratings to road sections and their subsequent averaging did not align with individual relationships, leading to their exclusion from the model. Before conducting the regression, the PP plot test was conducted for each of the nine dependent variables, and the results showed that all nine dependent variables conformed to a normal distribution.

Finally, all nine models were successfully regressed, and eight independent variables were entered into the model by excluding those with significance above 0.05 (Table 5).

Table 4. Descriptive statistics of the independent variables involved in the regression analysis.

	N	Minimum Value	Maximum Value	Average	Standard Deviation
Number of lanes	113	1	10	3.02	1.973
Buffer width (green belt, roadside parking, non-motorized lanes)	112	0.00	12.0	3.272	1.7007
Effective width of sidewalk	113	0.5	4.2	2.200	0.9041
Street enclosure (aspect ratio)	113	0.07	2.31	0.9188	0.56237
Building stick line rate	113	0.00	90.00	1.3789	8.41484
Ground floor facade transparency	113	0	176	78.97	36.988
Proportion of ground-floor commercial uses	113	0.00	1.00	0.6189	0.27276
Enclosure ratio	113	0.00	1.00	0.3359	0.29206
Proportion of sidewalks covered by tree canopy	113	0.00	0.94	0.6750	0.20707
Length of sidewalk	113	74	604	247.13	124.973
Valid Number (list status)	112	-	-	-	-

Table 5. Results of stepwise regression analysis.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig
		B	Standard Error	Beta		
M01 Street crossing safety	(Constant)	3.119	0.267		11.679	0.000
	Proportion of sidewalks covered by tree canopy	1.310	0.355	0.324	3.695	0.000
	Number of lanes	−0.110	0.036	0.272	−3.101	0.002
M02 Safety on the sidewalk	(Constant)	4.882	0.345		14.140	0.000
	Enclosure ratio	−1.648	0.332	−0.425	−4.968	0.000
	Ground floor facade transparency	−0.010	0.003	−0.312	−3.593	0.000
	Effective width of sidewalk	0.190	0.090	0.131	2.107	0.036
M03 Public security sense of personal safety	(Constant)	3.221	0.264		12.223	0.000
	Proportion of sidewalks covered by tree canopy	0.901	0.324	0.243	2.777	0.006
	Street enclosure (aspect ratio)	0.626	0.191	0.459	3.271	0.001
	Ground floor facade transparency	0.390	0.195	0.178	1.999	0.048
M04 Convenience of street crossing	(Constant)	2.751	0.353		7.797	0.000
	Number of lanes	−0.113	0.041	−0.252	−2.751	0.007
	Proportion of sidewalks covered by tree canopy	1.231	0.387	0.274	3.182	0.002
	Street enclosure (aspect ratio)	0.359	0.144	0.228	2.483	0.015
M05 Accessibility of facilities	(Constant)	4.551	0.158		28.887	0.000
	Length of sidewalk	−0.003	0.001	−0.395	−4.504	0.000
M06 Sidewalk Features	(Constant)	3.170	0.233		13.595	0.000
	Number of lanes	−0.106	0.031	−0.306	−3.430	0.001
	Proportion of sidewalks covered by tree canopy	0.763	0.310	0.220	2.464	0.015
M07 Unaffected by negative environment	(Constant)	2.671	0.278		9.595	0.000
	Proportion of sidewalks covered by tree canopy	1.089	0.370	0.266	2.948	0.004
	Number of lanes	−0.098	0.037	−0.239	−2.656	0.009
M08 Sense of street dimensions	(Constant)	2.439	0.305		8.005	0.000
	Street enclosure (aspect ratio)	0.381	0.132	0.262	2.887	0.005
	Proportion of sidewalks covered by tree canopy	0.974	0.377	0.235	2.585	0.011
M09 Street Diversity	(Constant)	4.075	0.239		17.053	0.000
	Number of lanes	−0.112	0.040	−0.259	−2.823	0.006
	Proportion of ground-floor commercial uses	−0.595	0.287	−0.190	−2.072	0.041

4.2.2. Scores Walkability Factors Based on the Perceived Choices of Walking Passengers

After obtaining the formulas for each of the nine factors based on the regression results, this study addressed the issue of weighting depending on passenger choice. The researcher asked passengers to select the factors they considered more important among the nine pleasant walking environments in the metro transit passenger survey, and then calculated

the weight values of each factor by calculating the proportion of each option. This study counted the proportion of each factor selected by walking passengers and those who took buses to the station separately. The comparison revealed a difference in the assignments of walking passengers and bus passengers, with walking passengers considering crossing safety, safety on the sidewalk, being unaffected by negative environmental influences, and street diversity more important than bus passengers did.

Based on the correlation coefficients, constant values, and weight assignments obtained from the above analysis, a composite index formula containing eight walkability indicators was derived as the basis for calculating the street segment and path walkability scores (Table 6). To improve clarity and academic rigor, the composite index formulae in Table 6 are expressed using symbolic variables. Each variable is defined in Table 7.

Table 6. Index formula with 8 walkability indicators.

Weights	Model Equation
0.14	$M01 = 3.119 + 1.310 \times TC - 0.110 \times NL$
+0.14	$M02 = 4.882 - 1.648 \times ER - 0.010 \times FT + 0.190 \times SW$
+0.09	$M03 = 3.221 + 0.901 \times TC + 0.626 \times SE + 0.390 \times FT$
+0.13	$M04 = 2.751 - 0.113 \times NL + 1.231 \times TC + 0.359 \times SE$
+0.1	$M05 = 4.551 - 0.003 \times SL$
+0.09	$M06 = 3.170 - 0.106 \times NL + 0.763 \times TC$
+0.21	$M07 = 2.671 + 1.089 \times TC - 0.098 \times NL$
+0.06	$M08 = 2.439 + 0.381 \times SE + 0.974 \times TC$
+0.04	$M09 = 4.075 - 0.112 \times NL - 0.595 \times PC$

Table 7. Symbol definitions.

Symbol	Description
TC	Proportion of sidewalks covered by tree canopy
NL	Number of lanes
ER	Enclosure ratio
FT	Ground floor facade transparency
SW	Effective width of sidewalk
SE	Street enclosure (aspect ratio)
SL	Length of sidewalk
PC	Proportion of ground-floor commercial uses

The Walking Composite Index (WCI) is ultimately calculated using the following weighted formula:

$$WCI = 0.14 \times M01 + 0.14 \times M02 + 0.09 \times M03 + 0.13 \times M04 + 0.10 \times M05 + 0.09 \times M06 + 0.21 \times M07 + 0.06 \times M08 + 0.04 \times M09 \quad (1)$$

5. Discussion

5.1. Comparing the Walkability of Stations in the Core and Edge Areas

We used the composite walkability index formula to calculate the walkability scores for each street segment at the four sites, as well as the path walkability scores for pedestrians. The results of the study visualize the distribution of walkability scores across the four metro station areas. The visual walkability maps show areas with particularly low or high walkability and reflect the direct impact of street-scale variables such as number of lanes and tree canopy coverage on the perceived pedestrian experience. Calculation of the composite index scores for the walkability measures for the four sites indicates that the core area sites have much higher walkability scores than the edge area sites (Figure 8). The average

walkability scores for Changping Road and Linping Road are 7.10 and 6.5, respectively, while those for Lianhua Road and Tonghe Xincun are 5.13 and 5.99, respectively.

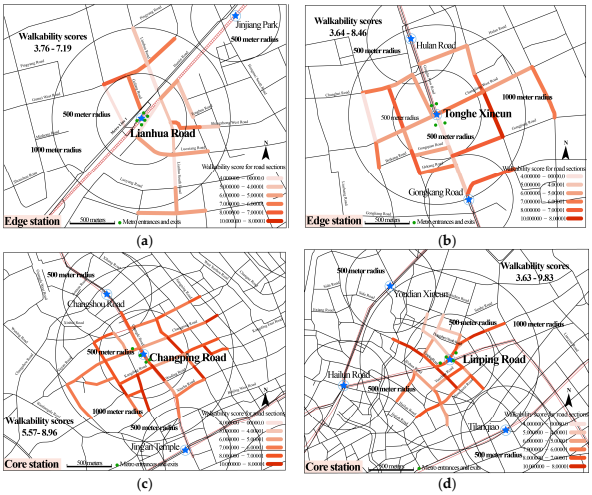


Figure 8. Comparison of walkability scores for roadway segments at edge zone stations and core zone stations. (**a**) Lianhua Road station; (**b**) Tonghe Xincun station; (**c**) Changping station. (**d**) Linping station.

This is also due to the higher density of the road network, the dense arrangement of the metro line network and stations, the intensive and abundant distribution of public and commercial services in the neighborhood, the low number of lanes, the appropriate scale and sense of enclosure of the street, the high transparency of the ground floor interface, the wider buffer zone and sidewalk, and the higher percentage of tree canopy coverage on the sidewalk in the area around the core site.

The composite index of walkability measures for the four sites in the core and fringe zone areas provides the following information:

(1) The walking transfer ratio of metro transit passengers is much higher in core area stations than in edge area stations; the average walking distance is shorter than that in edge area stations; and the walking detour coefficient is proportional to the neighborhood edge length.

(2) High-income passengers and those with small cars in their households demand more quality and comfort in the walking environment, while low-income passengers are more concerned with the safety and convenience of walking.

(3) According to this study, the number of lanes, the proportion of sidewalks covered by a tree canopy, street enclosure, and the transparency of ground-floor building facades are more important indicators for walkability scores.

(4) The average walkability scores of the core area stations were much higher than the scores of the edge area stations.

5.2. Directions for Future Pedestrian Environment Improvements in Site Areas

Micro-facility improvements can enhance the quality of the pedestrian environment by analyzing the obtained walkability indicators. Thus, there are some important strategies to be considered in the future improvement and design of the pedestrian environment around metro transit stations.

(1) For metro transit stations, as the flow of people starts from the station and spreads outward, the usage rate of streets within about 500 m around the station is the highest, and further outward forms a more concentrated branching channel. Therefore, it is important to improve the walkability of this key area and the main corridors in each direction, not

only to increase the chance of people walking but also to improve their quality of life and comfort.

(2) Increasing the proportion of commercial buildings on the ground floor can enhance street diversity and promote street vitality, thereby making the walking process more engaging and enhancing the sense of safety on foot.

(3) Reducing the segregation facilities between sidewalks and adjacent areas, particularly physical fences, can significantly improve the pedestrian experience. For example, fences, overly wide green belts, and barriers can diminish the communication between pedestrians and neighboring spaces.

(4) An appropriate street scale and sense of enclosure make people walk in the street with a good visual view and not feel depressed or alienated psychologically, which is an important influencing factor of walkability.

(5) When buffering negative impacts, particularly for traffic arteries, it is important to avoid long, continuous physical walls or blank plots. Instead, we should improve the pedestrian environment by implementing subtle measures like green belts and characteristic barriers, which are very effective.

(6) Street trees play a crucial role in enhancing the sidewalk environment and facilities, and numerous passengers have expressed that the cleanliness of sidewalks is an important factor they consider when selecting their routes. Thus, maintaining a certain density of street trees and sidewalk pavement can also make the walking experience more comfortable for pedestrians.

6. Conclusions

Our findings on the significance of street enclosure, number of lanes, and tree canopy coverage are in the same direction as those reported by Woldeamanuel & Kent [60] and Villaveces et al. [34], both of which emphasize the role of microenvironmental features in shaping walkability. Our study builds upon and extends these results by applying a composite index methodology. In contrast to previous studies, our research uniquely incorporates metro passengers' drawn walking paths and subjective evaluations into a regression-driven, perception-weighted composite index. This not only bridges the gap between qualitative and quantitative methods, but also provides a more contextualized and user-centered tool for evaluating and improving walkability around metro stations in high-density urban settings.

These findings have direct implications for urban planning and pedestrian-oriented design in high-density transit areas. Specifically, planners can prioritize reducing lane width or count in pedestrian-heavy areas to improve safety and comfort. Increasing the percentage of sidewalks covered by a tree canopy and improving building facade transparency can enhance walkability without requiring major structural changes. The composite index developed in this study provides a replicable tool for evaluating and optimizing walkability at the block level, supporting transit-oriented development (TOD) strategies that emphasize last-mile accessibility and street-level quality.

We used the data from the four-station survey in this study to analyze passenger perception, screen walkability indicators, and construct the composite index, but we did not verify its universality. In the regression analysis, the relationship between pedestrian flow and walkability was not analyzed because this study focused on the physical environment effects of the street and found that the density of pedestrian flow in the selected areas was generally not congested. Furthermore, we may need to further refine and study the method of obtaining perceptual data.

Author Contributions: Conceptualization, X.C. and Y.H.; methodology, X.C. and Z.S.; writing—original draft preparation, X.C. and Z.S.; supervision, Y.H.; project administration, Y.H.; funding acquisition, Y.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Youth Science Fund Project of National Natural Science Foundation of China, "Research on Spatial Configuration Optimization Model of Urban Complex Based on Travel Chain Response", grant number 51908411.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PERS	Pedestrian Environmental Rating System
PP plot	Probability-Probability Plot
WCI	Walking Composite Index

Appendix A

Metro Passenger Arrival Travel Survey

Abstract

Dear Sir/Madam: Greetings! We hereby commission our students to conduct this anonymous,n on-private sample survey on the characteristics of rail transit passengers' arrival and travel. Wewi ll strictly follow the provisions of Article 14, Chapter 3 of the Statistical Law and will not disclose t he information you have provided to any third party.

Please scan the upper left QR code or add the micro-signal ＊＊＊＊＊, the form will be double-sided photo sent back to this micro-signal, the recovery of valid questionnaires every 20 will be randomly selected to give a cell phone rechargeable card valued at 100 yuan.
Thank you for your participation and support of this survey!

August 2021

Part I

1.Your gender is (1) male (2) female, and your age is_____

2.Your work status is:
(1)Full-time
(2)Part-time
(3)Retired/unemployed
(4)Students/Internships

3.Your household income in 2021 was:
(1)Less than 80,000
(2)80,000 to 200,000
(3)200,000andabove

4.The status of your car usage is:
(1)No car at home
(2)I have a car at home but I don't usually use it.
(3)I have a car at home that I use on a regular basis

5.You often use metro transportation for the purpose of travel:
(1)Work
(2)Going to school
(3)Shopping
(4)Social activities/recreation
(5)Other

6.The frequency of your trips at home and at this site is:
(1)More than 3 times per week
(2)1-2 times per week
(3)Once every two weeks or less

7.The mode of transportation you often use to arrive at this site, or to get from this site to your destination, is (please select one of the following options):
(1)Walking (go directly to topic 8)
(2)Public transportation(direct to topic 10)
(3)Bicycles/ Electric vehicles(go directly to topic 10)
(4)Driving (godirectlytotopic 9)
(5)Taxi (direct to topic 9)
(6)Other (please specify_____)

8.If you chose to walk, please write the walking time:_____

9.If you chose "drive or take a taxi" in the last two questions, what was the main factor you considered (multiple choices allowed):
(1)Time saving
(2)Sites too far from home
(3)Unsafe to walk (given the traffic)
(4)Physical danger (taking into account the crime)
(5)Other (please specify_____)

10.Assuming that you have to walk to a subway station everyday,what factors do you value more (multiple choice):

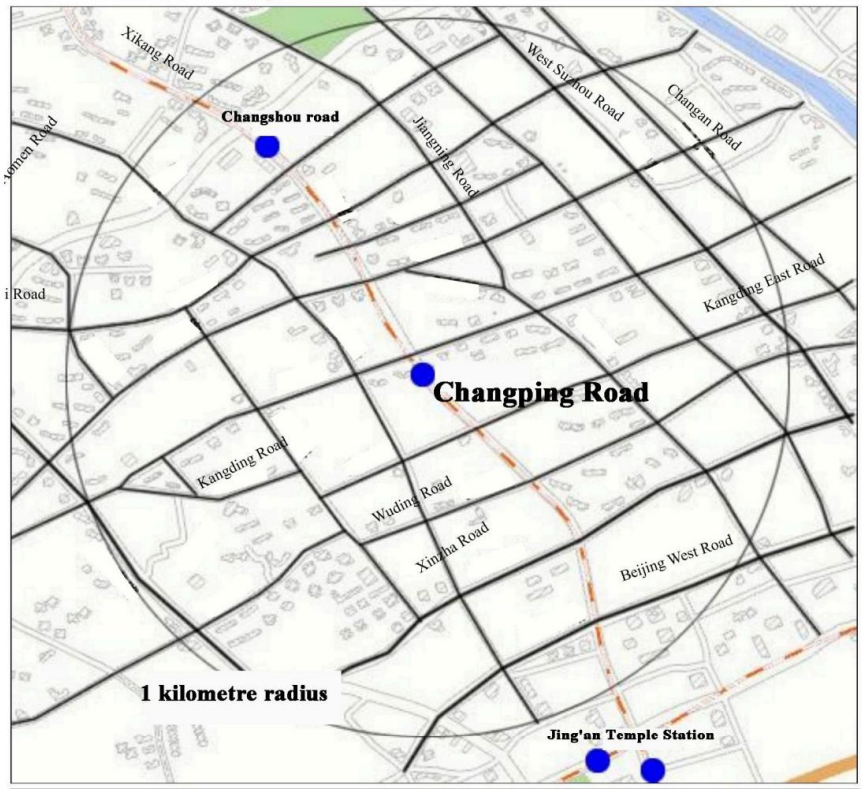
(1) Street crossing safety	(2) Sidewalk safety
(3) Good social security	(4) Easy to cross the street, no need to wait long
(5) Convenience with a wide range of living services	(6) Sidewalk width, continuous
(7) Shade, less exhaust and noise	(8) Pleasant street scale
(9) Street Fun	(10) Other

Figure A1. Metro passenger questionnaire Part I.

Part II

11. Write the name of the nearest intersection or road to your home; or the name of the bus stop to reach it.

12. Please draw the walking paths you regularly use in this area. First, please point to the location of your home and then draw the route to the stop.



13. Walking path distances_____

14. Please rate your walking path by giving each item a score of 1-5 in the table below, the higher the score, the better you feel.

safety	Cross-street traffic safety	
	Traffic safety on sidewalks	
	Good social security	
comforts	Pleasant street scale	
	No negative environmental impacts (solarization, exhaust noise)	
	Width of walkway	
	Trail continuity (few motorized interruptions)	
convenience	Easy to cross the street, short wait times	
	Lots of stores, restaurants and other facilities	
cheerfulness	Diversity of streets (greenery, lots of vignettes, diversity of façades, attractiveness)	

Figure A2. Metro passenger questionnaire Part II.

References

1. Wang, P.; Zhang, R.; Sun, S.; Gao, M.; Zheng, B.; Zhang, D.; Carmichael, G.R.; Zhang, H. Aggravated air pollution and health burden due to traffic congestion in urban China. *Atmos. Chem. Phys.* **2023**, *23*, 2983–2996. [CrossRef]
2. Liu, J.; Peng, Q.; Chen, J.; Yin, Y. Connectivity reliability on an urban rail transit network from the perspective of passenger travel. *Urban Rail Transit* **2020**, *6*, 1–14. [CrossRef]
3. Lin, D.; Nelson, J.D.; Cui, J. Exploring influencing factors on metro development in China from urban and economic perspectives. *Tunn. Undergr. Space Technol.* **2021**, *112*, 103877. [CrossRef]
4. Chen, H.; Zhao, K.; Zhang, Z.; Zhang, H.; Lu, L. Methods for the Performance Evaluation and Design Optimization of Metro Transit-Oriented Development Sites Based on Urban Big Data. *Land* **2024**, *13*, 1233. [CrossRef]
5. Sun, G.; Zacharias, J.; Ma, B.; Oreskovic, N.M. How do metro stations integrate with walking environments? Results from walking access within three types of built environment in Beijing. *Cities* **2016**, *56*, 91–98. [CrossRef]
6. Paydar, M.; Fard, A.K.; Khaghani, M.M. Walking toward Metro Stations: The Contribution of Distance, Attitudes, and Perceived Built Environment. *Sustainability* **2020**, *12*, 10291. [CrossRef]
7. Jiao, J.; Chen, Y.; He, N. Plan pedestrian friendly environments around subway stations: Lessons from Shanghai, China. *J. Urban Des.* **2017**, *22*, 796–811. [CrossRef] [PubMed]

8. Owen, N.; Humpel, N.; Leslie, E.; Bauman, A.; Sallis, J.F. Understanding environmental influences on walking: Review and research agenda. *Am. J. Prev. Med.* **2004**, *27*, 67–76. [CrossRef]
9. Lee, M.; Lee, H.; Hwang, S.; Choi, M. Understanding the impact of the walking environment on pedestrian perception and comprehension of the situation. *J. Transp. Health* **2021**, *23*, 101267. [CrossRef]
10. Li, Z.; Han, Z.; Xin, J.; Luo, X.; Su, S.; Weng, M. Transit oriented development among metro station areas in Shanghai, China: Variations, typology, optimization and implications for land use planning. *Land Use Policy* **2019**, *82*, 269–282. [CrossRef]
11. Khosravi, H.; Abrishami, M.; Mehrian, M.R.; Chamberlain, B. The positive impact of transit-oriented-development characteristics on Metro Station usage: A case study of Tehran's metro stations and TOD index calculation. *Cities* **2024**, *148*, 104840. [CrossRef]
12. Yao, C.; Li, G.; Yan, S. Design Strategies to Improve Metro Transit Station Walking Environments: Five Stations in Chongqing, China. *Buildings* **2024**, *14*, 1025. [CrossRef]
13. Salaheldin, H.T.; Major, M.D.; Ahmad, A.M.; Tannous, H.O. Analyzing walkability in the vicinity of three metro stations in Doha, Qatar. *Open House Int.* **2023**, *48*, 487–503. [CrossRef]
14. Kim, H.; Park, S.H.; So, J. Identifying walkability factors for urban metro station areas toward transit-oriented development. *Int. J. Urban Sci.* **2024**, 1–21. [CrossRef]
15. Yan, C.; Gao, Y.; Yang, Y. Exploring the Spatial Patterns of Accessibility to Metro Services Considering the Locations of Station Entrances/Exits. *Buildings* **2024**, *14*, 3532. [CrossRef]
16. Shanghai MaaS Public Travel Annual Report (2023). Available online: https://www.shmaas.cn/data.html (accessed on 23 September 2024).
17. 2024 Shanghai Urban Rail Transit Service Quality Evaluation Results Released. Available online: https://www.shanghai.gov.cn (accessed on 10 March 2025).
18. Bivina, G.R.; Gupta, A.; Parida, M. Influence of microscale environmental factors on perceived walk accessibility to metro stations. *Transp. Res. Part D Transp. Environ.* **2019**, *67*, 142–155. [CrossRef]
19. Fonseca, F.; Ribeiro, P.J.; Conticelli, E.; Jabbari, M.; Papageorgiou, G.; Tondelli, S.; Ramos, R.A. Built environment attributes and their influence on walkability. *Int. J. Sustain. Transp.* **2022**, *16*, 660–679. [CrossRef]
20. Kim, E.J.; Kim, J.; Kim, H. Does Environmental Walkability Matter? The Role of Walkable Environment in Active Commuting. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1261. [CrossRef]
21. Cepolina, E.M.; Menichini, F.; Rojas, P.G. Level of service of pedestrian facilities: Modelling human comfort perception in the evaluation of pedestrian behaviour patterns. *Transp. Res. Part F Traffic Psychol. Behav.* **2018**, *58*, 365–381. [CrossRef]
22. Bivina, G.R.; Gupta, A.; Parida, M. Walk accessibility to metro stations: An analysis based on meso-or micro-scale built environment factors. *Sustain. Cities Soc.* **2020**, *55*, 102047. [CrossRef]
23. Saelens, B.E.; Sallis, J.F.; Frank, L.D. Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Ann. Behav. Med.* **2003**, *25*, 80–91. [CrossRef]
24. Lamour, Q.; Morelli, A.M.; Marins, K.R.D.C. Improving walkability in a TOD context: Spatial strategies that enhance walking in the Belém neighbourhood, in São Paulo, Brazil. *Case Stud. Transp. Policy* **2019**, *7*, 280–292. [CrossRef]
25. Eom, S.; Kim, H.; Hasegawa, D.; Yamada, I. Pedestrian movement with large-scale GPS records and transit-oriented development attributes. *Sustain. Cities Soc.* **2024**, *102*, 105223. [CrossRef]
26. Live Where You Love. Available online: www.walkscore.com (accessed on 15 May 2024).
27. Liu, M.; Jiang, Y.; He, J. Quantitative evaluation on street vitality: A case study of Zhoujiadu community in Shanghai. *Sustainability* **2021**, *13*, 3027. [CrossRef]
28. Gu, P.; Han, Z.; Cao, Z.; Chen, Y.; Jiang, Y. Using open source data to measure street walkability and bikeability in China: A case of four cities. *Transp. Res. Rec.* **2018**, *2672*, 63–75. [CrossRef]
29. Chen, Z.; Huang, R.; Huang, Y.; Chen, Z.; Ye, Y. The measurements of fine-scale street walkability and precise design control: An evidence-based approach based on virtual reality and wearable bio-sensors. *Chin. Landsc. Archit.* **2022**, *38*, 70–75.
30. Telega, A.; Telega, I.; Bieda, A. Measuring Walkability with GIS—Methods Overview and New Approach Proposal. *Sustainability* **2021**, *13*, 1883. [CrossRef]
31. Tsiompras, A.B.; Photis, Y.N. What matters when it comes to "Walk and the city"? Defining a weighted GIS-based walkability index. *Transp. Res. Procedia* **2017**, *24*, 523–530. [CrossRef]
32. Mateo-Babiano, I. Pedestrian's needs matter: Examining Manila's walking environment. *Transp. Policy* **2016**, *45*, 107–115. [CrossRef]
33. Park, S. *Defining, Measuring, and Evaluating Path Walkability, and Testing Its Impacts on Transit Users' Mode Choice and Walking Distance to the Station*; University of California: Berkeley, CA, USA, 2008.
34. Villaveces, A.; Nieto, L.A.; Ortega, D.; Ríos, J.F.; Medina, J.J.; Gutiérrez, M.I.; Rodríguez, D. Pedestrians' perceptions of walkability and safety in relation to the built environment in Cali, Colombia, 2009–10. *Inj. Prev.* **2012**, *18*, 291–297. [CrossRef]
35. Hussain, M.S.; Kumari, R.; Nimesh, V.; Goswami, A.K. Assessing impact of urban street infrastructure on pedestrian safety perception. *Proc. Inst. Civ. Eng.-Urban Des. Plan.* **2021**, *174*, 76–84. [CrossRef]

36. Huang, G.; Yu, Y.; Lyu, M.; Sun, D.; Dewancker, B.; Gao, W. Impact of Physical Features on Visual Walkability Perception in Urban Commercial Streets by Using Street-View Images and Deep Learning. *Buildings* **2025**, *15*, 113. [CrossRef]
37. Fonseca, F.; Rodrigues, A.; Silva, H. Pedestrian Perceptions of Sidewalk Paving Attributes: Insights from a Pilot Study in Braga. *Infrastructures* **2025**, *10*, 79. [CrossRef]
38. Shach-Pinsly, D.; Ganor, T. A New Approach for Assessing Secure and Vulnerable Areas in Central Urban Neighborhoods Based on Social-Groups' Analysis. *Sustainability* **2021**, *13*, 1174. [CrossRef]
39. Chin, K.K.; Menon, G. Transport accessibility and infrastructure in Singapore–pedestrian facilities. *Proc. Inst. Civ. Eng.-Munic. Eng.* **2015**, *168*, 133–139. [CrossRef]
40. Eboli, L.; Forciniti, C.; Mazzulla, G.; Bellizzi, M.G. Establishing Performance Criteria for Evaluating Pedestrian Environments. *Sustainability* **2023**, *15*, 3523. [CrossRef]
41. Majumdar, B.B.; Sahu, P.K.; Patil, M.; Vendotti, N. Pedestrian satisfaction-based methodology for prioritization of critical sidewalk and crosswalk attributes influencing walkability. *J. Urban Plan. Dev.* **2021**, *147*, 04021032. [CrossRef]
42. Ewing, R.; Handy, S. Measuring the unmeasurable: Urban design qualities related to walkability. *J. Urban Des.* **2009**, *14*, 65–84. [CrossRef]
43. Singh, R. Factors affecting walkability of neighborhoods. *Procedia-Soc. Behav. Sci.* **2016**, *216*, 643–654. [CrossRef]
44. Nasar, J.L. Urban design aesthetics: The evaluative qualities of building exteriors. *Environ. Behav.* **1994**, *26*, 377–401. [CrossRef]
45. Li, Y.; Yabuki, N.; Fukuda, T. Measuring visual walkability perception using panoramic street view images, virtual reality, and deep learning. *Sustain. Cities Soc.* **2022**, *86*, 104140. [CrossRef]
46. Sevtsuk, A.; Kalvo, R.; Ekmekci, O. Pedestrian accessibility in grid layouts: The role of block, plot and street dimensions. *Urban Morphol.* **2016**, *20*, 89–106. [CrossRef]
47. Xuan, W.; Zhao, L. Research on correlation between spatial quality of urban streets and pedestrian walking characteristics in china based on street view big data. *J. Urban Plan. Dev.* **2022**, *148*, 05022035. [CrossRef]
48. Kweon, B.-S.; Rosenblatt-Naderi, J.; Ellis, C.D.; Shin, W.-H.; Danies, B.H. The Effects of Pedestrian Environments on Walking Behaviors and Perception of Pedestrian Safety. *Sustainability* **2021**, *13*, 8728. [CrossRef]
49. Boarnet, M.G.; Anderson, C.L.; Day, K.; McMillan, T.; Alfonzo, M. Evaluation of the California Safe Routes to School legislation: Urban form changes and children's active transportation to school. *Am. J. Prev. Med.* **2005**, *28*, 134–140. [CrossRef]
50. Yosifof, R.; Fisher-Gewirtzman, D. Hybrid quantitative mesoscale analyses for simulating pedestrians' visual perceptions: Comparison of three New York City streets. *Environ. Plan. B Urban Anal. City Sci.* **2024**, *51*, 140–156. [CrossRef]
51. Jacobs, J. *The Economy of Cities*; Vintage: New York, NY, USA, 2016.
52. Fonseca, F.; Papageorgiou, G.; Tondelli, S.; Ribeiro, P.; Conticelli, E.; Jabbari, M.; Ramos, R. Perceived walkability and respective urban determinants: Insights from Bologna and Porto. *Sustainability* **2022**, *14*, 9089. [CrossRef]
53. Basu, N.; Oviedo-Trespalacios, O.; King, M.; Kamruzzaman, M.; Haque, M.M. The influence of the built environment on pedestrians' perceptions of attractiveness, safety and security. *Transp. Res. Part F Traffic Psychol. Behav.* **2022**, *87*, 203–218. [CrossRef]
54. Sang, Y.; Hu, Y.; Qin, X.; Yan, H.; Wu, R.; Qian, F.; Nan, X.; Shao, F.; Bao, Z. Impacts of street tree canopy coverage on pedestrians' dynamic thermal perception and walking willingness. *Sustain. Cities Soc.* **2025**, *121*, 106196. [CrossRef]
55. Zordan, M.; Talamini, G.; Villani, C. The Association between Ground Floor Features and Public Open Space Face-To-Face Interactions: Evidence from Nantou Village, Shenzhen. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4934. [CrossRef]
56. Guo, J.; Wei, Y.D.; Chen, W.; Liu, W.; Wang, L. Daily Flows, Urban Polycentricity, and Transit Commuting Patterns: A Study of Shanghai, China. *Geogr. Rev.* **2024**, *114*, 243–267. [CrossRef]
57. Moura, F.; Cambra, P.; Gonçalves, A.B. Measuring walkability for distinct pedestrian groups with a participatory assessment method: A case study in Lisbon. *Landsc. Urban Plan.* **2017**, *157*, 282–296. [CrossRef]
58. Nakamura, K. The relationship between walkability and QOL outcomes in residential evaluation. *Cities* **2022**, *131*, 104008. [CrossRef]
59. Joshi, A.; Kale, S.; Chandel, S.; Pal, D.K. Likert scale: Explored and explained. *Br. J. Appl. Sci. Technol.* **2015**, *7*, 396. [CrossRef]
60. Woldeamanuel, M.; Kent, A. Measuring walk access to transit in terms of sidewalk availability, quality, and connectivity. *J. Urban Plan. Dev.* **2016**, *142*, 04015019. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.