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Enhancing Urban Riverside Greenways through Post-Occupancy Evaluation: A Case Study of the Yangtze River Greenway in Wuhan

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KEYWORDS

post-occupancy evaluation,
urban riverside greenway,
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yangtze river

ABSTRACT

In today's commitment to achieving the goal of double carbon and advocating low-carbon life, the riverside greenway, as an important ecological public space in the urban center, plays an important role in improving the quality of life of residents, optimizing the urban transportation structure, restoring the water environment ecology, and further building a low-carbon city. Based on the post-occupancy evaluation of the built environment, this paper takes the Wuchang Greenway, Qingshan Greenway and Hongshan Greenway on the Yangtze River in Wuhan as the research objects, comprehensively evaluates the built environment of the three greenways from the aspects of user behavior characteristics and post-use satisfaction, compares and analyzes the advantages and shortcomings of the three greenways according to the evaluation results, and proposes some optimization strategies for the design of urban riverside greenways.

1. Introduction

1.1. Research Background

The construction of ecological civilization has promoted the development of ecological value theory, prompting a significant change in people's ideological concepts from conquering nature to harmonious coexistence between man and nature [1]. During the "14th Five-Year Plan" period, China's ecological civilization construction has entered a key period focusing on decarbonization, aiming to achieve a qualitative change in the improvement of ecological environment quality from quantitative change to qualitative leap, thus proposing the "dual carbon" strategy of striving to reach peak carbon dioxide emissions before 2030 and striving to achieve carbon neutrality before 2060 [2]. Under the "dual carbon" background, it is particularly important to build a public space that is harmonious and integrated with nature. Many scholars have conducted relevant researches, such as Liu Yueqin and Lin Xuanquan exploring how to create a scientific urban waterfront greenway to achieve a balance between public recreation and ecological sustainable development[3]; Zhang Dou pointed out the functions of waterfront trails in revitalizing urban areas, restoring ecological functions, and highlighting cultural heritage with the example of the waterfront area renewal and reconstruction plan made by Sasaki Company for Lujiazui[4]; Liu Shengwei, Ding Rong, and others summarized the role of urban greenways in regional urban development and thought and explored the practical direction of greenways in future urban renewal[5]. Based on the above, urban waterfront greenways, as linear open

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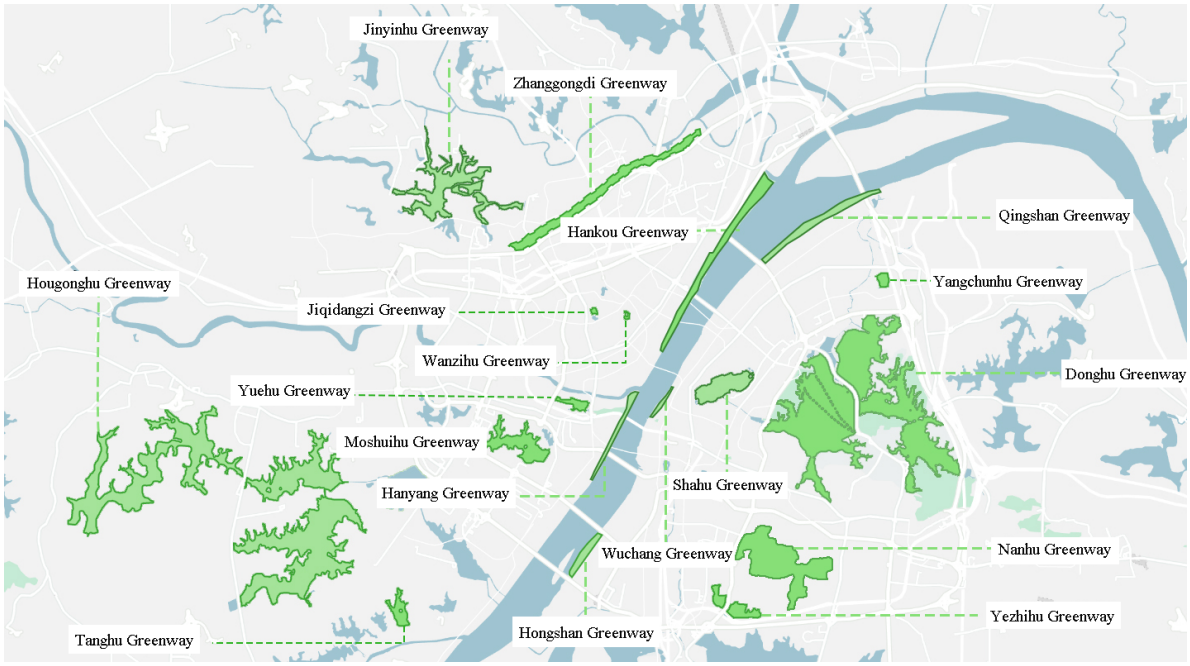

Fig. 1 Distribution of Wuhan's Riverside Greenways

spaces integrating ecological, recreational, social, and economic functions, have a great impact on improving environmental quality, optimizing urban traffic structure, and enhancing the integrity of urban space. Therefore, high-quality urban greenways require specific and effective evaluation, and based on this, more reasonable optimization suggestions can be put forward.

The most common and scientific method for evaluating the built environment of public space in China is the post-occupancy evaluation. In this regard, Liang Chen and Zeng Jian used environmental psychology to conduct post-occupancy evaluations on three waterfront spaces in Tianjin, and found problems in the aspects of activities and facilities[6]; Dong Baoying and others conducted post-occupancy evaluations on Xuanwu Lake Park in Nanjing, summarized the factors affecting the quality of use of urban park water space, and proposed corresponding optimization strategies[7]. Based on this, this paper adopts post-occupancy evaluation as the research method, takes the Yangtze River greenway in Wuhan as an example for investigation and analysis, explores the common problems in the current construction of urban riverside greenways, and provides corresponding optimization strategies for decision-making reference for management departments.

1.2. Research Objects and Methods

1.2.1. Research Objects

Wuhan is an important riverside city, but with the acceleration of urbanization in the Yangtze River Basin, the continuous increase of urban development area, and the beginning of environmental problems such as decreased connectivity, shrinking wetland area, eutrophication of lakes, and high intensity of shoreline development[8]. Therefore, comprehensively improving and repairing the ecological environment of the Yangtze River Basin has become an indispensable task. The planning and construction of urban riverside greenways play an important role in improving the ecological environment of the Yangtze River. Since Wuhan officially started the construction of greenways in 2012, more than 2000 km of various types of greenways have been planned and constructed within ten years (Fig. 1). Among them, the planning and construction of the "Hundred-Mile Yangtze River Ecological Corridor" is the most eye-catching, and the construction of Hankou Greenway, Hanyang Greenway, Wuchang Greenway, Qingshan Greenway, and Hongshan Greenway has been completed, and future transformation and construction will continue, with the goal of achieving a hundred-mile riverside greenway shoreline connection by 2025.

This study selects the Qingshan, Wuchang, and Hongshan riverside greenways on the east side of the Yangtze River in Wuhan for the study, and evaluates the use and satisfaction of the three greenways. The research section is located within the third ring road of Wuhan, where the location is superior, transportation is convenient, the scenery is

beautiful, and the coast has commercial, cultural, and educational functions, which is the face of Wuhan, and at the same time, the population flow is large, and the composition of the crowd is rich, which is convenient for the survey, and the obtained data is more representative.

1.2.2. Research Methods

The study first conducted on-site measurements of the three selected riverside greenways, and at the same time, questionnaires were issued to the users of the three greenways to determine the users' satisfaction with each indicator in the evaluation system. Finally, combinations of qualitative and quantitative analysis methods were used to compare and analyze the current use of the three greenways, and then summarize the advantages and disadvantages of the current riverside greenway construction and propose some optimization suggestions.

2. Construction of Wuhan Riverside Greenway Use Evaluation System

2.1. Construction of POE Evaluation System

2.1.1. Selection of Indicators

This paper combines AHP and SD methods for the evaluation of the use of riverside greenways, with the use of riverside greenways as the target layer, and the location conditions, slow traffic system, landscape system, service system, and functional facility system as the criteria layer. It summarizes and screens the adjective pairs used in related research at home and abroad using the SD method, and finally selects 24 indicators and corresponding adjective pairs as shown in Table 1.[9–11].

Table 1. Evaluation Indicators - Hierarchical Model

Target Layer	Criteria Layer	Factor Layer	Adjective Group
City Riverside Greenway Use Situation Evaluation	Location Condition	Accessibility	Accessible-Inaccessible
		Prosperity	Remote-Prosperous
		Transport Convenience	Inconvenient-Convenient
		Parking Lot	Scarce-Abundant
	Slow Traffic System	Road Width	Narrow-Wide
		Environmental Hygiene	Messy-Neat
		Node Continuity	Broken-Continuous
		Node Interest	Boring-Interesting
		Historical and Cultural Value	Low-High
		Safety	Dangerous-Safe
	Landscape System	Landscape Diversity	Scarce-Rich
		Plant Coverage Rate	Low-High
		Aquaticity	Close-Distant
		Water Quality	Poor-Good
	Service System	Sales Station	Scarce-Abundant
		Public Toilet	Scarce-Abundant
		Service Point	Scarce-Abundant
		Trash Can	Scarce-Abundant
		Visibility	Hidden - Obvious
	Functional Facility System	Rest Facilities	Scarce-Abundant
		Lighting Facilities	Dim-Bright
		Signage	Poor-Good
		Diversity	Single-Diverse
		Aesthetics	Ugly-Beautiful

2.2. Calculation and Analysis of Weights

Considering the large amount of calculation in the Analytic Hierarchy Process (AHP), this paper uses the AHP calculation software yaahp to build a hierarchical model, input the expert's assignment values for the evaluation indicators into the software to generate a judgment matrix, and then adjust the data with inconsistencies to finally obtain the weights of each evaluation indicator and the consistency check results (Table 2).

The complete process for calculating and testing the weights of indicators is as follows:

a. Construct the Judgment Matrix: Use the matrix scaling method to quantitatively assign values to the evaluation factors in the constructed hierarchical analysis model according to data collection, expert opinions, and the experience of scientific researchers to obtain the corresponding judgment matrix.
b. Calculate the Weights of Each Indicator: Use formula (1) to calculate the weight value Wi for each evaluation factor.
c. Conduct Consistency Check on the Judgment Matrix: First, use formula (2) to calculate the Consistency Index C.I (denoted as σ(C.I) in the formula), and according to formula (3), the ratio of the C.I value obtained in formula (2) to the average random consistency index R.I (denoted as σ(R.I) in the formula) of the same order is called the upper-level consistency ratio C.R (denoted as σ(C.R) in the formula). When σ(C.R) < 0.1, it is considered that the consistency of the judgment matrix is acceptable, and the calculation result is reasonable and effective; otherwise, the judgment matrix needs to be corrected[12].

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{ij}} \tag{1}$$

$$\lambda_{max} = \frac{1}{n}\sum_{i}\frac{(AW)_i}{W_i} \tag{2}$$

$$\sigma(C.I) = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

$$\sigma(\text{C.R}) = \frac{\sigma(\text{C.I})}{\sigma(\text{R.I})} \tag{4}$$

Table 2. Weight Values and Consistency Check Values of Each Factor Layer of Riverside Greenway

Criteria Layer	Factor Layer	Factor Weight Wi Value	Consistency Check C.I Value
Location Conditions	Accessibility	0.4445	0.0267＜0.1
	Prosperity	0.2832	
	Transport Convenience	0.1072	
	Parking Lot	0.1651	
Slow Traffic System	Road Width	0.1753	0.0480＜0.1
	Environmental Hygiene	0.1920	
	Node Continuity	0.1141	
	Node Interest	0.1421	
	Historical and Cultural Value	0.1026	
	Safety	0.2739	
Landscape System	Landscape Diversity	0.1397	0.0456＜0.1
	Plant Coverage Rate	0.2748	
	Aquaticity	0.1981	
	Water Quality	0.3873	
Service System	Sales Station	0.1078	0.0441＜0.1
	Public Toilet	0.2490	
	Service Point	0.1705	
	Trash Can	0.1929	
	Visibility	0.2798	
Functional Facility System	Rest Facilities	0.2838	0.0482＜0.1
	Lighting Facilities	0.2508	
	Signage	0.1419	
	Diversity	0.2171	
	Aesthetics	0.1063	

Fig. 2 Location Map of Wuchang, Qingshan, and Hongshan Riverside Greenways in Wuhan

It can be seen from Table 2. that among the 24 selected indicators, the top 5 in weight ratio are safety, accessibility, environmental hygiene, trash cans, and road width. This indicates that the people-oriented design concept is a consensus, and the design of riverside greenways needs to meet the requirements of safety, accessibility, and comfort.

3. Wuhan Riverside Greenway Location Conditions and Spatial Features

3.1. "Lungs of the City" - Ribbon Park Built Along the River

3.1.1. Basic Overview of Wuhan Riverside Greenway

This paper selects the Hongshan Greenway, Wuchang Greenway, and Qingshan Greenway of Wuhan as the research subjects, which are important riverside ecological parks in Wuhan (Fig. 2). Among them, the Hongshan Greenway (from Yangsi Port Bridge to Baishazhou Bridge section) is a total length of 3120m and is an important node project of Wuhan's hundred-mile ecological and cultural corridor[13]. The Wuchang Greenway (between the Yangtze River Bridge and the Yangtze River Tunnel) is a total length of 1200m and is one of the earliest constructed sections of the Wuchang Greenway. The Qingshan Greenway (from Erqi Bridge to Tianxingzhou Bridge section) is a total length of 7500m. As a part of the main axis of the Yangtze River, it is the first "river, beach, city" three-in-one ecological greenway in Wuhan, the first "sponge" greenway in Hubei Province, and also the greenway with the highest greening ratio.

3.1.2. Surrounding Entertainment and Commerce

With the center of Hongshan Greenway as the center, there are no large commercial areas within a 1.5 km radius, and the area south of the greenway is mostly residential (Fig. 3). With the center of Wuchang Greenway as the center, there are no large commercial areas within a 1.5 km radius, and the area south of the greenway is mostly residential. There are tourist attractions such as Tanhualin, Hubuxiang, and the Revolutionary Museum around (Fig. 4). With the center of Qingshan Greenway as the center, there are two medium-sized commercial areas within a 1.5 km radius, and the area south of the greenway is mostly residential (Fig. 5).

3.1.3. Traffic Analysis

The public transportation of Hongshan Greenway mainly relies on Metro Line 11 (under construction), with 8-11 bus stations within 1 km of each entrance and exit (only two open entrances are recorded). The public transportation of Wuchang Greenway mainly relies on Metro Lines 2 and 5, with 5-19 bus station stops within 1 km of each entrance and exit. The public transportation of Qingshan Greenway mainly relies on Metro Line 5, with 10-21 bus station stops within 1 km of each en-

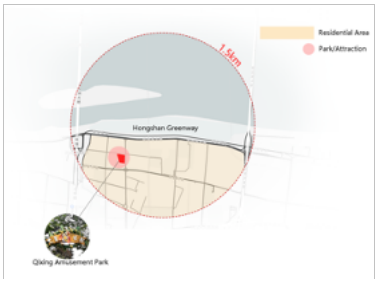

Fig. 3. Distribution Map of Entertainment and Commerce around Hongshan Greenway

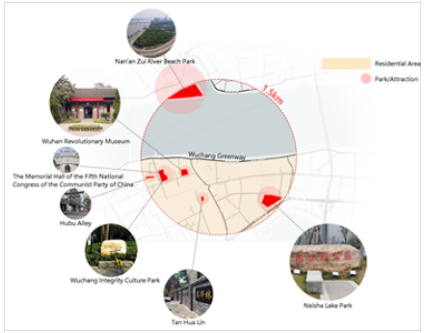

Fig. 4. Distribution Map of Entertainment and Commerce around Wuchang Greenway

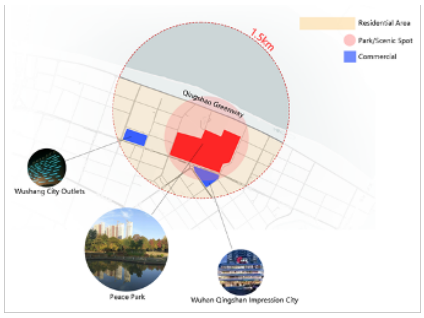

Fig. 5. Distribution Map of Entertainment and Commerce around Qingshan Greenway

trance and exit. Through the comparison in Table 3., it can be found that the convenience of Wuchang Greenway is higher than that of Qingshan Greenway, and Hongshan Greenway has the lowest.

3.2. "Quiet in the Bustle" - Linear Space under the Bustling City

3.2.1. "Three Zones and Three Belts" Features

In the long-axis direction, it consists of the sightseeing tour area, central square area, and leisure activity area, which are interconnected by landscape nodes. In the short-axis direction, it consists of the embankment viewing belt, leisure shade belt, and riverside feature belt, forming the "three belts"[9]. The embankment viewing belt is mainly planted with low shrubs, with some areas planted with trees; the leisure shade belt has a variety of plant types and is the area with the highest vegetation coverage, with Tingbu, small gravel paths, and trails as the traffic skeleton, connecting landscape, leisure and entertainment areas, and characteristic sculpture artworks, rest facilities; the riverside feature belt integrates high-platform viewing, platform

Table 3. Statistical Table of Public Transportation Station Information near Hongshan Greenway, Wuchang Greenway, and Qingshan Greenway

Entrance		Distance to the Nearest Subway Station (m)	Number of Subway Stations within 1.5km	Distance to the Nearest Bus Station (m)	Number of Bus Stations within 1km
Hongshan Greenway	Gate 1	1300 (under construction)	1 (under construction)	148	8
	Gate 2 (not open)	／	／	／	／
	Gate 3 (not open)	／	／	／	／
	Gate 4 (not open)	／	／	／	／
	Gate 5 (not open)	／	／	／	／
	Gate 6	1100 (under construction))	2 (under construction)	412	11
Wuchang Greenway	Main Entrance	575	3	111	18
	Gate 2	561	3	305	18
	Gate 3	542	3	587	5
	Gate 4	343	5	192	19
Qingshan Greenway	South Gate 1	1300	1	226	14
	South Gate 2	1300	2	239	10
	South Gate 3	950	1	142	19
	South Gate 4	904	1	87	21
	South Gate 5	1200	2	135	15
	South Gate 6	1100	1	120	15
	South Gate 7	995	1	120	14
	South Gate 8	1000	2	151	14
	South Gate 9	1100	2	365	18

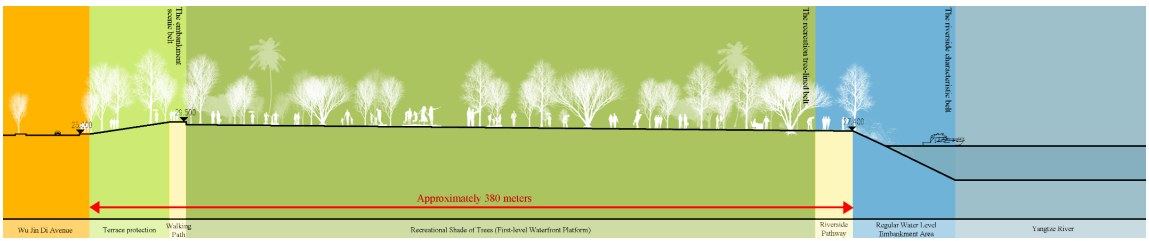

Fig. 6. Cross-sectional Analysis of Hongshan Greenway

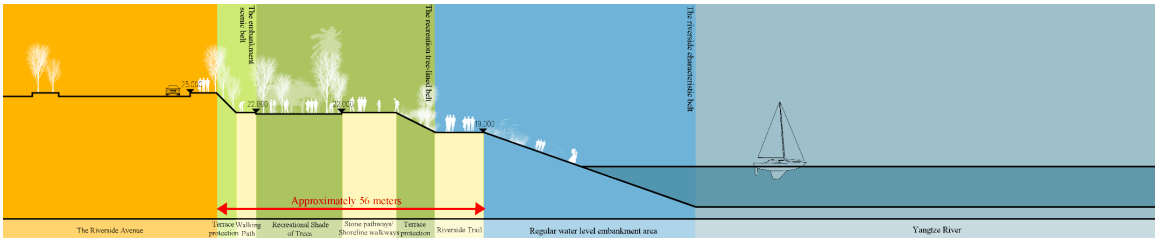

Fig. 7. Cross-sectional Analysis of Wuchang Greenway

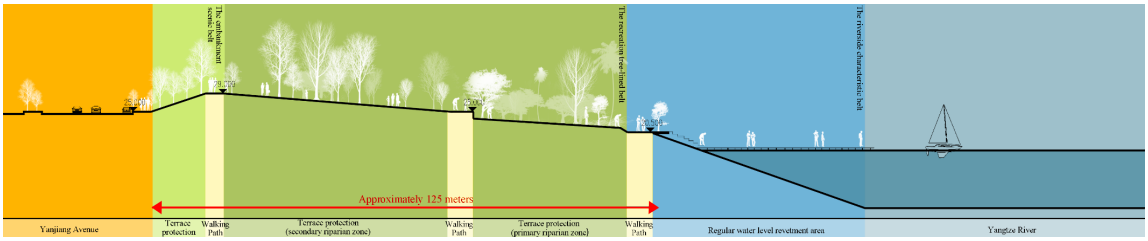

Fig. 8. Cross-sectional Analysis of Qingshan Greenway

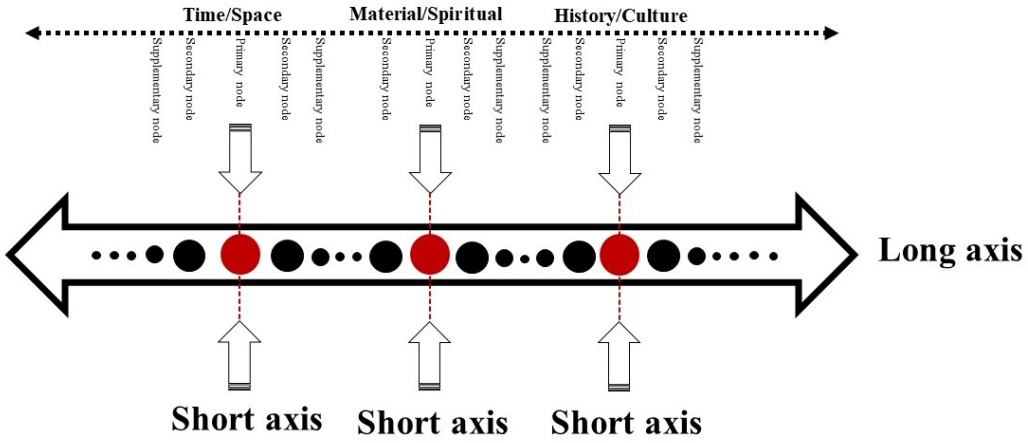

Fig. 9. Spatial Sequence of Ribbon Park

river viewing, and terrace water play, and is equipped with rest facilities along the way.

The overall pattern of the riverside greenway is "three zones and three belts". Wuchang Greenway has a short depth, steep slope, and fewer types of leisure compared to the other two greenways; Hongshan Greenway and Qingshan Greenway have a long depth and gentle slope, with ample space between the riverside trail and the street-side viewing trail to plant multi-level plants and set up a variety of leisure types (Fig. 6-8).

3.2.2. Linear Space Dominated by Square Nodes

In terms of spatial form, the riverside greenway is a linear space with a certain width, which is different from point-shaped and surface-shaped green spaces, and has continuous characteristics[14]. The three greenways all arrange the main nodes in the

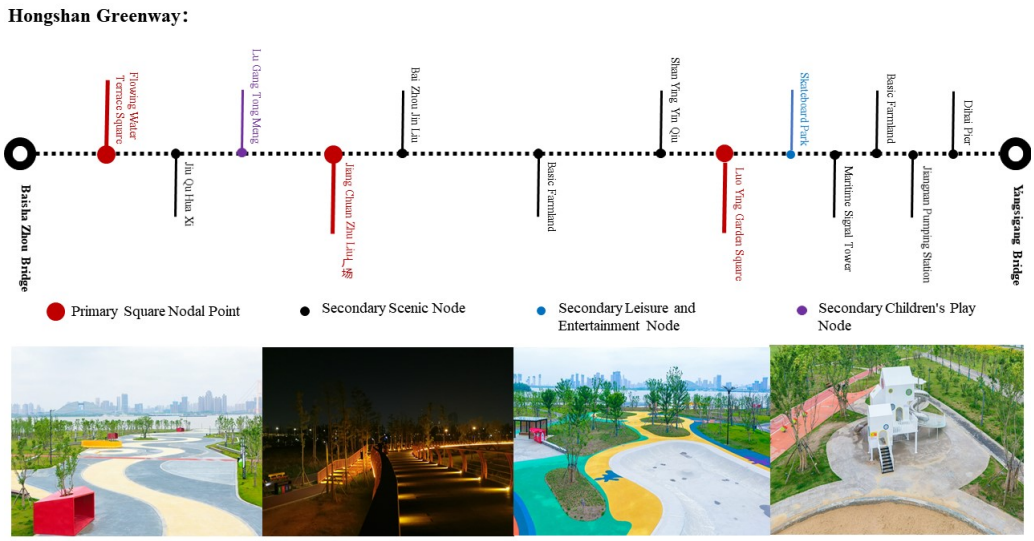

Fig. 10. Distribution Map of Nodes in Hongshan Greenway

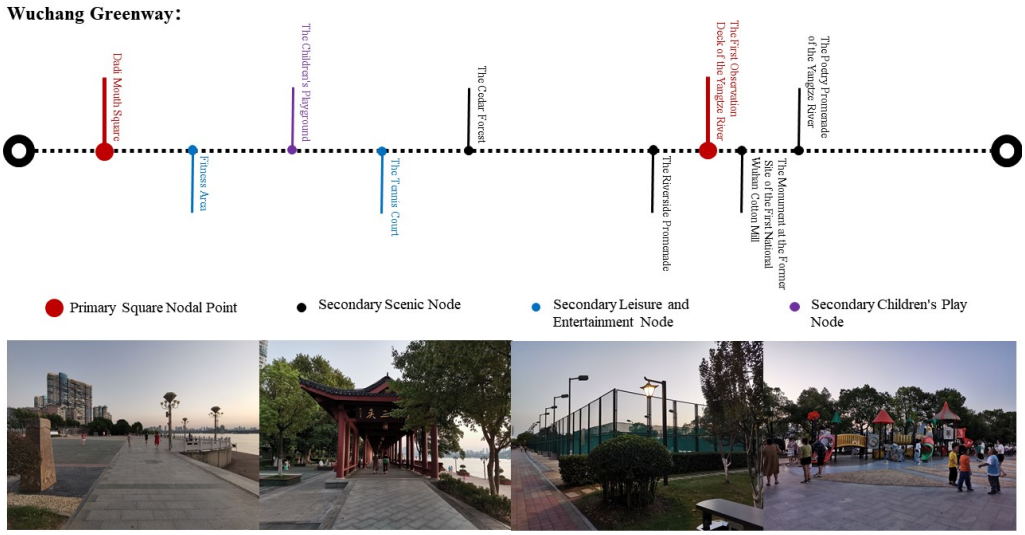

Fig. 11. Distribution Map of Nodes in Wuchang Greenway

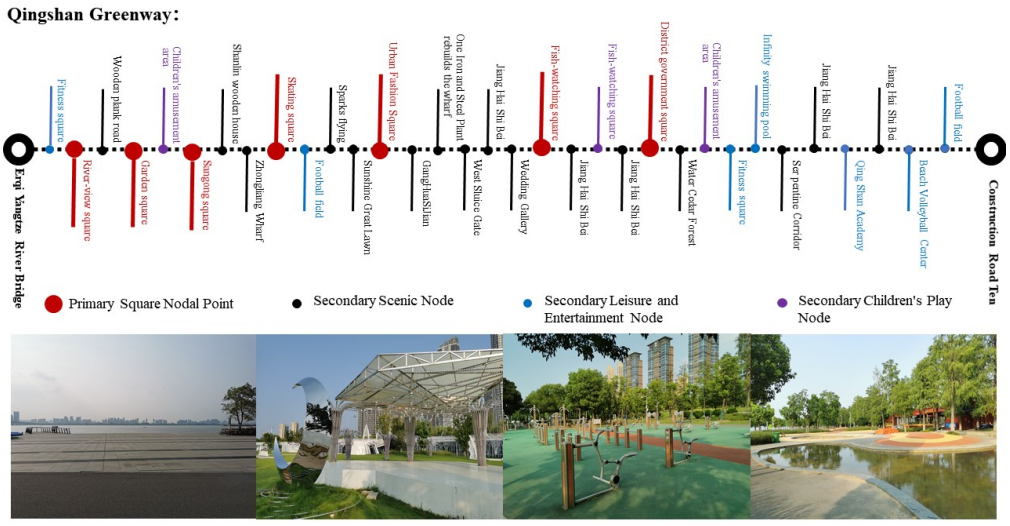

Fig. 12. Distribution Map of Nodes in Qingshan Greenway

long-axis direction, forming a spatial sequence dominated by square nodes, with landscape nodes, leisure and entertainment nodes, and children's play nodes as the second, and other supplementary nodes as the auxiliary (Fig. 9).

3.2.2.1. Diversified Node Types

Through field research, the nodes of the three riverside greenways are divided into four categories: square nodes, landscape nodes, leisure and entertainment nodes, and children's play nodes (Fig. 10-12). Among them, square nodes are often associated with entrances and exits, stations, public toilets, and other spaces, with large space and high passenger flow; landscape nodes add richness to the leisure route by combining cultural characteristics, setting landscape artworks, preserving historical docks and sluices, and special plant shapes; leisure and entertainment nodes include fitness squares, roller skating rinks, swimming pools, football fields, and other leisure and fitness venues, providing social space and enhancing physical fitness; children's play nodes are specially designed for children's play areas, stimulating the vitality of the park.

3.2.2.2. Continuous Spatial Sequence

The density of nodes and the way nodes transition will affect the formation of a continuous spatial sequence. Through the comparison in Table 4., it can be found that the node layout of Wuchang Greenway is relatively dense, with an average of one node every 133 meters. The node spacing of Hongshan Greenway is relatively far, about 238 meters. Overall, the proportion of landscape nodes is the highest, the proportion of children's play nodes is the lowest, and the proportion of square nodes is relatively average, around 21%. Among them, the proportion of landscape nodes in Hongshan Greenway is much higher than in the other two greenways, while the proportion of leisure and entertainment nodes is much lower than in the other two greenways, indicating that Hongshan Greenway focuses on landscape creation but neglects people's leisure and entertainment activities.

4. Current Survey of Wuhan Riverside Greenway

4.1. Slow Traffic System

The slow traffic system in the riverside greenway mainly includes pedestrian systems and sightseeing

Table 4. Node Statistics Table of Hongshan Greenway, Wuchang Greenway, and Qingshan Greenway

	Hongshan Greenway	Wuchang Greenway	Qingshan Greenway
Square Nodes	23.3%	22.2%	21.2%
Landscape Nodes	61.5%	44.4%	48.5%
Leisure and Entertainment Nodes	7.6%	22.2%	21.2%
Children's Play Nodes	7.6%	11.2%	9.1%
Total Number of Nodes	13	9	33
Node Spacing	About 238m	About 133m	About 227m

Table 5. Current Status of Green and Recreation System in Hongshan Greenway, Wuchang Greenway, and Qingshan Greenway

	Hongshan Greenway	Wuchang Greenway	Qingshan Greenway
Width of Leisure Shade Belt	245m	33m	89m
Rest Areas	Set along the landscape road, with a larger number	Set along the landscape road, with a smaller number	Set along the landscape road, with a spacing of about meters, with a larger number
Children's Play Areas	1	1	3
Plant Richness	Mainly shrubs, average plant richness		
Plant Neatness	Plant neatness is poor, with many areas lacking planning and trimming	Plant neatness is average, with dedicated staff for plant trimming	Plant neatness is good, with dedicated staff for plant trimming

car tour routes. There is no dedicated bicycle lane set up inside the greenway, and motor vehicles and non-motor vehicles are prohibited. The pedestrian system mainly includes embankment viewing trails, middle section leisure paths, and riverside trails, with sidewalk widths ranging from 2-6 meters. It can be seen from Figures 13-15 that Qingshan Greenway has the greatest number of trails, Wuchang Greenway has the fewest curves; Qingshan and Hongshan Greenways mainly feature winding and varied trails, yet daytime utilization is low due to insufficient shade. Wuchang Greenway opts for straight, direct sidewalks, resulting in high utilization.

4.2. Green and Recreation System

The current construction of the green and recreation system in Hongshan, Wuchang, and Qingshan greenways is shown in Table 5.

According to relevant information, when the width of the riverbank vegetation is greater than 30m, it can effectively reduce temperature, increase the supply of food for river organisms, and effectively filter pollutants. When the width is greater than 80-100m, it can better control sediment and soil element loss[10]. The widths of the riverbank vegetation in Hongshan, Wuchang, and Qingshan greenways are all greater than 30m, and the width of the riverbank vegetation in Hongshan Greenway is over 100m, with the best ecological regulation effect.

Overall, the green and recreation systems of the three greenways need to be further integrated and improved, with increased plant richness and enhanced maintenance and renewal of plants in the later period.

4.3. Service System

The greenway service system covers public service facilities, sales stations, public toilets, parking lots, etc. In the construction of greenways, the perfection of service facilities can bring a good experience to visitors[10]. The current construction of the service system in Hongshan, Wuchang, and Qingshan greenways is shown in Table 6.

Overall, the service facilities of the three greenways are inadequate, with existing facilities in small numbers, insufficient to meet user needs. It is essential to establish tourist information centers and medical first aid stations, as well as to incorporate sales kiosks or vending machines.

4.4. Greenway Signage System

The urban greenway signage system consists of signage carrier facilities and signs. The signage carrier facilities are composed of information walls, information strips, and information blocks, and the signs include seven categories: facility signs, directional signs, regulatory signs, warning signs, activity signs, safety signs, and educational signs[10]. The signage systems in Hongshan, Wuchang, and Qingshan greenways are relatively comprehensive, generally set at road forks or nodes, with obvious positions and clear and easy-to-understand signs. They basically meet the requirements.

4.5. Greenway Lighting System

The lighting system in the park greenway generally refers to the road lighting facilities and landscape lighting facilities at night. Through the application of lighting, it emphasizes the greenway axis, and enhances the ornamentality and characteristics of the signs, places, and special landscape nodes[10]. Hongshan Greenway mainly uses road lighting facilities along the way, and also has ground light

Table 6. Current Status of Service System in Hongshan Greenway, Wuchang Greenway, and Qingshan Greenway

	Hongshan Greenway	Wuchang Greenway	Qingshan Greenway
Tourist Consultation Service Center	0	0	0
Bicycle Rental Points	0	0	0
Parking Lot	4	1	7
Public Toilets	4	1	10
Sales Stations	3	3	6
Medical First Aid Points	0	0	0
Bus Stations	There are bus stations near the entrances and exits		

Fig. 13. Layout of Facilities in Hongshan Greenway

Fig. 14. Layout of Facilities in Wuchang Greenway

Fig. 15. Layout of Facilities in Qingshan Greenway

strips, luminous sculptures, etc., with a rich variety of lighting; Wuchang Greenway only meets the lighting of the main trails, with a single functional lighting facility and lack of attractiveness; Qingshan Greenway has complete lighting facilities, meeting the basic needs, with some changes in lighting types. In addition, all three greenways have a common shortcoming that the coverage of lighting is low. In addition to the main trails that can meet the lighting needs, the shaded paths and some landscape nodes lack lighting, and the overall feeling of the greenway at night is dim.

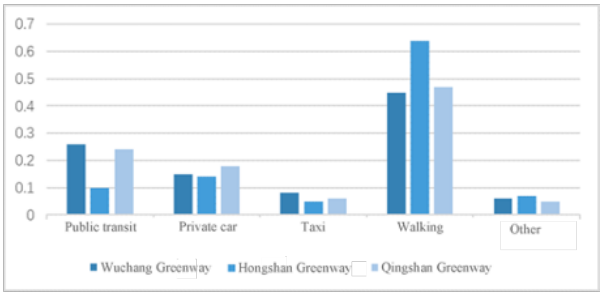

Fig. 16. Statistical Results of User Travel Methods

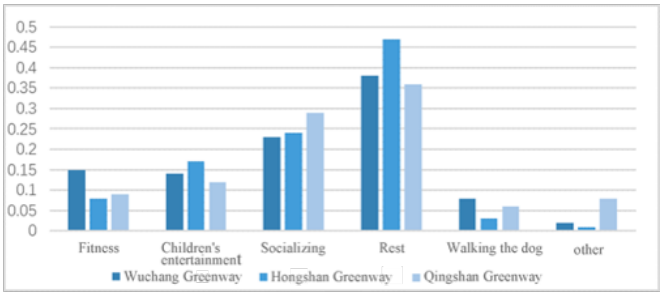

Fig. 17. Statistical Results of User Activity Preferences

5. Wuhan Riverside Greenway Use Evaluation and Analysis

5.1. Evaluation Based on User Behavior

5.1.1. Basic Information of Survey Respondents

After sorting out the questionnaires, it can be known that the gender ratio of users tends to be 1:1, most of them are local residents, and a few are tourists from other places. In terms of age composition, middle-aged and young people are also the majority, most of whom are office workers and students. In terms of travel methods, all three greenways are mainly on foot, which also indirectly reflects that the main users of the greenway are still the surrounding residents, among which the proportion of Hongshan Greenway users choosing to walk is the highest. The second is public transportation, but the proportion of public transportation travel in Hongshan Greenway is slightly lower than that of private cars, which is also related to the underdeveloped public transportation around Hongshan Greenway and the average convenience.(Fig. 16)

5.1.2. Time Rules and Activity Preferences

The research results show that the use time of users is mainly concentrated on weekends and holidays, and the morning and evening are peak periods, which just happens to be the time when students are dismissed from school and office workers get off work. For surrounding residents, it is a good time for leisure or exercise. The usage frequency of users is mostly once or twice a week or three to four times a week. Among the survey respondents of the three greenways, leisure, children's entertainment, and social interaction are the top three needs, which is related to the functional positioning of the riverside greenway and people's daily needs. (Fig. 17)

5.1.3. Analysis of Greenway Space Usage Characteristics Based on Behavior Maps

Behavior maps use different behavioral graphic symbols to record various types of behaviors in a place, which can be used to study the behavioral patterns of users and compare the actual usage with the intended situation. The record of the behavior maps this time were taken at dawn (6:30-7:30) and evening (18:30-19:30) on three weekends, which are also the peak flow times. The author has comprehensively organized the number of people using each functional area during the two time periods to finally obtain the behavior maps of the three riverside greenways.

Through Figures 18 to 20, among them, the greenway with the largest flow of people is Wuchang Greenway, followed by Qingshan, and finally Hongshan. The types of activities of the user groups include walking, running, fitness, leisure, children's entertainment, and stopping to enjoy the view. Walking and running as the main activities are widely distributed and relatively concentrated in some areas, such as the riverside walkways; leisure groups mainly stay on the rest seats next to the slow-moving paths; fitness groups are relatively few and mainly distributed in scattered fitness areas; children's entertainment activities are gathered in designated children's activity areas; people who stop and stay are distributed at nodes, mostly taking photos and viewing the river.

Overall, the three greenways have a high usage frequency and are in good condition, but there are also some problems. First, the utilization rate of some spaces is low. For example, fitness, as a main function attached to the greenway, is not frequently used in the fitness area of Wuchang Greenway. The main reasons are outdated facilities, average environmental hygiene, and poor visibility. Hongshan Greenway, due to its ongoing construction, has not yet formed a systematic fitness area and needs to be strengthened. The second issue is about the placement of rest seats. At present, the rest seats of Wuchang Greenway and Qingshan Greenway are

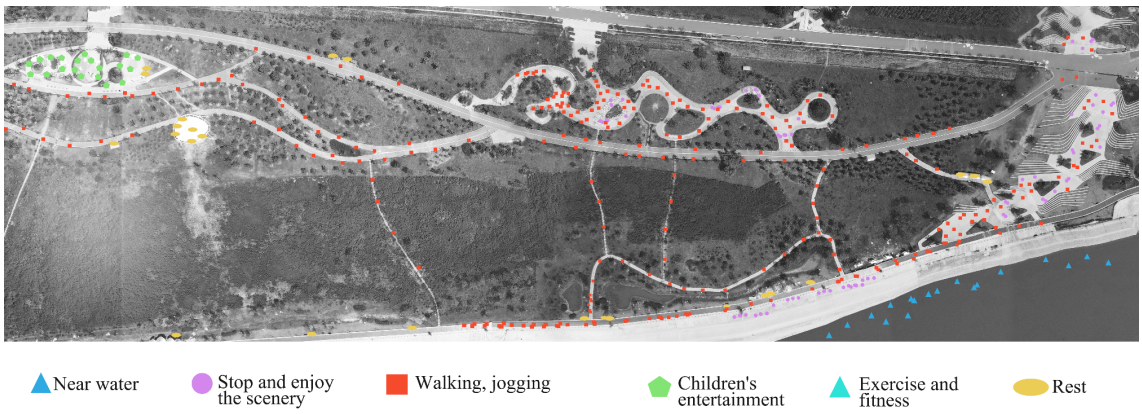

Fig. 18. Behavior Map of Hongshan Greenway

Fig. 19. Behavior Map of Wuchang Greenway

Fig. 20. Behavior Map of Qingshan Greenway

basically arranged along the edge of the path. However, for large areas of green space, these seats cannot provide shade and shelter from rain for users and may also shorten their service life. In contrast, the rest seats of Hongshan Greenway are arranged according to the surrounding environment with different rest seats, which are both aesthetically pleasing and practical.

5.1.4. Summary of User Behavior Characteristics

From the basic information and travel methods of the users of the three greenways, the main user groups of the three greenways differ in age structure, occupational characteristics, and place of belonging. Different types of user entities will also affect the functional positioning of the greenways, and corresponding configurations should be made in the service facilities and functional facilities of the greenways; from the user's activity preferences,

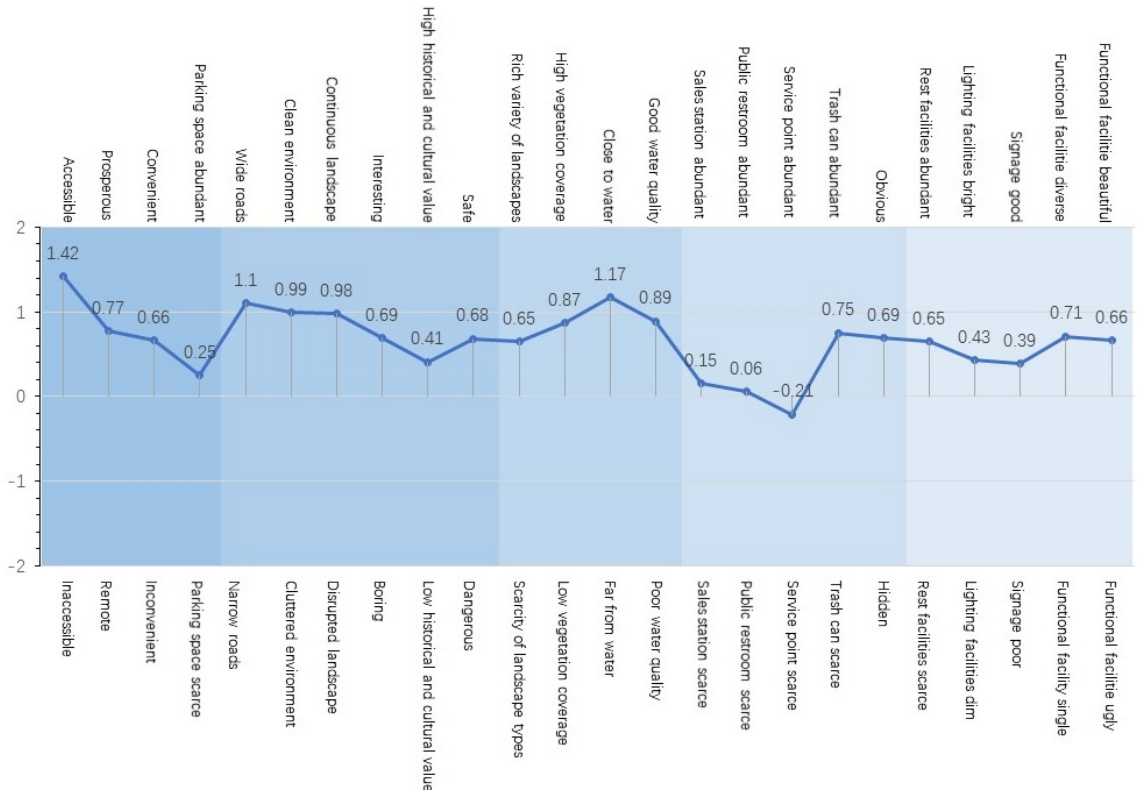

Fig. 21. SD Curve Chart of Hongshan Greenway

people tend to engage in activities such as walking, resting, socializing, and children's entertainment. Therefore, places such as riverside walkways, children's entertainment areas, and rest seats have a larger number of users and obvious signs of use. The daily maintenance and management of these areas need to pay more attention to ensure the safety and aesthetics of the greenway interior.

5.2. Satisfaction Evaluation

During the survey, questionnaires were distributed to users of the three greenways on-site and online, and interviews were conducted to statistically evaluate the satisfaction of user groups with various aspects of these three greenways. A total of 100 questionnaires were distributed for each river beach greenway, with 93, 89, and 87 valid questionnaires collected for Wuchang, Qingshan, and Hongshan Greenways, respectively, totaling 269 valid questionnaires. Then, the final scores were obtained based on the weight of each evaluation index and the questionnaire scores.

5.2.1. SD Analysis

5.2.1.1. Hongshan Greenway

From Figure 21, there is 1 negative factor in the entire curve. In the service system, "Few Service Points - Many" scored the lowest with a factor value of -0.21. In location conditions, "Inaccessible - Accessible" scored the highest with a factor value of 1.42. Looking at the entire SD curve, users generally rate Hongshan Greenway as average.

5.2.1.2. Wuchang Greenway

As shown in Figure 22, there are 5 negative factors in the entire curve. In location conditions, "Scarce Parking Lots - Abundant" has a factor value of -0.32. In the functional facility system, "Dim Lighting Facilities - Bright" is a negative value with a factor value of -0.15. The service system has 3 negative values, indicating issues such as insufficient number of sales stations, inadequate public toilet facilities, and lack of service points. Overall, the slow traffic system and landscape system are highly rated, while the service system is rated the lowest, with users generally rating Wuchang Greenway as average in overall satisfaction.

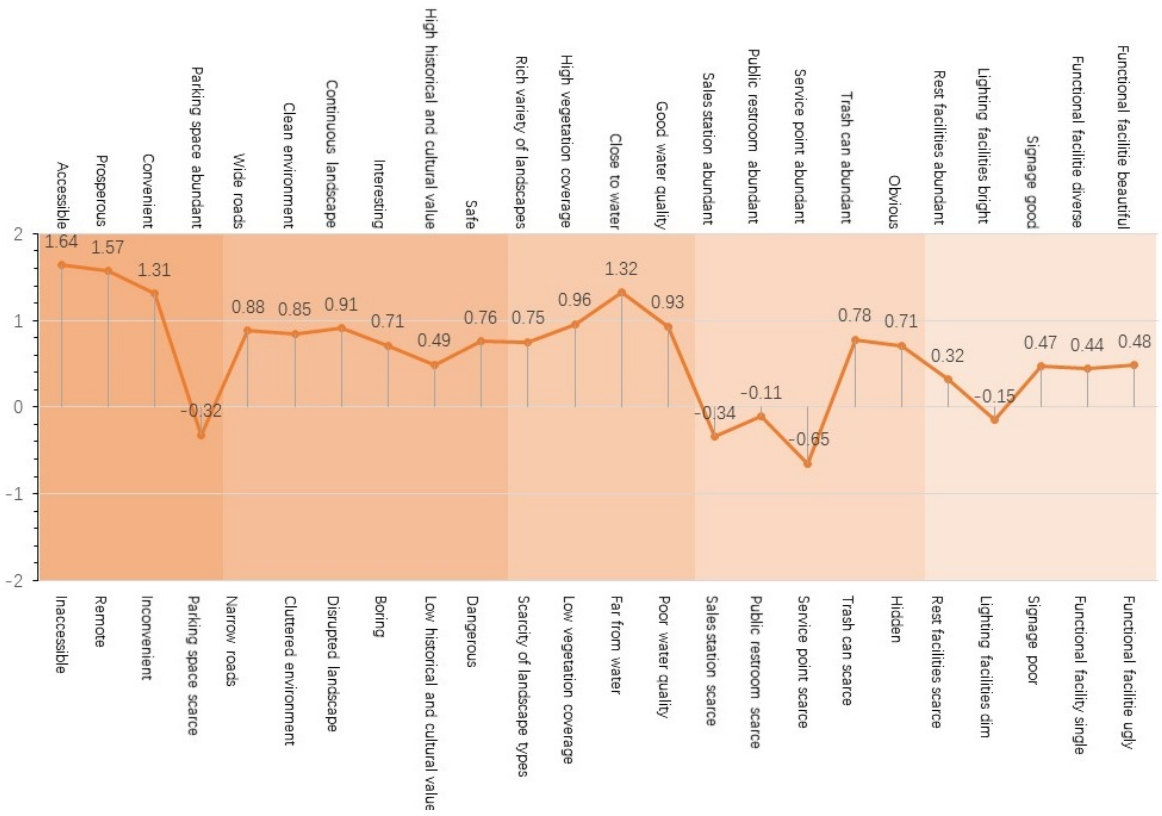

Fig. 22. SD Curve Chart of Wuchang Greenway

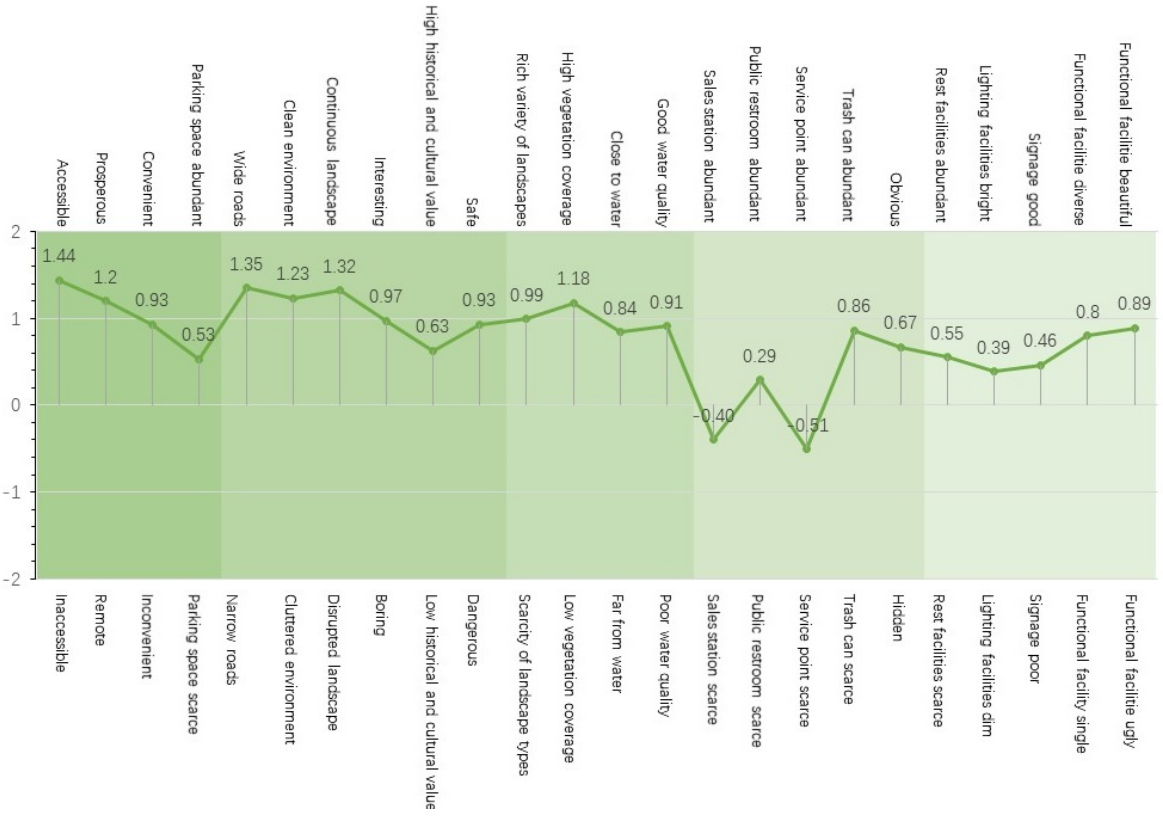

Fig. 23. SD Curve Chart of Qingshan Greenway

5.2.1.3. Qingshan Greenway

From Figure 23, there are 2 negative factors in the entire curve. The service system has 2 negative values, indicating issues such as insufficient number of sales stations and lack of service points. Overall, the location conditions, slow traffic system, and landscape system are highly rated in satisfaction, while the service system is rated the lowest. Users generally rate Qingshan Greenway as having good overall satisfaction.

5.2.2. Fuzzy Comprehensive Evaluation

Based on the SD factor values obtained from the research of the three greenways, weighted calculations were performed using the weight values obtained from the aforementioned AHP, and to more intuitively display the evaluation results, the results were converted to a percentage system. The calculation formulas are as follows:

Among them, Formula (5) converts the SD factor values into a percentage system, where SDi represents the original score of the secondary evaluation factor, and Ti represents the converted score of the SD factor. Formula (6) uses the weight to calculate the comprehensive score of the criterion layer based on the converted SD scores, where Ki is the weight value of the factor. Formula (7) serves to evaluate the final score of the greenway satisfaction, which is calculated in a similar way to Formula (2). The final results are shown in Table 7.

$$T_i = 20(SDi + 3) \quad (5)$$

$$F_i = \sum_{i=1}^{n} T_i K_i \quad (6)$$

$$D = \sum_{i=1}^{n} F_i K_i \quad (7)$$

According to the SD factor scoring standard corresponding to the percentage system, satisfaction can be divided into 5 levels, with specific evaluation criteria as shown in Table 8.

Combining Table 7. and Table 8., the following conclusions can be drawn for the three greenways:

Wuchang Greenway has good satisfaction in location conditions and landscape system, attracting more residents and tourists with its good accessibility and environmental landscape conditions. However, the overall satisfaction is pulled down by issues such as lack of service points and dim lighting facilities. In comparison, Wuchang Greenway has the lowest satisfaction among the three greenways.

Qingshan Greenway has well integrated with the local historical and regional characteristics and has made significant improvements in environmental landscape. The shortcomings lie in the insufficient

Table 7. Satisfaction Evaluation Scores of Riverside Greenways

	Wuchang Greenway	Qingshan Greenway	Hongshan Greenway
Location Conditions	85.2	83.3	79.2
Slow Traffic System	75.6	81.6	76.4
Landscape System	79.8	79.6	78.1
Service System	63.5	65.9	66.7
Functional Facilities System	65.3	71.7	71.4
Overall Score	70.2	73.5	71.5

Table 8. Satisfaction Evaluation Grade Division Standard for Riverside Greenways

Score Range	Satisfaction Level	Grade
90-100	Very Satisfied	Excellent
80-90	Comparatively Satisfied	Good
70-80	General Satisfaction	Average
60-70	Comparatively Dissatisfied	Poor
＜60	Very Dissatisfied	Very Poor

Table 9. Summary of POE Evaluation for Riverside Greenways

Research Object	Features	Advantages	Disadvantages
Wuchang Greenway	Located in the city's core area with high foot traffic and a narrow, elongated space.	Convenient transportation, high space utilization rate, strong water affinity.	Aging service facilities, lack of configuration.
Qingshan Greenway	Located in a general city area with high accessibility and larger space.	Rich in historical and cultural characteristics, diverse functional facilities, rich landscape levels.	Large spatial scale, insufficient water affinity; slightly lacking service facilities.
Hongshan Greenway	Located in a general city area with a larger space.	Exquisite public service facility design, good spatial experience.	Inconvenient transportation, incomplete functional facilities, greening environment to be improved.

internal functional service facilities. In comparison, Qingshan Greenway has the highest satisfaction.

Hongshan Greenway is still under construction, with insufficient transportation convenience and public service facility completeness. However, with the completeness of existing facility planning and the detail of design, people have good expectations for the future construction of Hongshan Greenway, thus it still has a certain level of satisfaction.

5.2.3. Summary of Satisfaction Evaluation

Summarizing the POE evaluation results, it can be known that the three greenways each have their strengths and weaknesses (Table 9.). Qingshan Greenway has gained the highest user satisfaction with its distinctive historical and cultural characteristics and well-equipped public service facilities, but there are still deficiencies in water design and service facility configuration; Wuchang Greenway has the highest flow of people due to its good location conditions, but due to the early construction time, the existing public service facility configuration cannot meet the current needs of people, and more consideration is needed in environmental design details; Hongshan Greenway currently cannot fully meet people's needs due to imperfect public transportation system, insufficient traffic convenience, and poor completeness of public service facilities and environmental landscape.

6. Optimization Suggestions for Wuhan Riverside Greenway

6.1. Strengthen the Design of Characteristic Water-Affinity Spaces

With the unique water resource conditions of the riverside greenway, people have a strong affinity for water. In the design of waterside spaces, the main aspects are visibility, approachability, and touchability. Through research, it has been found that the three greenways have achieved visibility, using viewing squares, viewing platforms, viewing pavilions, and other spaces to create a distance between users and water. Compared with Wuchang Greenway, Hongshan Greenway and Qingshan Greenway need to strengthen "approachability" and "touchability", and can set up water trestles, water-affinity steps, preserve original beaches, etc.[9] (Fig. 24-25).

6.2. Improve the Functional Service System

6.2.1. Improve Site Facilities

6.2.1.1. Increase Commercial Facilities

Currently, the commercial facilities along the three greenways are insufficiently set up, with existing sales stations being too few and too far apart. Some users have also pointed out the difficulty of purchasing water and food within the greenways, and many sales stations are set up but not in operation, sometimes necessitating the purchase of items outside the greenway, which brings great inconvenience to the journey. To meet user needs, sales stations can be set up in large squares, fitness squares, or children's playgrounds where there is a large flow of people, and other important nodes can be replaced with vending machines (Fig. 26).

6.2.1.2. Add Public Toilets

According to field research, the number of public toilets along the three greenways is insufficient and does not meet the demand. Wuchang Greenway

Fig. 24. Current Status Map of Water-Affinity Spaces for Hongshan Greenway, Wuchang Greenway, and Qingshan Greenway

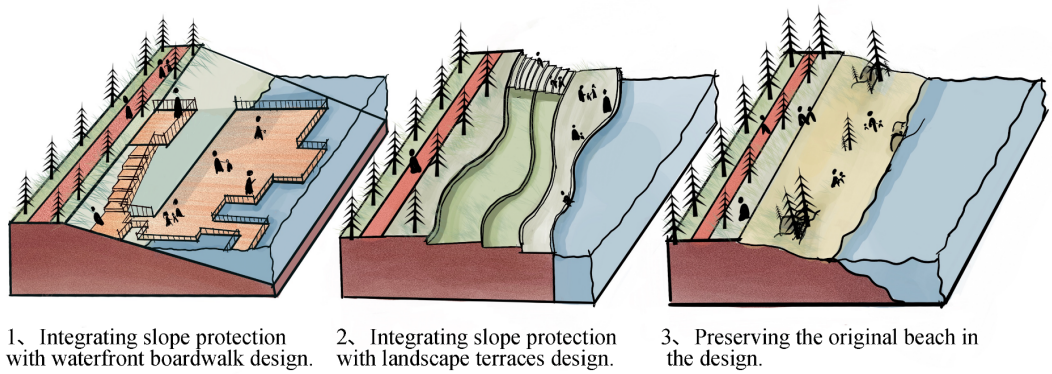

Fig. 25. Analysis of Water-Affinity Space Design Techniques

only has one public toilet set up. The following optimization strategies are proposed:

Set up regular toilets in places with dense pedestrian traffic, and set up mobile toilets in other areas to ensure that toilets can be found within a 10-minute walk; the setting of toilet squat positions should be designed according to the characteristics of the number of people in the area, at a ratio of 50 people per toilet, while also considering the addition of women's toilets, mother and baby dedicated toilets, and accessible toilets (Fig. 26).

6.2.1.3. Set Up Service Points and First Aid Medical Points

Currently, the number of service points and first aid medical points along the three greenways does not meet user needs. There are few service points, and some areas are not within the service radius. It is necessary to add service points in conspicuous locations and provide clear signs for users. In addition, all three greenways lack first aid medical points. It is recommended to set up first aid medical points in sections with moderate foot traffic and good accessibility to handle emergencies within the greenway and ensure the safety of users[9]. (Fig. 26).

6.2.1.4. Increase the Number of Rest Facilities

In the long linear space, rest benches should be set up along the way, and a large rest pavilion should be set up at regular intervals, combined with the landscape. This can serve as a place for daily rest and communication, and can also become a secondary node of the greenway, increasing the continuity of the spatial sequence (Fig. 26).

6.2.1.5. Improve Lighting Facilities

In the three greenways, some areas have single lighting facilities with poor lighting effects. It is advisable to use ground lights, luminous sculpture pieces, and characteristic streetlights to increase the types of lighting and enhance the richness of the landscape. At the same time, solar-powered streetlights using photovoltaic power generation can be arranged along the walkways to save resources and implement sustainable development (Fig. 26).

6.2.2. Improve Parking Spaces

During the research process, it was found that the parking spaces of Wuchang Greenway do not meet the usage requirements at all. Wuchang Greenway is accessible, convenient for transportation, and well-known, attracting many people to visit every

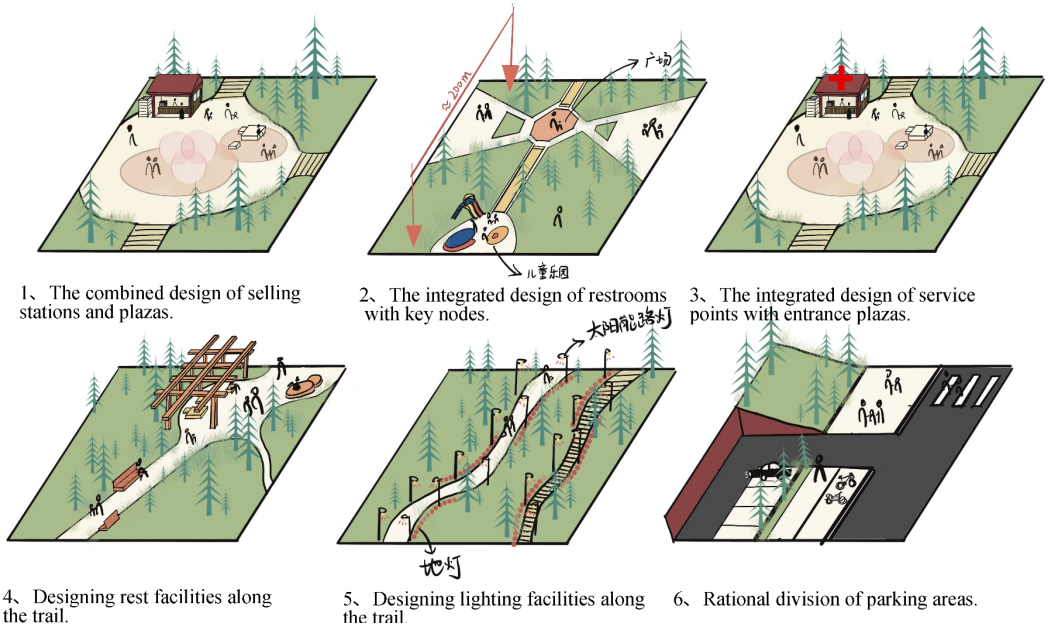

Fig. 26. Site Facilities Design Analysis Diagram

day. The available parking spaces are insufficient, leading to random parking on the street sidewalks, traffic congestion, and overcrowded roads. To solve these problems, the situation can be improved by building underground parking lots around, reasonably dividing parking areas, and increasing ground non-motor vehicle parking spaces (Fig.26).

6.2.3. Enrich the Types of Slow Traffic Systems

At present, the main slow traffic systems of the three greenways include pedestrian systems and sightseeing tour car systems, lacking a bicycle tour system. In the future, the types of slow traffic systems should be improved, and a dedicated bicycle riding greenway should be set up to enrich the types of visitors' tours. At the same time, pay attention to improving the barrier-free transportation system. Cycling activities are closely related to the barrier-free transportation system. The lack of a barrier-free transportation system may make it difficult or impossible for cycling vehicles to enter the cycling path[15].

7. Conclusion

Urban waterfront greenways, against the backdrop of transitioning from an era of growth to an era of stock, are constantly progressing and developing as one of the important strategies for low-carbon city construction, with their multifunctional characteristics of connecting public spaces, activating urban vitality, driving regional development, and restoring aquatic ecological environments. However, at the same time, it is still necessary to examine the current built environment of urban waterfront greenways from different perspectives and to think about the future development and construction of waterfront greenways, in order to build a waterfront greenway that prioritizes ecology and people.

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