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Research on the Evaluation of Street Space Friendliness of Residential Blocks : Based on Residents' Subjective Observation Perspective

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ABSTRACT: This paper takes 20 residential streets in Hexi district of Nanjing as the research objects, investigates pedestrians' subjective perception and object environment data of the street space environment, analyzes pedestrians' psychological evaluation structure of the street which includes social interaction, spatial atmosphere, vegetation and facilities. On the basis of each evaluation score of the streets based on the common factors,the paper studies the correlation between the subjective evaluation of the street and the object index, concludes the influence mechanism of street object indicators on residents' psychological perception, and explores the street space environment indicators that are conducive to pedestrian-friendly residential blocks.

KEY WORDS: *walking-friendly*; *residential blocks*; *street space*; *Semantic Differential*; *correlation*; *subjective observation*

1 Background

Residential neighborhood streets refer to urban roads that divide residential blocks (neighborhoods) within a residential area. As the most frequently used spatial carrier for residents' daily commuting, leisure activities, and various life activities, these streets serve not only the transportation functions but also create community interaction spaces with social attributes. However, many streets exhibit pedestrian-accessible issues such as excessive width, uneven distribution of road rights, monotonous spatial experiences, and poor road maintenance. In the current urban environment development shifting from "incremental" to "quality improvement", there is a necessity for detailed and scientific research on street spaces to address these shortcomings. Exploring the relationship between residential neighborhood street space environment and walking behavior from residents' subjective perspectives is of great theoretical and practical significance for establishing a pedestrian environment evaluation system and fostering pedestrian-friendly cities.

Many studies on the quality of street walking environments mainly focus on exploring the impact of pedestrian-friendly environmental elements and built environment elements on residents' walking behavior at a macro level. Scholars such as Cervero R (1997), Southworth M (2005), Koohsari M J (2016), Chen Yong (2017), and Lu Peidong (2019) have proposed relevant environmental indicators of walkability, including land use mix, road net-

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work connectivity, accessibility of facilities, and commercial density. Other scholars have examined the influence of street spatial form, scale, streetscape characteristics, and municipal facilities on walking behavior at a micro level. Scholars like Jaskiewicz F (2000), Purciel M (2009), and Dover V (2013) argue that factors such as street enclosure, pleasant scale, tree canopy coverage, and sidewalk facilities contribute to enhancing residents' willingness to walk [6-8]. Studies by Shin W H (2011), Liu Jun (2017), Yin L (2016), focused on the specific preferences of walking behavior for particular groups, highlighting the impact of micro-environmental variables in the street such as greenery density, effective pedestrian pathway width, and green view rates [9-11]. Compared to foreign research, which has achieved multi-disciplinary comprehensive studies in this field, related research in China is still in its early stages. Considering the importance of residential neighborhood street spaces for the lifestyle and travel mode choices of residents within the community circle, especially for the widespread enclosed residential neighborhoods in China, there is a need for a comprehensive study from the urban design perspective based on subjective measures. Research on the constituent elements of street spaces and their relationship with walking behavior in residential neighborhood streets, from the perspective of urban design, incorporating emotional perception measures and psychological evaluations of pedestrians, is essential.

This study focuses on 20 residential neighborhood streets in the Hexi area of Nanjing city. It conducts a questionnaire survey using the semantic differential method to assess pedestrians' psychological perceptions and emotions. Additionally, data on the built environment of the streets are collected through drawings and on-site measurements. Based on this data, factor analysis is employed to extract common factors in the evaluation of street design (SD), determining the psychological evaluation structure of pedestrians towards the streets and the evaluation scores of each street based on these common factors. This approach aims to stratify and quantify residents' subjective perceptions of the streets. Subsequently, a mathematical model is established to analyze the correlation between various indicators at different levels, such as spatial scale, boundary spaces, functional facilities, street greening, within the built environment of the streets and residents' subjective ratings. This analysis aims to identify street environmental elements that significantly influence subjective perceptions, thereby providing recommendations for enhancing the pedestrian-friendliness of the streets. The research outcomes aim to provide reference and guidance for spatial construction and design guidelines for residential neighborhood streets, particularly those in high-density, enclosed residential areas. The streets studied in this research are open urban streets adjacent to residential land within residential neighborhoods, often serving as boundaries between different residential blocks.

2 Research methods

2.1 Semantic Differential method

The Semantic Differential method quantifies subjects' psychological perceptions through verbal scales to obtain their feelings towards the research subject and establish quantitative data. Currently, it is widely used in fields such as psychology, sociology, market research, and landscape design. The evaluation factors in the Semantic Differential method consist of sets of adjective pairs, each pair comprising two words with opposite meanings to express positive and negative connotations. Each set of adjective pairs generally includes 5 or 7 rating intervals and values to represent the intensity of psychological feelings, translating affective assessments into quantitative evaluations.

Compared to commonly used methods and tools in Europe and America such as PERS, NEWS, and CSR, the SD method utilizes adjective pairs that represent pedestrians' psychological perceptions, placing relatively more emphasis on pedestrians' emotional aspects.

2.2 Sample selection for survey

The samples are located in the Longjiang and Olympic Sports Center (OTC) areas of Nanjing, both situated on the west side of the old city. These areas were constructed from the late 1990s to the mid-2000s and from the mid-2000s to the mid-2010s, intended to alleviate population pressure in the old city by developing new urban areas characterized by high residential land use ratios, well-equipped functional facilities, and mature development (Figure 1). Residential neighborhoods in these areas predominantly feature enclosed block forms with plot ratios ranging from 1.8 to 2.5. The road network density in these areas is lower than that of the old city, ranging from 8 to 9.5 km/km2. Longjiang was developed earlier than the Olympic Sports Center, featuring relatively smaller block and street spatial scales with more organic street forms and relatively outdated street facilities. In contrast, the Olympic Sports Center boasts larger spatial scales, a well-organized grid road network, and relatively improved street facilities.

This study selected 20 residential street sections with typical spatial characteristics based on the functional attributes of the streets, land use types on both sides, road grades, spatial scales, and enclosure interface types (Figures 2-3). These 20 streets are situated between residential neighborhoods (districts) and are classified as urban secondary roads and service roads. The land uses on both sides of the streets are residential, with one side of L8 surrounded by educational land walls. Residential buildings along the Longjiang streets primarily consist of 6-11 floors, while the Olympic Sports Center features predominantly high-rise residential buildings ranging from 18 to 31 floors. Enclosure interfaces include a single type or a combination of commercial spaces along residential complexes, community fences, squares, and green spaces. Pedestrian spaces are included in all road allocations. The study sections of the streets are delimited by the endpoints of two blocks at intersections and road redlines, with street lengths ranging from 180 to 380 meters.

2.3 Research content and data collection

The research content consists of two parts: street psychological perception and built environment. The survey on street psychological perception uses the Semantic Differential (SD) method, conducting surveys through questionnaires to investigate pedestrians' emotional responses and perceptual evaluations of the sampled streets. The research on the built environment utilizes CAD terrain maps as the foundational data, combined with on-site investigations for data correction to obtain spatial element data. The content includes sub-indicators on four aspects: overall street spatial scale, boundary spaces, functional facility layout, and street greening.

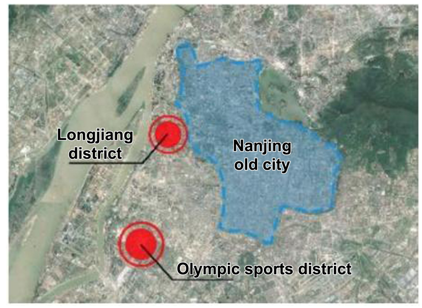

Figure 1 Schematic of the location of AoTic and Longjiang districts

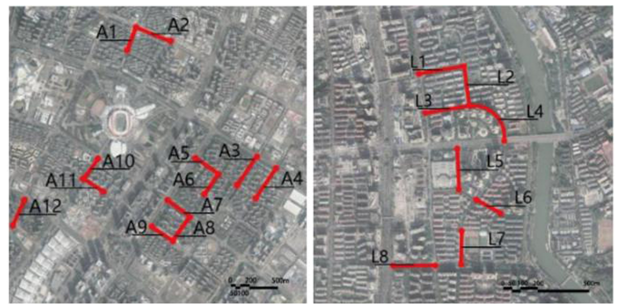

Figure 2 Schematic of the positions of the 12 streets in AoTic district and the 8 streets in Longjiang district

(1) Street psychological perception

Based on the characteristics of residential streets, this paper considers the impact of street spatial environment, ambience creation, and attractiveness on pedestrian behaviors and psychology. Drawing on the research experiences of several scholars [16-18], 15 sets of adjectives were selected as subjective evaluation factors, including: satisfaction, comfort, tranquility, liveliness, activity richness, interest, attractiveness, spatial openness, convenience, landscape richness, street tidiness, safety, tree shade density, facility completeness, and daily communication richness. Each evaluation factor is rated on a 5-point scale: very poor, poor, fair, good, very good, corresponding to scores of-2,-1, 0, 1, 2 respectively.

The survey was conducted by 20 graduate students majoring in architecture using interview-style questionnaires over 2 days. Each street planned to distribute 25 questionnaires, totaling 500, with 487 effective questionnaires ultimately collected, achieving a 97% response rate. Respondents were screened through inquiries to ensure they were local residents before proceeding with the questionnaire interview to ensure that the respondents were long-term users of the street and familiar with the living environment. Emphasis was placed on balanced age and gender distribution in participant selection. The survey was conducted on weekends to ensure diversity among respondents. In the surveyed areas, the male-to-female ratio of respondents was 1.25; the age distribution included 8.2% in the 12-18 age group, 39.8% in the 18-30 age group, 40.4% in the 31-60 age group, and 11.4% aged 60 and above; educational levels comprised 28.3% with education below college level, 50.9% with college education, and 20.7% with master's degree or higher. The demographic structure of respondents in the two areas was similar, with proportions close to the overall statistical average.

Figure 3 Photorealistic image of sample street

(2) Street built environment

The street built environment includes data collection on four spatial attribute levels. The overall spatial scale involves three indicators: street length, street width, and street height-to-width ratio to reflect the basic spatial scale of streets. Boundary space spatial elements refer to linear spaces between streets and adjacent residential areas that impact pedestrian behaviors, including sidewalk width, boundary permeability coefficient, density of community entrances and exits, density of node public squares, and proportion of commercial interaction interfaces. Street functional facilities are divided into public service facilities and public engineering facilities, providing various building facilities for public services and service facilities for transportation and activities, with related indicators such as the quantity of along-street functional facilities, functional mix, density of along-street seating, density of bicycle parking areas, density of bus stops, and density of crosswalks. Street greening includes indicators such as boundary greenery density, isolation greenery density, tree shade ratio, coverage ratio of shrubs and trees, and green view ratio (Table 1).

3 Data statistics and preliminary analysis

3.1 Psychological measurements

Statistical analysis was conducted on the questionnaire survey data to obtain the SD measurements of pedestrians' perception of street space in each street (Table 2). The average scores of factors in both areas mostly ranged between 0-1, indicating a tendency towards positive evaluations. The Olympic Sports Center area tended towards a "good" standard, while the Longjiang area tended towards a "fair" standard; both areas had negative evaluations in the "convenience" factor.

By comparing the scores of various factors between the two areas, it was observed that pedestrians in the Olympic Sports Center area had slightly higher overall satisfaction with the streets compared to the Longjiang area. Additionally, the factor evaluation scores for comfort, tranquility, attractiveness, openness, landscape richness, street tidiness, safety, and richness of daily communication spaces were all higher in the Olympic Sports Center area than in the Longjiang area. This to some extent reflects the recognition of the Olympic Sports Center area in terms of pedestrian space scale and street landscape construction. On the other hand, the Longjiang area scored slightly higher in factors such as richness of street activities, interest, and completeness of facilities, indicating a certain advantage in resident activity participation and completeness of living facilities.

Table 1 Conceptual definition and quantification of built environment indicators

	Indicators	Conceptual definition	Quantitative formulas
Overall spatial scale	Street segment length	Total length of street segments in sample streets	—
	Street width	Average crossing width for pedestrians	Streetaveragewidth $W_r = S_r/n$ S_r is the total length of crossing facilities, n is the number of crossing facilities
	Street height-to-width ratio	Weighted ratio of building height to street width along the street	Streetaspectratio $P_i = \sum_{i=1}^{N} h_i \times l_i/d_i \times L$ h_i is the height of building i along the street, l_i is the length of building i along the street, d_i is the distance from the building along the street to the road centerline, L is the length of the street segment
Boundary space	Sidewalk width	Effective average width of sidewalks	SidewalkWidth $W_s = S_e/L$ S_e is the effective area of the sidewalk, L is the length of the street segment
	Interface transparency coefficient	Degree of enclosure and openness of street boundary enclosure interfaces; dividing interfaces into three categories: closed, semi-closed, and open, with relative values assigned to reflect their transparency based on different material forms	Transparency Coefficient $C= 0* a_1+ 0.5* a_2+ 1* a_3/L$ a_1、a_2、a_3 are the lengths of closed, semi-closed, and open interfaces respectively; L is the length of the street segment
	Entrance and exit density of the neighborhood	Average number of entrances and exits to residential neighborhoods per unit length of street	Entranceandexitdensityoftheneighborhood $D_c = N_c/L$ N_c is the total number of entrances and exits to neighborhoods along the street, L is the length of the street segment
	Node density of public plaza	Total area of public plazas along the street per unit length of street	Nodedensityofpublicplaza $D_g = S_g/L$ S_g is the total area of public plazas along the street nodes, L is the length of the street segment
	Ratio of commercial interactive interfaces	Percentage of building interfaces with main functions of shopping, dining, and lifestyle services	Ratioofcommercialinteractiveinterfaces $F_b = L_b/L$ L_b is the total length of commercial interactive interfaces on the street, L is the length of the street segment

Table 1 (continued)

		Indicators	Conceptual definition	Quantitative formulas
Functional facilities	Public service facilities	Number of functional facilities along the street	Number of Points of Interest (POIs) for service facilities on both sides of the street	—
		Degree of functional mix	Balance of types and quantities of functional facilities along street buildings; measured by the average information entropy	Degreeoffunctionalmixalongstreetbuildings $H_s = -\sum_{i=1}^{N} P_i \times \log P_i$ $P_i = \frac{A_i}{\sum_{i=1}^{N} A_i}$ P_i is the probability of information entropy of facilities of class i, A_i is the quantity of class i facilities
	Public engineering facilities	Density of street seating	Length of street seating per unit length of street	Densityofstreetseating $D_s = L_s/L$ L_s is the total length of public seating along the street, L is the length of the street segment
		Bicycle parking area density	Area of bicycle parking zones along the street per unit length of street	Bicycleparkingareadensity $D_z = S_z/L$ S_z is the area of bicycle parking zones along the street, L is the length of the street segment
		Bus stop density	Number of bus stops per unit length of street	Busstopdensity $D_b = N_b/L$ N_b is the number of bus stops along the street, L is the length of the street segment
		Crosswalk density	Number of crosswalks per unit length of street	Crosswalkdensity $D_m = N_m/L$ N_m is the number of crosswalks, L is the length of the street segment
Street greenery		Boundary greening density	Area of boundary greening per unit length of street	Boundarygreeningdensity $D_b = S_b/L$ S_b is the total area of boundary greening, L is the length of the street segment
		Isolation greening density	Area of isolation green belts per unit length of street	Isolationgreeningdensity $D_i = S_i/L$ S_b is the total area of isolation green belts, L is the length of the street segment
		Shade rate of trees	Proportion of shading area from the vertical projection of street trees' canopies on the road surface	\(S_y\) is the shading area from the vertical projection of the canopies of street trees, \(S\) is the area of the street
		Coverage ratio of Shrubs and trees	Ratio of shrub greening area to tree shading area	Coverageratioofshrubsandtrees $R = S_s/S_y$ S_s is the area of shrub greening, S_y is the area of tree shading
		Green view rate	Average proportion of green elements in 6 points and 18 pedestrian view images extracted using the Segnet technology for image semantic segmentation based on street view image data	Greenviewrate $V = \sum_{i=1}^{N} g_i/p_i$ g_i is the green elements in pedestrian view images, p_i is all elements in pedestrian view images

Comparing the SD evaluation curves visually (Figure 4, Figure 5), it can be observed that the fluctuation range of the evaluation curve in the Olympic Sports Center area is smaller than that of Longjiang, reflecting a more balanced evaluation of street construction in various aspects and higher overall acceptance. In contrast, the differences in evaluations in Longjiang are more pronounced, with clear strengths and weaknesses. Furthermore, the evaluation curves in the Olympic Sports Center area tend to be more similar to each other compared to Longjiang, indicating a closer alignment between the spatial characteristics and acceptance levels of each street in the Olympic Sports Center area, while there is greater variability in the spatial characteristics and evaluation differences among different streets in Longjiang.

Table 2 Statistical analysis of average scores of subjective perception by sample streets using the semantic differential method (SD)

District	Satisfaction	Comfort	Quietness	Vibrancy	Activity abundance	Amusement	Attractiveness	Openness	Convenience	Landscape abundance	Street frontage neatness	Safety	Canopy coverage	Facilities completeness	Social spaces diversity
Olympic sports	0.99	1.04	0.72	0.32	0.06	0.07	0.28	0.76	- 0.05	0.54	0.98	1.01	0.87	- 0.11	0.33
Longjiang	0.62	0.51	0.24	0.48	0.14	0.12	0.18	0.22	- 0.11	0.13	0.40	0.59	0.74	0.09	0.03

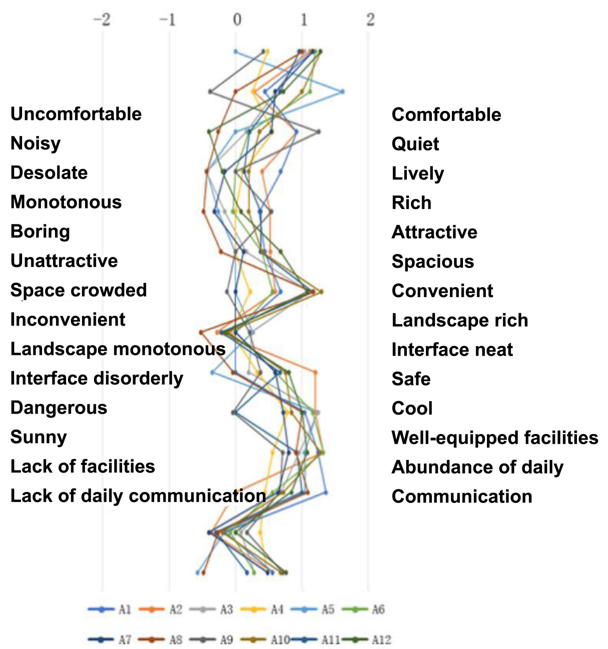

Figure 4 Evaluation curve of street design in sample streets of the Olympic sports center area (SD)

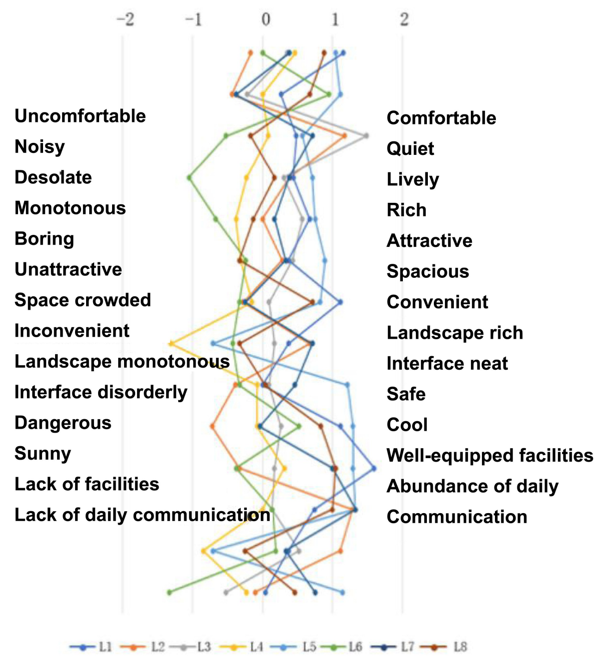

Figure 5 Evaluation curve of street design in sample streets of the Longjiang area (SD)

3.2 Completed environmental data

The statistics of related indicators in four aspects of the overall spatial scale, boundary space, functional facilities, and street greenery of the built environment are as follows (Table 3).

Overall spatial scale: the average street length in both areas is approximately 300m and 220m, with average street widths around 40m and 24m. In the Olympic Sports Center (OSC), both street length and width are higher than Longjiang. The comparison of average height-to-width ratio of streets shows that the ratio is 0.9 in the OSC, lower than the 1.4 in Longjiang.

Table 3 Street built environment data statistics table

District	Overall spatial scale			Boundary space					Functional facilities						Street greenery				
	Length of street segment (m)	Street width (m)	Street height-to-width ratio	Sidewalk width (m)	Transparency coefficient of interface	Residential entrance density (units/100m)	Node public square density (m2/100m)	Percentage of commercial interactive interface	Mixing degree of functions	Number of street service facilities	Density of street seats (units/100m)	Density of bicycle parking areas (m2/100m)	Density of bus stops (units/100m)	Density of crosswalks (units/100m)	Boundary greenery density (m2/100m)	Isolation greenery density (m2/100m)	Canopy coverage of deciduous trees	Coverage ratio of evergreen trees	Green view ratio
Olympic sports	296.17	39.25	0.91	2.41	0.51	0.4	196.2	0.23	0.485	14.75	4.1	21.5	0.4	0.7	280.2	153.4	0.28	0.22	0.54
Longjiang	219.50	23.50	1.43	1.73	0.56	0.9	40.1	0.26	0.532	14.25	3.6	38.9	0.1	0.6	285.8	96.3	0.67	0.11	0.49

Boundary space: the average values of the interface permeability coefficient and the proportion of commercial interactive interfaces are similar in both areas. The effective width of sidewalks in the OSC is 2.4m, higher than the 1.7m in Longjiang; the density of entrance and exit points in residential areas shows that there is an entrance or exit nearly every 200m, lower than the 0.9 per 100m in Longjiang. The density of public squares in the OSC is significantly higher than in the Longjiang area, providing relatively more densely distributed outdoor activity spaces.

Functional facilities: the functional mix of Longjiang along the streets is slightly higher than in the OSC, with a relatively greater variety and more balanced distribution of different types of functional facilities. In terms of public engineering facility-related indicators, the difference in seat density and crosswalk density between the two areas is not significant. The density of bus stops along streets in the OSC is higher than in Longjiang, while the density of bicycle parking areas along streets is lower than in Longjiang.

Street greenery: the average values of boundary greening density indicators are basically the same in both areas; the comparison of isolation greening density indicators shows that the isolation greening density in the OSC is higher, indicating that pedestrians in the area are less disturbed by cars and non-motorized vehicles, making the walking environment safer. There is a significant difference in tree canopy coverage, with the OSC ranging between 20% and 38%, while Longjiang ranges between 42% and 93%. The ratio of shrub and tree coverage in the OSC and Longjiang ranges between 6%-35% and 0%-20%, respectively, reflecting better shrub greening in the OSC and a richer landscape. The green view rates in both areas are relatively high, around 50%, with small differences.

4 Establishing of variables of built environmental that affecting subjective perception

The following sections will first utilize factor analysis to extract key attributes and common factors from SD evaluation adjectives, calculating subjective perception scores for streets. Subsequently, through correlation analysis, the built environment variables influencing subjective perception will be selected. By establishing a bivariate correlation model between pedestrian evaluation factor scores of streets and built environment indicators on a street-by-street basis, significant indicators in the built environment that affect pedestrians' psychological perception and emotions will be identified.

4.1 Street walkability analysis of SD evaluation factors

Factor analysis is a statistical method used to extract common factors from a group of variables with overlapping information. It is primarily employed when there are too many variables with certain correlations, grouping factors with strong correlations together to significantly reduce the number of variables and capture most of the original variables' information.

In order to analyze pedestrians' basic impressions of the street environment and their psychological evaluation structure of the streets, this study employed factor analysis to summarize multiple sets of adjective pairs into a few evaluation factors. By calculating the factor loadings of the adjective variables in each group, new factor evaluation scores were obtained. Using SPSS software, we conducted a principal component analysis on 14 SD adjective pairs excluding overall satisfaction, employing the Maximum Variance method for rotating the matrix, resulting in four feature variables and their respective constructions, referred to as new evaluation factors (Table 4). Factor 1 primarily describes pedestrians' preferences for daily social activities on streets, named the "Social" factor. Factor 2 describes the imagery of street spatial environmental elements on pedestrians' psychological level, named the "Spatial Ambiance" factor; Factors 3 and 4 are named "Greenery" and "Facilities," respectively.

By describing common factors with linear combination functions of original variables and using the regression method in the least squares sense to calculate the factor coefficients of each principal component factor (Table 5). When calculating the "Social" factor, adjective pairs such as "monotonous activities-rich activities" and "boring-interesting" had high weights, indicating respondents' perceptions of street social activities, with most other adjective pairs having negative weights, aligning with the actual traits of the factor. Similarly, the adjective pairs with high weights in the "Spatial Ambiance," "Greenery," and "Facilities" factors are consistent with their actual characteristics and meanings.

Table 4 Rotated adjective factor loading matrix

	Factors			
	Factor1	Factor 2	Factor 3	Factor 4
Uninteresting-interesting	.859	.168	.008	−.072
Monotonous activities-rich activities	.819	−.009	.099	−.040
Unattractive-attractive	.691	.250	.178	.004
Quiet-lively	.678	−.287	.271	.077
Lack of daily communication-rich daily communication	.468	.289	.461	−.028
Uncomfortable-comfortable	.208	.745	.163	−.124
Noisy-quiet	−.111	.724	−.045	−.351
Chaotic street facade-neat street facade	.013	.676	.219	−.190
Crowded space-spacious space	.084	.671	.227	.139
Dangerous-safe	.187	.546	.506	−.056
Exposed to direct sunlight-cool	.109	.138	.766	.028
Monotonous landscape-rich landscape	.227	.226	.662	−.292
Inconvenient to use-convenient to use	.007	−.042	.035	.844
Lack of facilities-well-equipped facilities	−.074	−.310	−.315	.650
Extraction method: principal component analysis. Rotation method: Kaiser normalization maximum variance method.				
The rotation has converged after 5 iterations.				

Table 5 Factor score coefficient matrix

Factor SD	Main factors			
	Social environment	atmosphere	Green plant	Facilities
Uncomfortable-comfortable	.059	.334	−.135	.059
Noisy-quiet	−.029	.335	−.240	−.137
Cold and quiet-warm and lively	.240	−.217	.147	.004
Monotonous activities-rich activities	.354	−.039	−.129	−.047
Uninteresting-interesting	.398	.077	−.273	−.042
Unattractive-attractive	.274	.088	−.099	.050
Crowded space-spacious space	−.022	.330	−.009	.265
Inconvenient to use-convenient to use	−.025	.143	.090	.687
Monotonous landscape-rich landscape	−.063	−.129	.441	−.160
Chaotic street facade-neat street facade	−.045	.266	−.018	−.003
Dangerous-safe	−.044	.140	.235	.093
Exposed to direct sunlight-cool	−.153	−.141	.607	.094
Lack of facilities-well-equipped facilities	.034	.058	−.130	.453
Lack of daily communication-rich daily communication	.096	.020	.196	.054

Table 6 Street factor score table

District	Social factors	Spatial atmosphere factors	Greenery factors	Facility factors
Olympic sports	0.001	1.002	0.732	0.195
Longjiang	0.121	0.297	0.492	0.124

Through factor score coefficients and variable values, factor score functions were applied to obtain the evaluation scores of each sampled street based on common factors (Table 6). From the table, it can be observed that in terms of social creation, the streets in the Longjiang area are generally slightly better than those in the Olympic Sports Center (OSC), with most streets having ample communication spaces and a balanced distribution of functions. In the evaluation of the spatial ambiance and greenery factors, the OSC area scored higher, with pedestrians perceiving its walking environment to be more comfortable, quiet, and secure. Regarding facility evaluation factors, there isn't a significant difference between the two areas, with most pedestrians finding the use of roadside service facilities convenient.

4.2 Analysis of correlation between street evaluation factor scores and built environment

The street evaluation factor scores were analyzed for their correlation with various indicators across four aspects of the built environment for streets (Table 7).

Overall spatial scale perspective: there was no significant correlation observed between street segment length and the four evaluation factors; street width showed a certain degree of positive correlation with the Spatial Ambiance factor and Greenery factor scores, while the aspect ratio of streets displayed a negative correlation with the Spatial Ambiance factor score. Streets with an aspect ratio of 0.9 had better spatial ambiance values compared to those in the Longjiang area with a ratio of 1.4.

Boundary space perspective: the effective width of sidewalks did not exhibit clear correlations with the four evaluation factors. The transparency coefficient of interfaces showed a positive correlation with the Street Social factor, and the proportion of commercial interactive interfaces correlated positively with scores in both the Street Social and Facilities factors. The density of residential area entrances and exits had a significantly negative correlation with the Spatial Ambiance factor score, while node public square density showed a positive correlation with spatial ambiance. The lack of correlation between the effective width of sidewalks and evaluation factors deviated slightly from expectations, suggesting that the widths of 1.7m in Longjiang and 2.4m in the Olympic Sports Center may both meet pedestrians' needs to some extent, resulting in inconclusive correlation analysis results.

Functional facilities perspective: the quantity of functional facilities exhibited positive correlations with the Social and Facilities factors. The density of pedestrian crosswalks showed a positive correlation with the Spatial Ambiance factor.

Street greenery perspective: the density of boundary greening, isolation greening density, and Greenery factor score all showed positive correlations. The tree canopy coverage rate was negatively correlated with the Greenery factor score, while the green view rate did not show significant correlation. Contrary to past beliefs, scatter plot analysis revealed that the psychological evaluation values of the Greenery factor for sampled streets were positive. High factor scores were observed when the tree canopy coverage rate was in the range of 20%-45%; however, scores decreased beyond 45%. The average green view rate for sampled streets was above 35%, with scores decreasing slightly when it exceeded 60%. The coverage ratio of shrubs and trees showed a positive correlation with Spatial Ambiance, indicating that increasing shrub planting can enhance residents' perception of spatial ambiance.

5 Conclusion

Through factor analysis of pedestrians' psychological evaluations of sampled streets, the psychological evaluation structure was summarized into four main component factors: Social, Spatial Ambiance, Greenery, and Facilities.

From the perspective of urban design and referencing the built environment data and correlation analysis results, we believe that the pedestrian-friendliness of residential street areas can be enhanced in the following aspects: (1) optimizing service facility layout, interface design, and spatial enclosure sensation can Improve the friendliness of the street enclosure interface by enhancing pedestrian perception of social ambiance and street vitality through transparency coefficient of interfaces, proportion of commercial interactive interfaces, and quantity of service facilities. Based on subjective measurements, achieving a transparency coefficient of 0.5 and a commercial interactive interface proportion of 0.22 would result in a non-negative evaluation of social vitality perception on the street. When the street aspect ratio is 0.9, pedestrians perceive a more positive spatial ambiance compared to a ratio of 1.5, reflecting a preference for a more open spatial scale and enclosure sensation among residential pedestrians. (2) Optimizing street cross-sections and boundary space design can ensure effective sidewalk widths and increase isolation greening density and shrub planting density. A street width of around 40m and an effective sidewalk width above 1.7m will evoke a more positive emotional perception of the street ambiance by pedestrians. Pedestrians rate wider streets of 40m higher than Longjiang's 24m wide streets, emphasizing the importance of street cross-section dimensions and boundary space design. Focusing on planting density of isolation and boundary greenery, increasing shrub planting proportion can enhance pedestrians' greenery perception and create a positive street ambiance. The tree canopy coverage rate on sidewalks is more important to pedestrians than the overall street; excessive shading on the street may lead to a slightly oppressive spatial ambiance, highlighting the necessity of a certain sky visibility rate. (3) Enhancing the behavior guidance design of residential entrance spaces and street node public spaces can minimize vehicle traffic disturbances to pedestrian spaces, provide diverse activity areas. High density of residential entrances and exits and roadside bicycle parking areas can create negative perceptions among pedestrians, while increasing the density of node public squares can enhance the perception of spatial ambiance.

Table 7 Correlation analysis results of street built environment dimension indicators and evaluation factor scores

		Specific indicators	Social factor		Spatial atmosphere factor		Greening factor		Facilities factor	
			Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)
Overall spatial scale		Street segment length	-.103	.665	.226	.337	.114	.631	-.301	.197
		Street width	-.030	.900	.555*	.011	.471*	.036	-.109	.649
		Street height-to-width ratio	.301	.198	-.493*	.027	-.108	.650	-.176	.458
Boundary space	Passage space	Sidewalk width	.156	.510	-.078	.743	.235	.319	.274	.243
	Interface	Interface transparency coefficient	.478*	.033	-.265	.259	.003	.990	.195	.409
		Commercial interactive interface ratio	.480*	.032	-.302	.196	.199	.401	.536*	.015
	Others	Neighborhood entrance density	.209	.378	-.683**	.001	.068	.777	.048	.840
		Node public plaza density	-.108	.652	.444*	.050	.301	.197	-.177	.456

Table 7 (continued)

		Specific indicators	Social factor		Spatial atmosphere factor		Greening factor		Facilities factor	
			Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)
Functional facilities	Public service facilities	Number of functional facilities along the street	.495*	.027	－.387	.092	.279	.234	.546*	.013
		Street functional mix degree	.357	.123	－.069	.772	.335	.148	.288	.218
	Public engineering facilities	Bus stop density	－.093	.695	.419	.066	.105	.659	.010	.966
		Street seat density	.035	.882	.146	.538	.268	.253	－.295	.207
		Street bicycle parking area density	.189	.424	－.451*	.046	－.066	.782	.352	.128
		Crosswalk density	－.065	.787	.487*	.029	.132	.578	－.101	.673
Street greening		Boundary greening density	.135	.569	.332	.153	.513*	.021	－.166	.484
		Isolation greening density	.006	.980	.340	.143	.484*	.031	－.304	.193
		Tree canopy coverage ratio	.006	.980	－.351	.129	－.456*	.043	－.135	.569
		Shrubs and trees coverage ratio	.098	.681	.472*	.036	.429	.059	－.125	.600
		Green view rate	.207	.381	－.032	.895	.154	.518	－.147	.537

Note：* - Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.

Due to limitations in the number of sampled streets and the structured interview questionnaires, there may be some bias in the data analysis results, indicating areas for further refinement in future research. Additionally, the high quality of green planting in Nanjing city and the overall high green coverage in built-up areas resulted in minimal differences in greenery among sampled residential streets. Future research and sample selection should emphasize the differentiation of street characteristics to better represent variations in tree canopy coverage rates and green view rates, further clarifying the impact of tree greening on residents' psychological perceptions. This is an area where the thesis can be improved.

Figure and table sources

All images in the paper were taken or created by the author.

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