Article

Quantitative Evaluation of Friendliness in Streets’ Pedestrian Networks Based on Complete Streets: A Case Study in Wuhan, China

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Abstract: In recent years, with the rapid growth in the number of cars, the safe and convenient street pedestrian traffic network in cities has been broken by motor vehicle lanes. The pedestrian traffic function of streets as an important urban public space has been lost, and the pedestrian friendliness of streets needs urgent improvement. However, the existing pedestrian-friendly street space assessment has not yet formed a set of full-factor quantitative evaluation systems, making the construction of pedestrian-friendly streets still in the conceptual stage and lacking practical significance. The complete streets design concept clarifies the goal of street pedestrian space construction and proposes the full elements of street pedestrian space design, which provides important support for the construction of the street pedestrian friendliness evaluation system. Based on the complete streets design concept, this study constructs a complete set of quantitative evaluation systems of street walkability from three aspects of street space: traffic, environment and function. Meanwhile, a street pedestrian usability evaluation method is proposed to further explore the actual demand of streets. Combined with the comprehensive evaluation matrix of street pedestrian friendliness and usability, the areas where the planning of street pedestrian space does not match with the actual space are explored. The case study in Wuhan found that the overall pedestrian friendliness was high in the area, but there was significant variability. The study area is dominated by streets in need of improvement, with medium demand–low friendliness, and both the pedestrian friendliness and usability of the streets need to be improved.

Keywords: complete streets; street pedestrian friendliness; street pedestrian space; street optimization; street renewal

1. Introduction

Before the automobile became the main mode of transportation in cities, urban spaces were mainly connected by street pedestrian networks, and pedestrian transportation was an important part of urban life [1]. During the rapid urban expansion in the early 20th century, a traffic pattern dominated by car traffic was formed due to the continuous expansion of urban space and population size. The safe and convenient pedestrian traffic network in cities was broken by motorised lanes, and the street space became purely traffic space, which aggravated the deterioration of the street pedestrian environment and contributed to the pedestrian unfriendliness [2–4].

With the initial completion of large-scale urban development, there was a call to return the street to the pedestrian. As a result, the concept of “complete streets” was first introduced in the field of transportation planning and design in North America [5]. Complete streets are designed to meet the needs of different modes of transportation, such as walking, cycling and driving, on the one hand, and to provide good pedestrian
space for recreational and leisure activities, such as walking and communication, on the other [6,7]. The focus on pedestrian space in the complete streets concept has contributed to a transformation from “walkability” to “pedestrian friendliness”, and the concept of “pedestrian friendliness” has emerged. Street pedestrian friendliness (SPF) proposes to focus on the needs and perceptions of walkers and pursue human-centred street design [8–10].

In addition, streets are designed to serve residents, and it is equally important to understand the needs and feedback of street walkers on the design of streets [11]. In past research, these characteristics have often been taken as evaluation factors for SPF [12,13]. Therefore, we separate these factors from the SPF evaluation system and propose the concept of street pedestrian usability (SPU). In contrast to the objective physical space environment of the street reflected by SPF, SPU represents the subjective perception of people. We define SPU as a street space that can be used safely, comfortably, conveniently and in a variety of ways with a certain frequency of use, a positive subjective perception by pedestrians and a social activity service for pedestrians. SPU reflects the pedestrian use characteristics and needs of people in the street, such as frequency of passing and pedestrian satisfaction.

The objective and quantitative evaluation of the SPF and the observation of the SPU are of great significance in the process of reshaping street walking space and improving the resilience of urban space in the new era of urban space creation [14,15]. However, the reality is that the imperfect quantitative evaluation system of SPF and the lack of evaluation system of SPU hinder the understanding of what unfriendly elements exist in streets, what is not usable and how to improve street walkable spaces to build humane cities.

Inspired by the above facts, this study creates a comprehensive set of quantitative assessment index systems for SPF from the standpoint of street pedestrian users. The systems include three aspects of street traffic components, environmental elements and functional elements, and they conduct a comprehensive evaluation from two dimensions of street pedestrian environment (SPE) and street pedestrian attractiveness (SPA). In addition, we propose the SPU evaluation method, including the pedestrian flow of streets, pedestrian passing frequency and pedestrian satisfaction and street activity richness, to directly observe the actual feedback of street usage. On this basis, a comprehensive matrix analysis of the SPF and SPU is conducted to explore the discrepancies between the evaluation of indicators and the observed needs, to identify deficiencies in the current state or design of streets and to demonstrate their validation and practical implication. The main contributions of this paper can be listed as follows:

1. We constructed a full-factor quantitative SPF evaluation system as comprehensively as possible and used deep learning, hierarchical analysis and GIS methods to measure SPF quantitatively.
2. To our knowledge, it should be the first time that the concept of SPU, a walking evaluation method based on human behavioural characteristics, is proposed.
3. We created a comprehensive evaluation matrix that combined subjective and objective measures to identify areas where street construction and use did not match. These results can uncover potential urban street pedestrian features to promote sustainably built pedestrian-friendly streets.

The rest of the paper is structured as follows. A review of the existing research is presented in Section 2. We describe the methodology of the study, the physical and social context of the study area and the data sources and pre-processing in Section 3. The results are reported in Section 4. A discussion of the content of the study, conclusions and recommendations are presented in Sections 5 and 6.

2. Literature Review
2.1. Complete Streets and Street Pedestrian Space

In the 1970s, the United States began to rethink the concept and goals of street development in order to address the conflict between motorised traffic and slow-moving
traffic. The concept of “complete streets” was introduced [16]. The complete streets concept is a new way of thinking about street design, which advocates a change in the focus of transportation design from primarily serving motorised trips to accommodating all modes of transportation [6,17]. The complete streets concept is the first to suggest that street planning, design and renewal should ensure that users of all ages and abilities can travel safely, conveniently and comfortably by any mode of transportation, advocating for a safe and inclusive street environment [7]. The complete streets design concept clarifies the objectives of street pedestrian space construction, proposes all the elements of street pedestrian space design and provides important support for the construction of the street pedestrian friendliness evaluation system.

With the introduction of the complete streets concept, street pedestrian space has received renewed attention and generated a great deal of scholarly research [18,19]. In traditional street design concepts, the pavement is commonly used as a space for pedestrians, i.e., the ground space from the outer rimstone ramp to the boundary of the red line of the road [20]. In recent years, under the influence of the complete streets concept, research on street pedestrian space has focused more on the needs and perceptions of pedestrians. In subsequent studies, scholars have continued to expand and study the basic elements of street pedestrian space, including pedestrian paths, non-motorised paths, building setback spaces, amenity strips, safety separation spaces, public services and municipal facilities and landscape greenery, etc., and discuss them in categories according to the attributes of different streets [21,22].

In this paper, street pedestrian space is defined as a public open space on both sides of a city street, as shown in Figure 1. The research process combines the macro-scale elements of road network and land use with the micro-scale elements of pavement, rimstone ramp and rest facilities, which together form the components of street pedestrian space.

![Diagram of the extent of street pedestrian space.](image)

**Figure 1.** Diagram of the extent of street pedestrian space.

### 2.2. Studies on SPF Concept

SPF is a derivative of the concept of street walkability. The concept of “walkability” was first introduced in American transportation research in the mid-1990s, covering the built environment dimensions of cities related to pedestrian transport and reflecting the extent to which urban built environment spaces support walking behaviour. It has since been studied in a variety of fields, including sports, public health and urban planning theory and practice [23–25]. Russo, A. et al. coupled urban walkability assessment with space syntax in the context of urban infrastructure configuration [26]. Campisi, T. et al. used a qualitative analysis based on the critical path method to assess the walkability of urban environments in terms of specific populations [27]. As the study of street walkability has gradually moved into a systematic stage, the concept of SPF has been developed based on street walkability.
SPF is a spatial attribute that emphasises the ability of the physical spatial environment to guide people on foot. At its core, it encompasses the spatial proximity between departure and destination as well as the safety, convenience and comfort of walking between these two points [28]. The type and spatial distribution of the starting and finishing points for walking determine the possibilities for walking trips, while the environmental factors in the walking paths determine the safety, convenience and comfort of the trips [29].

2.3. Studies on the Evaluation Framework of SPF

In existing research on the SPF, in addition to the functional attributes of traffic inherent in street pedestrian spaces, researchers have gradually begun to focus on the place and environmental elements of street pedestrian spaces, establishing relevant indicator systems to assess streets from the perspective of facilities and suggesting elements of street design, among other things [30–33]. Some scholars have conducted studies to assess a particular attribute, such as the quality, vitality and landscape interface of the street [34–36]. In addition, some scholars have begun to focus on the human scale of the street.

Based on existing theoretical research, scholars have proposed a series of frameworks and methods for evaluating the urban physical space environment based on SPF. The 5C urban street design framework, developed by the London Planning Advisory Committee in 1996, measures the pedestrian quality of streets in terms of comfort, connectivity, convenience, conspicuousness and conviviality [37]. In recent years, American researchers have developed the concept of a walk score that considers the type of demand, spatial distribution and attenuation of daily services and is widely used to assess the SPF [38]. Su et al. developed a pedestrian environmental friendliness evaluation index system to achieve balanced development of motorways and footpaths [37]. Zhou et al. further responded to pedestrian friendliness and equity by measuring the visual walkability of streets in different areas, which can be used to improve urban planning [39]. Li et al. measured the friendliness of street pedestrian facilities by quantifying the pedestrian friendliness of footbridges [40].

2.4. Literature Summary

By summarizing the literature on the concept of SPF and related evaluation systems, it can be seen that research on SPF influencing factors and evaluation frameworks has achieved some results, but there are still some deficiencies. Most of the existing studies discuss the influencing factors of SPF from a single dimension, lacking a comprehensive consideration of psychological characteristics and the physical environment. At the same time, the existing evaluation system of SPF is based on simple statistical assessment and subjective expert assessment and has not yet formed a complete set of quantitative evaluation systems covering all attributes of streets. Therefore, this study constructs a comprehensive quantitative evaluation system for the SPF based on the concept of complete streets that integrates the traffic function, environmental function and place function of streets, bridging the gap in related research. At the same time, a comprehensive evaluation matrix combining the physical environment characteristics of SPF and the psychological characteristics of SPU is proposed to further provide data support for the pre-renovation assessment and post-renovation effect comparison of urban street pedestrian spaces.

3. Methods and Materials

3.1. Study Methods

3.1.1. SPF Evaluation System Construction

The evaluation system is based on conventional SPF research, along with street design standards from various Chinese cities, and considers the concepts of safety, convenience, comfort and variety in the establishment of street pedestrian space, and evaluates SPF from two aspects: SPE and SPA. Among these, the SPE shows the friendliness of the street’s physical space environment, and the SPA reflects the diversity and friendliness of the street’s function services.
Selection and Quantification of SPE Indicators

Scholars have defined the SPE from many aspects, such as the spatial function, spatial structure and service type of the street in current study on street pedestrian space [6,28,41–44]. The evaluation index system of street pedestrian environment is created from three aspects: safety, convenience and comfort. Table 1 depicts the index system and computation process.

Table 1. Evaluation indicators of SPE.

<table>
<thead>
<tr>
<th>Primary Indicators</th>
<th>Secondary Indicators</th>
<th>Calculation Method</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$X_1 = \frac{S_{car} + S_{mo} + S_{motor}}{A}$</td>
<td>$S_{car}$, $S_{mo}$, $S_{motor}$ are the pixel areas of cars, motorcycles and other motor vehicles in the street view image; $A$ is the total pixel area of the street view image.</td>
</tr>
<tr>
<td>Street motorization degree $X_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-motorised road settings $X_2$</td>
<td></td>
<td>$X_2 = \frac{L_{m}}{A}$</td>
<td>$L_{m}$ is the total length of the motorway on both sides of the street; $A$ is the length of the street unit</td>
</tr>
<tr>
<td>Sidewalk occupation degree $X_3$</td>
<td></td>
<td>$X_3 = \frac{N_{m}}{A}$</td>
<td>$N_{m}$ is the number of motor vehicles parked in the space on both sides of the street where no parking spaces are provided.</td>
</tr>
<tr>
<td>Safety C1</td>
<td>Sidewalk divider security $X_4$</td>
<td>$X_4 = \frac{L_{s}}{A}$</td>
<td>$L_{s}$ is the safety coefficient of different isolation methods; $A$ is the safety coefficient of different isolation methods.</td>
</tr>
<tr>
<td></td>
<td>Rimstone ramp integrity $X_5$</td>
<td>$X_5 = \frac{N_{r} + N_{d}}{A}$</td>
<td>$N_{r}$ is the number of rimstone ramps installed in the street but not up to standard; $N_{d}$ is the number of curb ramps that should be installed in the street but are not actually installed; $A$ indicates the total number of curb ramps that should be installed in the street.</td>
</tr>
<tr>
<td></td>
<td>Blindside integrity $X_6$</td>
<td>$X_6 = \frac{N_{b}}{A}$</td>
<td>$N_{b}$ is the total number of blind discontinuity points in the street.</td>
</tr>
<tr>
<td>Street surveillance degree $X_7$</td>
<td></td>
<td>$X_7 = \frac{S_{s}}{A}$</td>
<td>$S_{s}$ is the pixel area of the pedestrian in the street view image.</td>
</tr>
<tr>
<td>Convenience C2</td>
<td>Sidewalk continuity $X_8$</td>
<td>$X_8 = \frac{N_{ip} + N_{dp}}{A}$</td>
<td>$N_{ip}$, $N_{dp}$ are the number of intermittent points or points of sharp change in width of the sidewalk in the street.</td>
</tr>
<tr>
<td></td>
<td>Public transportation accessibility $X_9$</td>
<td>$X_9 = \frac{N_{subway} + N_{bus}}{A}$</td>
<td>$N_{subway}$, $N_{bus}$ denote the number of bus stations and subway stations within the street buffer.</td>
</tr>
<tr>
<td></td>
<td>Road accessibility $X_{10}$</td>
<td>$X_{10} = \frac{L_{b}}{A}$</td>
<td>$L_{b}$ denotes the total length of the road network within the 300 m buffer of the street; $A$ is the total area of the street unit.</td>
</tr>
<tr>
<td></td>
<td>Sidewalk effective width ratio $X_{11}$</td>
<td>$X_{11} = \frac{L_{e}}{A}$</td>
<td>$L_{e}$ is the length of sidewalks of different width types on both sides of the street unit; $\beta$ is the width coefficient.</td>
</tr>
<tr>
<td></td>
<td>Crosswalk spacing $X_{12}$</td>
<td>$X_{12} = \frac{N_{c}}{A}$</td>
<td>$N_{c}$ is the total number of crosswalks in the street.</td>
</tr>
<tr>
<td></td>
<td>Public transportation station integrity $X_{13}$</td>
<td>$X_{13} = \frac{N_{pt}}{A}$</td>
<td>$N_{pt}$ is the total number of public transportation stations with different facility configurations; $A$ is the total number of public transportation stations; $\beta$ is the facility coefficient.</td>
</tr>
<tr>
<td>Comfort C3</td>
<td>Interface transparency $X_{14}$</td>
<td>$X_{14} = \frac{L_{i}}{A}$</td>
<td>$L_{i}$ is the length of the different street interface types of the street; $\beta$ is the street interface coefficient.</td>
</tr>
<tr>
<td></td>
<td>Sky visibility $X_{15}$</td>
<td>$X_{15} = \frac{S_{sky}}{A}$</td>
<td>$S_{sky}$ is the pixel area of the sky in the street view image.</td>
</tr>
<tr>
<td></td>
<td>Pedestrian green vision $X_{16}$</td>
<td>$X_{16} = \frac{S_{green}}{A}$</td>
<td>$S_{green}$ is the pixel area of the plants in the street view image.</td>
</tr>
<tr>
<td></td>
<td>Greenery coverage $X_{17}$</td>
<td>$X_{17} = \frac{S_{g}}{A}$</td>
<td>$S_{g}$ is the area covered by greenery within the street.</td>
</tr>
<tr>
<td></td>
<td>Rest facility integrity $X_{18}$</td>
<td>$X_{18} = \frac{N_{r}}{A}$</td>
<td>$N_{r}$ is the total number of rest facilities on both sides of the street.</td>
</tr>
<tr>
<td></td>
<td>Sanitation integrity $X_{19}$</td>
<td>$X_{19} = \frac{N_{san}}{A}$</td>
<td>$N_{san}$ is the total number of sanitation facilities on both sides of the street.</td>
</tr>
<tr>
<td></td>
<td>Sidewalk pavement integrity $X_{20}$</td>
<td>$X_{20} = \frac{L_{dp}}{A}$</td>
<td>$L_{dp}$ is the length of sidewalk on both sides of each street unit for different pavement types; $\gamma$ is the pavement coefficient.</td>
</tr>
</tbody>
</table>

The specific classification criteria for all the coefficients mentioned in the table are shown in Appendix A.

Selection and Quantification of SPA

Streets serve as public open spaces in the city that serve a variety of functions, like public activities, social interaction, entertainment and shopping, in addition to being places...
where pedestrian traffic activities take place [45]. The study evaluates SPA in two aspects: street walk score $C_4$ and street function mix $X_22$ (Table 2).

Table 2. Evaluation indicators of SPA.

<table>
<thead>
<tr>
<th>Primary Indicators</th>
<th>Calculation Method</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street walk score $C_4$</td>
<td>$C_4 = \sum_{i,k} (W_i \times D_{i,k})$</td>
<td>$W_i$ is the facility weights, $D_{i,k}$ is the influence coefficient of the facility, $i$ is the different types of facilities and $k$ is the walking distance of different types of facilities.</td>
</tr>
<tr>
<td>Street function mix $C_5$</td>
<td>$C_5 = -\sum_{i} (Q_i \times \log Q_i)$</td>
<td>$Q_i$ refers to the proportion of the number of points of interest (POIs) in one category to the total number of POIs in the $i$-th street unit; $n$ is the POI category.</td>
</tr>
</tbody>
</table>

The specific calculation of the street walk score is shown in Appendix A.

3.1.2. SPU Evaluation System Construction

SPU is a bottom-up comment on street renewal and design from the perspective of street walkers. In the study, four metrics were chosen for evaluation, and Table 3 shows the specific calculating technique and methodology.

Table 3. SPU evaluation indicators.

<table>
<thead>
<tr>
<th>Primary Indicators</th>
<th>Calculation Method</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian flow $Y_1$</td>
<td>$Y_1 = \frac{N_{use}}{L_i}$</td>
<td>$N_{use}$ is the total number of pedestrians walking in a week in the street unit.</td>
</tr>
<tr>
<td>Passage frequency $Y_2$</td>
<td>$Y_2 = \frac{N_{pf}}{t_c}$</td>
<td>$N_{pf}$ is the average frequency of pedestrians within a street unit for a week.</td>
</tr>
<tr>
<td>Walking satisfaction $Y_3$</td>
<td>$Y_3 = \frac{s_{ws}}{t_c}$</td>
<td>$s_{ws}$ is the mean of walking satisfaction scores within the street unit.</td>
</tr>
<tr>
<td>Street activities richness $Y_4$</td>
<td>$Y_4 = \frac{N_{an}}{t_c}$</td>
<td>$N_{an}$ is the total number of types of activities occurring on both sides of the street unit.</td>
</tr>
</tbody>
</table>

In the evaluation of the richness of street activities, the social activities included in the street pedestrian space are divided into the following categories, excluding the basic traffic function of the street: 1. rest, 2. conversation and communication, 3. sports and exercise, 4. chess and card games, 5. shopping, 6. restaurants, 7. gatherings, 8. games and entertainment, 9. sightseeing and tourism, 10. reading.

3.1.3. Analytic Hierarchy Process (AHP)-Based Subjective Weighting Method

Different street indicators have different units. The unit constraint of the data can be overcome by standardizing the data, allowing indications with varied units and magnitudes to be compared and weighted [46]. The findings of the street evaluation are processed utilizing a deviation standardization approach in this study. This approach linearly varies the raw data of various index measure outcomes such that they are uniformly mapped onto the [0, 1] interval. The equations to vary for different street unit $m_1$, $m_2$, $m_3$ ... $m_k$ are as follows.

$$M_{kj} = \frac{(m_{kj} - \min(m_j))}{(\max(m_j) - \min(m_j))}$$

where $m_{kj}$ represents the raw score of the $j$-th indicator for the $k$-th street unit ($k = 1, 2, \ldots$, $n$, $n$ is the total number of street unit; $j = 1, 2, \ldots, z$, $z$ is the total number of indicators), $M_{kj}$ is the score after normalization, $\min(m_j)$ and $\max(m_j)$ are the minimum and maximum values of the original result of indicator $j$.

The hierarchical analysis is a multi-objective decision making strategy that integrates qualitative and quantitative approaches as well as systematic reasoning. In this work, a hierarchical analysis was used to calculate the weights of the indicators for the evaluation.
system. We invited two experts and eight researchers in the field of urban and rural planning to provide relative importance scores based on their expertise. By solving the judgment matrix of the obtained indications, the weights were computed. The matrix findings were checked for consistency to confirm the legitimacy and reasonableness of the produced weight vectors. The Consistency Ratio (CR) values of the expert scoring findings in this study are all less than 0.1 and pass the consistency test. The geometric mean approach is employed in this study to allocate weights to each expert.

3.1.4. SPF–SPU Matrix Construction

Matrix analysis is a quantitative multivariate statistical method that transforms multiple variables into a few composite variables by quantifying the relationships between distinct parts using data matrix diagrams [47]. The correlation and difference between the evaluation results of SPF and SPU are examined using matrix analysis in this paper. Meanwhile, SPF represents pedestrian friendliness and SPU reflects pedestrian demand. The natural breakpoint approach was used to construct the SPF–SPU matrix, which divided SPF and SPU into high, middle and low levels (Figure 2).

![Figure 2. SPF–SPU matrix.](image)

3.2. Study Area

3.2.1. Study Area Overview

The research site is in Wuhan (113°41′ – 115°05′ E, 29°58′ – 22°31′ N). Wuhan is the capital city of Hubei Province and the central city of China. It is located in the eastern part of the Jianghan Plain and the middle reaches of the Yangtze River, where the Yangtze River, the third largest river in the world, and its largest tributary, the Han River, meet to form the towns of Wuchang, Hankou and Hanyang (Figure 3).

![Figure 3. Location of Wuhan.](image)
We take into account the sample’s representativeness and variability and choose the urban street space of the historic district of Jianghan Road and Zhongshan Avenue in Wuhan as the study area (Figure 4). The historic district of Jianghan Road and Zhongshan Avenue is located in the Jiang’an District of Wuhan, which is a famous historical and cultural district of Wuhan. It has two important historical roads, Jianghan Road and Zhongshan Avenue, as its backbone. The study area runs through the central part of Hankou and is characterised by a regular grid pattern, with a continuous and varied street interface, which basically maintains the ‘street + street outline’ character of the modern city of Hankou and is representative of the typical neighbourhood form of Wuhan.

![Image](image_url)

**Figure 4.** Location and overview of the study area: (a) Jianghan Road and Zhongshan Avenue Historic District Scope Diagram; (b) study area.

The Wuhan Urban Road Planning and Design Guidelines for All Elements (later referred to as the Guidelines) is a guiding code for street design with legal effect issued by the City of Wuhan [48]. The streets inside Wuhan’s Third Ring Road are classified according to the elements of street land use, street activities and natural landscape in Guidelines (Figure 5). The streets in the research region are divided into four types: living streets, transportation streets, business streets and shared streets, which include the majority of street types in Wuhan and are typical of the city.

![Image](image_url)

**Figure 5.** Functional classification of streets within the Third Ring Road of Wuhan City.

### 3.2.2. Street Unit Division

Long-distance urban roadways vary in various ways, including land use, road width, facility layout and traffic characteristics; therefore, their street pedestrian friendliness...
changes appropriately [49]. Therefore, it is necessary to further divide the long-distance streets so that a section of streets with similar characteristics is used as a study unit. The indefinite length method and the fixed length method are two common ways of dividing road sections. Considering the current situation of streets in the study area, the indefinite length approach is used in this work to split the streets inside the study region, and road sections with comparable features are treated as the same unit. The streets in the research region were classified into 67 street units based on several criteria, such as road junctions, land use and traffic forms (Figure 6). The length of each street unit spans from 65.98 m to 185 m, with an average size of 1626.30 m². The street unit is used as the fundamental unit in this study to explore, measure and assess the street pedestrian friendliness.

Figure 6. Street unit division results.

3.3. Data Sources and Pre-Processing

3.3.1. Street Data

Streets serve as both the foundation for network analysis and the research unit for measuring pedestrian friendliness. Wuhan City red and yellow line data, OSM road network data and building profile data were used in this article. Wuhan City 2015 municipal red and yellow line data were gathered from the Wuhan Planning Research Institute. The base street boundary was obtained by processing the road red line and centerline data. The OSM road network data and building contour data were obtained from the 2018 Wuhan City urban geospatial vector data obtained from the OpenStreetMap (www.openstreetmap.org (accessed on 2 March 2021)) [50].

3.3.2. Baidu Street View Data

The Baidu Maps software, developed in 2005 by Baidu.com in Beijing, China, started releasing street maps in 2013, which are available for users to browse along with an application programming interface (API) to download [31]. We sampled the road network inside the research region at 30 m intervals by ArcGIS 10.7 and collected street view photos in two directions of 0° and 180° at each sampling point location by Baidu Map API (http://quanjing.baidu.com/apipickup/ (accessed on 11 July 2021)). A total of 172 sampling points were located in the research region; eventually, 344 street view photos with a resolution of 1024 × 512 were collected (Figure 7).
Figure 7. Street data within the study area.

A deep learning complete convolutional network trained on the ADE20K dataset is used to segment the street view photos. After picture segmentation is acquired by feeding the street scene view photos into the trained network, the proportions of motor vehicles, people, sky and vegetation in the street view images are obtained. Figure 8 depicts the neural network structure and operations.

Figure 8. Street view image segmentation program structure and workflow [52]: (a) neural network structure; (b) neural network workflow.

3.3.3. Cellular Signalling Data

Cell phone signalling data can accurately represent people’s behavioural characteristics and the amount of traffic used on the street [53,54]. The mobile phone signalling data utilised in this study were gathered by a large communication operator in Wuhan, and the number of users represented 67% of the city’s cell phone users. The data have high universality and representativeness and may reflect most of people’s travel behaviour in Wuhan [55]. The data were obtained from 5 March 2018 to 11 March 2018, a period of five working days and two rest days that can adequately represent a human activity cycle. A total of 1,016,526 cell phone signalling data were gathered from 485 base stations inside the research area’s 500 m buffer zone. Each set of communication data comprises time and location information, and no sensitive information was included.

3.3.4. POI Data

POI data, which are both fine-grained and large in volume, are commonly employed in street-scale analysis, which can effectively reflect the distribution and quantity of various facilities around the street. The POI data for Wuhan City 2018 were gathered through the Baidu Map API interface, and a total of 168,424 data were obtained in 13 categories, including name, category, latitude and longitude information. The obtained POI data were cleaned, classified and sorted according to the needed categories, and a total of
94,387 POI points in 9 categories were preserved inside the research area’s 500 m buffer zone (Table 4).

Table 4. POI classification and number.

<table>
<thead>
<tr>
<th>POI Type</th>
<th>Number</th>
<th>POI Type</th>
<th>Number</th>
<th>POI Type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accommodation</td>
<td>7160</td>
<td>Recreation</td>
<td>52,698</td>
<td>Hospitals and Schools</td>
<td>5919</td>
</tr>
<tr>
<td>Restaurants</td>
<td>17,719</td>
<td>Public Transportation</td>
<td>2643</td>
<td>Sports Facilities</td>
<td>1</td>
</tr>
<tr>
<td>Living Services</td>
<td>1860</td>
<td>Parks and Squares</td>
<td>1214</td>
<td>Others</td>
<td>5173</td>
</tr>
</tbody>
</table>

3.3.5. Remote Sensing Image Data

In remote sensing photos, there are clear variations in spectral properties between vegetation and other feature categories [56]. We mostly employ domestic HMS-1 satellite image data in this work. The spectral representation of vegetation is red when remotely sensed pictures are shown in false colour in near-red, red and green bands, and the vegetation border may be directly defined, which can effectively reflect the green cover in the street. Some areas that are closely related to houses or roadways have been artificially adjusted.

3.3.6. Survey and Questionnaire Data

The research was carried out manually to count the types of activities that occur in each street unit, and a questionnaire was distributed at random in each street unit to count the frequency of pedestrian movement and satisfaction with walking. The questionnaire data were collected in March 2022, which is one of the best months of the year for walking activity and is typical of the month when there are no major Chinese festivals and the weather is favourable compared to other months. The number of surveys distributed in each street unit ranged from 10 to 15, with a total of 542 valid questionnaires (Appendix B). To gather the essential data for the pedestrian usability study, the research and questionnaire findings were cleaned and structured. SPSS was used to assess the reliability and validity of the questionnaire data to confirm their validity, and the results all passed the significance test.

4. Results

4.1. SPF Evaluation Results and Distribution

The evaluation results of the SPE are classified into three main sections: safety, convenience and comfort (Figure 9). Figure 10 shows the comprehensive SPE evaluation conclusions. The evaluation results and analysis of SPE secondary indicators are shown in Appendix C.

Firstly, the safety index is mainly in the range of 0.421–1.000, with a relatively good safety score for the pedestrian space. The safety index of the commercial streets on the southwest side of the study area, represented by Jianghan Road, is significantly better than that of other areas. The middle section of Zhongshan Avenue on the northwest side of the study area has obvious safety deficient units. The general safety index of the lifestyle street units on the east side of the study area is lower than that of the other units, and the level of pedestrian safety is the worst. Secondly, the convenience of street pedestrian spaces is poor and has significant variability. In the western part of the study area, there are parts of the road network that are compact where aggregation presents a superior level of convenience. Further, in the north side of the lifestyle streets, the overall score for pedestrian convenience is low. Thirdly, the comfort indices within the study area are generally distributed in the ranges of 0.447–0.650 and 0.651–1.000. The overall street pedestrian space has a high level of comfort. The highest scores for pedestrian comfort were found in the street units in and around Zhongshan Avenue on the western side of the study area.
The scores of the street units are mainly distributed in the ranges of 0.298–0.461 and 0.447–0.650, with the SPE showing a relatively good performance. Shared streets such as Zhongshan Avenue on the west side of the study area have the highest SPE scores, while the scores of the street units on the east side of the study area is lower than that of the other units, and the level of pedestrian safety is the worst. Secondly, the convenience of street pedestrian spaces is low. Thirdly, the comfort indices within the study area are generally distributed in the ranges of 0.537–1.000, with the SPE showing a relatively good performance.

The scores of the street units are mainly distributed in the ranges of 0.298–0.461 and 0.537–1.000, with the SPE showing a relatively good performance. Shared streets such as

**Figure 9.** Evaluation results of primary indicators for SPE: (a) safety C₁; (b) convenience C₂; (c) comfort C₃.

**Figure 10.** Comprehensive evaluation results of SPE.

The comprehensive evaluation findings of the SPE were obtained based on the evaluation of safety, convenience and comfort, and the normalised scores are given in Figure 10. The scores of the street units are mainly distributed in the ranges of 0.298–0.461 and 0.537–1.000, with the SPE showing a relatively good performance. Shared streets such
as Zhongshan Avenue on the west side of the study area have the highest SPE scores, while living streets on the east and northeast sides of the study area have the worst SPE performance.

The spatial structure of the walking score shows a clear circle characteristic, with the score decreasing from the west side to the east side of the study area (Figure 11a). The spatial distribution of street function mix ranges from 0.353 to 0.829, with a low mix on the west side and a high mix on the east side, and a low mix of commercial and transport-oriented streets and a high mix of living and shared streets (Figure 11b).

![Figure 11](image1.png)  
**Figure 11.** Evaluation results of street pedestrian attractiveness indicators: (a) street walk score $X_{21}$; (b) street function mix $X_{22}$.

The level of SPA is relatively high and evenly distributed, with scores mainly in the 0.205–0.392 and 0.507–1.000 ranges (Figure 12). Commercial streets that scored in the high range of 0.507–1.000 were the most pedestrian-friendly, while lifestyle and transport streets scored the lowest and were the least pedestrian-friendly.

![Figure 12](image2.png)  
**Figure 12.** Comprehensive evaluation results of SPA.

The street units in the study area exhibit good SPF, and the spatial structure demonstrates the distribution characteristics of high friendliness of commercial streets, low friendliness of living streets and traffic streets, high friendliness of streets that have been planned and renewed and low friendliness of unreconstructed streets (Figure 13).
4.2. Distribution Characteristics of SPU

Figures 14 and 15 show the results of SPU. The results of the week-long use of street units in the study area range from 24,429.055 to 1871.013, with the majority of streets having a total of approximately 6821–12,418 users per week per unit length of street. The higher the road class of the street unit, the more pedestrian traffic there is. The highest street pedestrian satisfaction scores were found in commercial streets, with over 80% of streets scoring over 9.

Figure 14. Evaluation results of SPU indicators: (a) pedestrian flow $Y_1$; (b) passage frequency $Y_2$; (c) walking satisfaction $Y_3$; (d) street activities richness $Y_4$. 
Overall, the study area shows significant variation in SPU, with scores predominantly distributed between 0.514 and 1.000 in commercial streets and only 0.219–0.392 in lifestyle streets.

4.3. Comprehensive Evaluation of SPF–SPU Matrix

4.3.1. SPF–SPU Grading Evaluation Results

Using the natural breakpoint method, the normalised SPF and SPU evaluation findings were classified as high (0.000–0.290), middle (0.291–0.560) and low (0.561–1.000). Figure 16 shows the results of the grading.

The study area’s SPF and SPU classifications show substantial consistency and diversity, particularly at the high and middle friendliness and high and middle demand levels. The distribution of SPF is observed on commercial and traffic streets. There are, however, certain areas with little demand and low real usability. The general SPF of living streets is bad, and there is a mismatch problem with the high demand, middle demand problem indicated by the SPU. Furthermore, the SPF has a negative impact on SPU in the research area.
4.3.2. SPF–SPU Matrix Evaluation Results Distribution

Based on the correlation and differential characteristics of the degree of street friendliness and demand, we analysed and reclassified the potential level of pedestrian demand and street service potential into five types based on the comprehensive evaluation matrix of SPF–SPU (Figure 17).

Figure 17. Reclassified SPF–SPU evaluation matrix.

Figure 18 shows the result of the matrix evaluation after classification. According to the findings, the majority of the streets in the research region are mid-demand–low-friendliness, low-demand–low-friendliness streets needing improvement and mid-demand–mid-friendliness and low-demand–mid-friendliness life-commuting streets. The degree of street pedestrian friendliness is higher in commercial and shared streets, but the level of demand is polarised, with low-demand–high-friendliness and high-demand–high-friendliness streets dominating. In lifestyle streets, the general level of demand and friendliness is low.

Figure 18. SPF–SPU matrix evaluation results.
5. Discussion

5.1. Discussion

Based on the complete streets design concept, this study constructs a complete set of full-factor quantitative SPF evaluation systems and provides the SPU assessment concept and the SPF–SPU comprehensive matrix analysis approach. The study provides an all-around and multi-level quantitative evaluation of urban street pedestrian space and fully realises the practical relevance of the complete street. The results within the Jianghan Road and Zhongshan Avenue neighbourhoods of Wuhan show that:

(1) In terms of SPF evaluation, the street pedestrian space in the study area has significant deficiencies in terms of not having separate non-motorised lanes, motor vehicles encroaching on the pavement, insufficient effective width of the pavement, long distances between facilities and uneven types of facilities, which seriously affects SPF. This is similar to the results of a previous study in another city, Barranquilla [57]. However, unlike the results of the Bogota study, the findings of our study show that the distribution of basic pedestrian infrastructure performs poorly in both commercial-oriented streets where the rich are active and in lifestyle-oriented streets where the poor are active, with the exception of Zhongshan Avenue and Jianghan Road [12]. The pedestrian walkways of Zhongshan Avenue and Jianghan Road, which serve as the skeleton of the Protection Plan for the Historic and Cultural Neighborhoods in the Jianghan Road and Zhongshan Avenue areas of Wuhan City implemented in 2016, have significantly better SPF than other areas but still lack some transportation facilities.

(2) With regard to the evaluation of SPU, previous research has shown that much more street space is dedicated to motorised traffic in low-income districts and less to pedestrians [58]. Similarly, our findings show that SPU is significantly higher in commercial-oriented streets where rich people congregate than in lifestyle-oriented streets and transportation-oriented streets, even though lifestyle-oriented streets have a richer variety of activity types. In contrast, among the areas where the rich gather, represented by Zhongshan Avenue and Jianghan Road, which are well-served by public transportation and have a good pedestrian environment, pedestrians are more willing and satisfied to engage in activities in the area, thus showing a higher level of SPU.

(3) In terms of the matrix evaluation results, the types of streets after classification are mainly mid demand–low friendly, low demand–low friendly streets in need of urgent improvement and mid demand–mid friendly, low demand–mid friendly streets for commuting in daily life. These areas tend to have a low number of residences, dilapidated street environments and low pedestrian demand. The pedestrian-friendly environment of the street cannot meet the needs of pedestrians during holidays and breaks when the city is flooded with all kinds of people. There is an “oversupply” distribution of high demand–low friendliness and high demand–mid friendliness. However, during normal working hours, the place is unoccupied and the space is seriously wasted.

At the same time, the results of the study in Wuhan City show that the SPF evaluation system proposed in this paper can effectively identify the outstanding problems of street pedestrian space. The combination of the SPF–SPU matrix can effectively identify pedestrian-unfriendly spaces that need to be improved and can provide constructive advice for the development of strategies to optimise actual street spaces.

5.2. Optimisation Strategies and Planning Recommendations

5.2.1. SPF Enhancement Strategy

We summarise the problems affecting SPF in the study region from two perspectives, SPE and SPA, and propose strategies for optimizing street walking space (Tables 5 and 6).
Table 5. SPE problems and optimization strategies.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>SPE Problems</th>
<th>Optimization Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>No independent non-motorised lanes, motor vehicles encroaching on sidewalks, rim ramps not set or not qualified, blind alleys are missing and badly damaged.</td>
<td>Pay attention to traffic demand and reasonably set up non-motorised lanes, reasonably plan motor vehicle parking space and entrances and exits, repair and update the edge ramps to weaken the road height difference, safe and continuous barrier-free facilities and set up clear signage facilities.</td>
</tr>
<tr>
<td>Convenience</td>
<td>Discontinuous sidewalks, uneven distribution of public transportation and lack of supporting facilities, insufficient effective width of sidewalks.</td>
<td>Reasonably increase the number of public transportation stations, improve station facilities, expand pedestrian space, ensure reasonable sidewalk width and provide additional street-crossing facilities.</td>
</tr>
<tr>
<td>Comfort</td>
<td>Low permeability of interface, lack of greenery, insufficient number of resting facilities, pavement to be improved.</td>
<td>Reasonable planning of the ground floor interface with permeable sight lines, good lighting facilities, increased rest facilities, improved landscape environment of the street and improved pavement quality.</td>
</tr>
</tbody>
</table>

Table 6. SPA problems and optimization strategies.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>SPA Problems</th>
<th>Optimization Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street walk score</td>
<td>Large differences in facility density, lengthy distances between facilities and disparities in facility kinds.</td>
<td>Reasonable allocation of different types of service facilities, increasing the density of facilities and shortening the distance between facilities.</td>
</tr>
<tr>
<td>Street function mix</td>
<td>High functional similarity of street facilities and single character of land use.</td>
<td>Enrichment of facility types and diversified mixed land use.</td>
</tr>
</tbody>
</table>

5.2.2. Street Classification and Control Strategy

The reclassified streets are graded according to the direction and necessity of street pedestrian space expansion, and the streets of different grades are classified and controlled based on the results of matrix analysis. According to the street kinds and demands, street classification and control can provide more effective and reasonable pedestrian-friendliness development options. The four factors of classed streets are as follows.

The first priority is high-demand streets that are in urgent need of SPF improvements. Pedestrian conflicts are most prominent on high-demand–low-friendliness and high-demand–mid-friendliness streets, which are less pedestrian-friendly but have a high number of pedestrian users and prospective pedestrian demand. As a result, they are given first priority for retrofitting. These streets are located near public service facilities, such as major public venues, squares and green spaces and commercial pedestrian streets. Their service level cannot satisfy the high level of external demand, resulting in issues such as insufficient effective sidewalk width and motor vehicles crowding the pedestrian space in the streets. The demand for regional street pedestrian space can be fully assessed and road resources can be reasonably allocated in the subsequent optimization and improvement process, which can make full use of the surrounding vacant roads for reasonable traffic diversion and slow down the traffic pressure of single-street space.

The second priority involves streets that urgently need to be made more pedestrian-friendly. This category contains four types of streets, all of which are primarily living streets: mid demand–low friendliness, low demand–low friendliness, mid demand–mid friendliness and low demand–mid friendliness. These streets have a poor pedestrian environment as well as a lack of services and facilities to attract internal pedestrian traffic, resulting in a low degree of pedestrian friendliness and usability. We may then enlarge the street area, widen the sidewalks, improve pedestrian accessibility and add service facilities based on the demands of the street during the future optimization and enhancement phase. This will improve the street’s pedestrian friendliness and improve the degree of pedestrian demand and usability.
The third priority is pedestrian-friendly streets that rely on their friendliness to generate service possibilities. This group contains streets with mid demand–high friendliness and low demand–high friendliness, primarily shared streets and some commercial streets. These streets have great street service potential; however, it has yet to be exploited owing to traffic accessibility and facility kinds. The potential for street service can be fully realised by introducing various types of street service facilities, increasing public transportation stops, improving road accessibility and relying on excellent pedestrian friendliness to attract external pedestrian traffic.

The fourth priority is high-demand and high-quality streets that maintain the status quo. These are high friendliness–high-demand streets, including commercial streets, streets around historic districts and streets that have been renewed. They have a high pedestrian demand while also providing excellent street pedestrian friendliness, and the current street pedestrian space and accompanying services are part of a virtuous cycle process. Therefore, following usage, we should pay attention to the regular maintenance and improvement of the street pedestrian environment and change dynamically based on demand to continuously maintain excellent street pedestrian friendliness and usability.

6. Conclusions

With the development of urbanization, the function of street space is no longer limited to the basic function of traffic passage, and the demand for street pedestrian users is progressively rising. The objective and quantitative evaluation of the friendliness of street walking, as well as the targeted development of street pedestrian space, has emerged as the primary focus of urban street space construction.

Based on the complete streets design concept, this study constructs a set of full-factor quantitative SPF evaluation systems and provides the SPU assessment concept and the SPF–SPU comprehensive matrix analysis approach. With the use of big data, this evaluation approach supports urban planning managers in making the most of limited street space resources, as well as providing theoretical and statistical support for the transformation and renewal of street walking space. As a result, it contributes to providing pedestrians with safer, more pleasant, convenient and diversified street walking spaces, increasing street walking usability, improving the vibrancy of urban streets and beautifying the image of cities and streets.

At present, the construction of complete streets and the evaluation of street pedestrian space are still in the exploratory stage. The research results for Jianghan Road and Zhongshan Avenue prove the feasibility of this approach. Wuhan is an advanced metropolis with a long history, developed transportation and a large population. It has a complex and diverse urban spatial environment that is representative of the rapidly developing cities of central China. These representative characteristics ensure that the research results obtained for Wuhan can be extended to similar cities.

At the same time, there are several limitations to this study. First, due to the limitation of the time when the research was conducted, there were inconsistencies between the collection time of cellular signalling data and questionnaire data and other data. Second, there are more professional fields involved in the study, and we are not professional enough in the way of index quantification. Finally, we evaluated the SPF of different types of streets in the study area with uniform criteria; however, in real life, different types of streets have different characteristics and needs. A variety of data collection and evaluation methods will be attempted in subsequent studies to increase the accuracy and credibility of the study.

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**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

**Appendix A**

This section supplements the coefficients and methods used in the calculation of SPF evaluation in Section 3 of the research methods.

1. **Evaluation indicators of SPE**

Tables A1–A5 show the calculation methods and grading of all the coefficients involved in the SPE evaluation.

**Table A1. Safety coefficient.**

<table>
<thead>
<tr>
<th>Isolation Methods</th>
<th>No Isolation</th>
<th>Scribing Isolation</th>
<th>Spatial Isolation</th>
<th>Physical Isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Coefficient $\alpha$</td>
<td>0</td>
<td>0.6</td>
<td>0.9</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table A2. Width coefficient.**

<table>
<thead>
<tr>
<th>Sidewalk Width Types</th>
<th>Width $= 0$</th>
<th>$0 &lt; \text{Width} &lt; \text{Normative Minimum}$</th>
<th>$\text{Width} \geq \text{Normative Minimum}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width Coefficient $\beta$</td>
<td>0</td>
<td>0.9</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table A3. Facility coefficient.**

<table>
<thead>
<tr>
<th>Facility Configurations</th>
<th>No Stations</th>
<th>Not Equipped</th>
<th>Partially Equipped</th>
<th>Fully Equipped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility Coefficient $\mu$</td>
<td>0</td>
<td>0.1</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table A4. Street interface coefficient.**

<table>
<thead>
<tr>
<th>Street Interface</th>
<th>Closed Interface</th>
<th>See-through Interface</th>
<th>Translucent Interface</th>
<th>Transparent Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface Coefficient $\epsilon$</td>
<td>0</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table A5. Pavement coefficient.**

<table>
<thead>
<tr>
<th>Sidewalk Pavement Condition</th>
<th>Pavement Does Not Meet the Requirements</th>
<th>Pavement Meets the Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Coefficient $\gamma$</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
2. Evaluation indicators of SPA

Walk score is a walking possibility metric developed by American academics in 2007, which incorporates factors such as distance decay, block length and road intersection density and may effectively indicate the pedestrian attractiveness of streets [59]. Considering streets provide regional services, POIs within the 500 m buffer zone on both sides of the street are chosen for computation in this study. POIs are classified into nine categories and allocated varying weight coefficients based on the current fundamental calculation method of walk score (Table A6). The POIs within 500 m on both sides of the roadway are then separated into three levels based on distance using the typical walking pace in the regular season, and the influence coefficients of each level are displayed in Table A7.

Table A6. POI facility classification and weights.

<table>
<thead>
<tr>
<th>POI Type</th>
<th>Weight</th>
<th>POI Type</th>
<th>Weight</th>
<th>POI Type</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accommodation</td>
<td>2</td>
<td>Recreation</td>
<td>3</td>
<td>Hospitals and Schools</td>
<td>2</td>
</tr>
<tr>
<td>Restaurants</td>
<td>3</td>
<td>Public Transportation</td>
<td>2</td>
<td>Sports Facilities</td>
<td>1</td>
</tr>
<tr>
<td>Living Services</td>
<td>2</td>
<td>Parks and Squares</td>
<td>1</td>
<td>Others</td>
<td>1</td>
</tr>
</tbody>
</table>

Table A7. Influence coefficient for different POI distance.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;100</td>
<td>100–300</td>
<td>300–500</td>
</tr>
<tr>
<td>Influence Coefficient</td>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

To produce the walk score for each street unit, the weights and influence coefficients of the various categories were superimposed.

\[
C_4 = \sum_{i=1,k=1}^{m,n} (W_i \times D_{i,k})
\]  

where \( W_i \) is the facility weights, \( D_{i,k} \) is the influence coefficient of the facility, \( i \) is the different types of facilities and \( k \) is the walking distance of different types of facilities.

Appendix B
Street Pedestrian Usability Research Questionnaire

Hello, we are a research team from XX University. We are currently conducting research related to the pedestrian space in the historic district of Jianghan Road and Zhongshan Avenue and would like to conduct a brief interview with you. This questionnaire is anonymous and the data obtained will only be used for statistical analysis and will not be used for other purposes.

With the continuous improvement of public transport and street space in cities, pedestrian transport is now an important mode of transport. There is a growing public interest in the friendliness of street walking. We would like to use this questionnaire to find out how you feel about walking on your current street and to find out more about your needs and experiences of street pedestrian space. This will help us to improve the pedestrian space in the streets.

1. The number of times per week you walk through your street is ____.  
2. How would you rate your satisfaction with walking in your current street? (out of 10)  
   Your score is ____.  
3. How would you rate safety, convenience and comfort of walking in your current street? (out of 10)  
   Your score for street safety is ____.  
   Your score for street convenience is ____.
4. Which aspect of street safety, convenience or comfort do you value most in your use? Please rank according to your level of importance (rank can be repeated)

| Safety | Convenience | Comfort |

5. Which of the following types of behaviour or activities have you carried out in your street? (multiple choice)

- rest
- conversation and communication
- sports and exercise
- chess and card games
- shopping
- restaurants
- gatherings
- games and entertainment
- sightseeing and tourism
- reading

Appendix C

This section is supplemented with the evaluation results and analysis of SPE secondary indicators.

The results of the evaluation of street pedestrian safety indicators are shown in Figure A1. Only two street units in the study area have separate non-motorised lanes, with the average length of non-motorised lanes on both sides of the street accounting for 14.80% and 46.60% of the total length of the street unit, respectively, both of which are less than half of the total length of the street. They are concentrated in the shared streets on the north side of the study area. At the same time, the degree of pavement occupation ranges from 0.00% to 17.40%; i.e., 0–3 motor vehicles may encroach on the pavement for every 50 m of street space. Further, the commercial streets on the west side of the study area have the lowest level of encroachment and the lifestyle streets on the east and northeast sides have the highest level of encroachment. The pavement segregation safety index in the study area is mainly in the range of 0.786–0.924. Based on the segregation coefficient, it can be seen that the majority of streets use spatial segregation to raise the pavement by 5–10 cm to separate the pavement.

Figure A1. Cont.
Figure A1. Evaluation results of safety indicators for street pedestrian environment: (a) street motorization degree $X_1$; (b) non-motorised road settings $X_2$; (c) sidewalk occupation degree $X_3$; (d) sidewalk divider security $X_4$; (e) rimstone ramp integrity $X_5$; (f) blindside integrity $X_6$; (g) street surveillance degree $X_7$.
Figure A2 shows the results of the evaluation of each index of street walking convenience. The pavement continuity index of each street unit in the study area generally ranges from 0.000 to 0.024, and there are generally only 0–1 interruption points, which basically ensure the continuity of street walking. The total length of roads per unit area within the 300 m buffer zone of the study area ranges from 0.525 to 4.038; i.e., for every 1 m² of street space in the study area, there are 0.525 to 4.038 m of roads serving the street. The average effective width ratio of pavements on both sides of the street ranges from 16.40% to 100.00%. The total length of pavement meeting the regulatory width requirements is above 85.3% in most streets, and above 50% in the vast majority of streets, with an overall high level of accessibility. The pavement setting index per unit length in the study area ranges from 0.000 to 0.030, with a general performance between 0.001 and 0.009, with an average of one pedestrian crossing every 142.8 m. The installation spacing is in line with the installation requirements in the Guidelines.

Figure A3 shows the results of the evaluation of street walking comfort indicators evaluation. The overall street interface permeability in the study area is greater than 44.10%, with the interfaces on both sides of the street space exhibiting penetrating and translucent interfaces. The sky visibility of most streets is distributed between 12.30% and 16.80%, and the visibility of the street sky is low, especially in the living streets on the east side of the study area. The pedestrian greenery and greenery coverage are distributed between 0.20–52.70% and 0.40–89.20%, with a maximum of 0.892 m² of shade per 1 m² of street in summer and a minimum of 0.004 m². The commercial streets on the west and south sides of the study area have the worst performance in terms of greenery and greenery coverage. The pavement integrity is mainly distributed between 61.60% and 84.00%, with more than 60% of the length of the pavement on both sides of the street pedestrian space being kept intact and clean, neat and orderly.
100.00%. The total length of pavement meeting the regulatory width requirements is above 85.3% in most streets, and above 50% in the vast majority of streets, with an overall high level of accessibility. The pavement seating index per unit length in the study area ranges from 0.000 to 0.030, with a general performance between 0.001 and 0.009, with an average of one pedestrian crossing every 142.8 m. The installation spacing is in line with the installation requirements in the Guidelines.

**Figure A2.** Evaluation results of convenience indicators for street pedestrian environment: (a) sidewalk continuity X8; (b) public transportation accessibility X9; (c) road accessibility X10; (d) sidewalk effective width ratio X11; (e) crosswalk spacing X12; (f) public transportation station integrity X13.

Figure A3 shows the results of the evaluation of street walking comfort indicators evaluation. The overall street interface permeability in the study area is greater than 44.10%, with the interfaces on both sides of the street space exhibiting penetrating and translucent interfaces. The sky visibility of most streets is distributed between 12.30% and 16.80%, and the visibility of the street sky is low, especially in the living streets on the east side of the study area. The pedestrian greenery and greenery coverage are distributed between 0.20–52.70% and 0.40–89.20%, with a maximum of 0.892 m² of shade per 1 m² of street in summer and a minimum of 0.004 m². The commercial streets on the west and south sides of the study area have the worst performance in terms of greenery and greenery coverage. The pavement integrity is mainly distributed between 61.60% and 84.00%, with more than 60% of the length of the pavement on both sides of the street pedestrian space being kept intact and clean, neat and orderly.

**Figure A3. Cont.**
Figure A3. Evaluation results of comfort indicators for street pedestrian environment: (a) interface transparency $X_{14}$; (b) sky visibility $X_{15}$; (c) pedestrian green vision $X_{16}$; (d) greenery coverage $X_{17}$; (e) rest facility integrity $X_{18}$; (f) sanitation integrity $X_{19}$; (g) sidewalk pavement integrity $X_{20}$.

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