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Article

Quantitative Analysis of the Impact of Optimized Design of Urban Negative Space Living Environment on Community Vitality Based on Spatial Syntax Theory

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Abstract: In order to obtain intuitive and quantitative analysis results, this paper chooses spatial syntax theory as the main basic theory of the study. Through field research in three typical negative spaces in linear cities around residential stations, we obtain the characteristics of pedestrian behavior and public needs, apply spatial syntax variables to quantitatively analyze the urban residential environment, explore the problems of urban public spaces and propose optimization strategies. Taking the spatial characteristics of the residential environment as the independent variable and the spatial vitality as the dependent variable, a model of the overall vitality influencing factors of the linear urban public space around the residential sites is established to obtain the degree of influence of each spatial carrier element on the vitality of the community. Analyze the optimized urban residential space based on spatial syntax as well as community vitality. The optimized urban residential environment has a high degree of integration and accessibility and a smooth road system. The spatial design is adjusted using spatial syntax to include the internal road network of open parks, in which the growth rates of the vitality parameter values of Longjiang Street, Hohsing Third Avenue Street, and Hengdao Street, for example, are 81.09%, 92.38%, and 73.40%, respectively, and the values of the vitality parameters of these streets are improved significantly.

Keywords: spatial syntax; negative space; spatial characteristics; spatial vitality; accessibility

1. Introduction

With the acceleration of urbanization, underutilized, misused, unused and abandoned surplus spaces have appeared in the urban spatial structure, which may bring physical and psychological burdens, thus affecting people's quality of life and health [1-3]. The livability of a city is often reflected in the comfort of the built environment of the city as well as the public's recognition of the city in which it is located, and good spatial quality can well improve the quality of life of the residents [4-5]. Nowadays, a large number of negative spaces remain in the city, which is like the collapse of the city. If the negative spaces in the city can be effectively activated and utilized, so that they can be revitalized and used by the citizens, the sense of belonging of the city will be strengthened, and at the same time, it will become beautiful and moving [6-8].

Specifically, negative urban spaces are those wasted or vacant urban open spaces that fail to meet the needs of people and society and are not fully developed and utilized due to multiple reasons [9]. For example, the subsidiary space outside the building with no specific use function, the transitional space that cuts off the connection between different functional areas, the public space that is seldom visited



after completion, and the unused vacant land that has not been developed and utilized, etc. [10-11]. In the era of urban experience that focuses on quality and on meeting people's needs, methods of revitalizing negative community spaces are explored in order to improve the quality of the third living space for urban residents [12-13]. By improving the livability of the community, enriching the experience of residents' residential life, and increasing the vitality of the community, we can effectively promote the economic, social and cultural development of the community, satisfy the people's aspirations and pursuit of a better life, and truly embody the people-centered development concept [14-16].

In this paper, on the basis of obtaining the public's evaluation of the use of linear urban public space around residential stations, we use spatial syntactic variables to analyze the urban negative space and optimize the urban living environment by combining spatial vitality correlation factors. Among the linear urban public spaces around residential stations, three negative spaces outside the stations with relatively good spatial continuity are selected for user rating surveys and intentional demand statistics. Correlation analysis and multiple linear regression analysis were conducted to explore the influencing factors of spatial vitality. The optimization results of the spatial syntax method for the linear urban public spaces around the residential stations in the city are evaluated in terms of overall space and local space, and the values of the community vitality parameters of the optimized urban residential environment are investigated.

2. Research base

2.1. Spatial Syntax Theory

Spatial syntax is a theory and method to quantify the spatial structure of buildings, settlements, cities and even landscapes in human settlements, and it is a discipline to explore people and space [17-18].

The research method of spatial syntax is to describe and analyze the spatial pattern by the relationship of configuration. Applying it to urban planning, architectural design and other fields, a complete theoretical framework has been established today.

The idea of spatial syntax theory is to quantify the space, analyze the spatial elements with quantitative algorithms, and finally present the results in the form of charts and colors. Different algorithms are used for different experimental purposes to construct corresponding spatial models to describe and analyze the spatial pattern in terms of conformational relationships, so as to better understand the relationship between human activities and spatial structure.

The core of spatial syntax is to study the interactive relationship between space and human beings, and to study space as an independent system. It also links the form and content of space so that it is abstracted into graphical elements, and quantifies the interrelationships between different elements. The results are analyzed using algorithms to study the associations between the space itself and the elements within it. After carefully analyzing and parsing the core idea of space syntax theory, it is divided into the following three aspects:

(1) Space is an important place for people's activities, as well as the main constituent element of people's activities.

(2) The characteristics and attributes of individual space do not exist in isolation, but are jointly determined by the interrelationships in the space system in which it is located.

(3) The creation of space originates from the influence of human beings, and in the process of its development and evolution, human behavioral activities and space are interrelated, and the interaction between them produces a variety of social effects.

The basic principle of spatial syntax is spatial segmentation, and according to the spatial situation of the city, there are three different basic methods for spatial segmentation: convex spatial method, axial method and visual field analysis method.

In this paper, we mainly use the two analysis methods, axis analysis and visual field analysis, to analyze the public space of urban residential environment from the aspects of actual walking paths and line of sight.

2.1.1. Spatial syntactic variables

The spatial syntax theory quantitatively describes the morphological structure of real spatial systems with specific syntactic variables defined as shown below:

(1) Connection value

Connection value C_i is defined as the total number of other nodes (or spaces) directly connected to the i nd node (or space). In a real space system, the connection value then represents the total

number of other spaces connected to a space. The formula is shown below:

$$C_i = k \quad (1)$$

Where, C_i is the connection value of the i nd node. k is the number of nodes directly connected to the i th node.

(2) Control value

The control value $Ctrl_i$ is defined as the sum of the reciprocal of the connection values of the other nodes directly connected to the i th node. In a real space system, the control value indicates the degree of control that a space has over other spaces that intersect it. The formula is shown below:

$$Ctrl_i \sum_{j=1}^k \frac{1}{c_j} \quad (2)$$

Where, $Ctrl_i$ is the control value of the i nd node. $j(j=1,2,\dots,k)$ is the node directly connected to the i th node, C_j is the connection value of the j th node. k is the number of nodes directly connected to the i th node.

(3) Degree of selectivity or penetration

Selectivity is defined as the frequency of the i th node as the shortest distance (i.e., minimum number of topological steps) between the other two nodes.

(4) Depth value

Depth value D_i is defined as the sum of the shortest distance (i.e., the minimum number of topological steps) for the i th node to reach all other nodes. It is known that in spatial syntax the distance between a node to reach another neighboring node is recorded as a topological step, so it is important to note that the depth value does not indicate the actual distance but emphasizes the number of transitions of a particular node. The formula is shown below:

$$D_i = \sum_{j=1}^n d_{ij} \quad (3)$$

Where, D_i is the depth value of the i nd node. $j(j=1,2,\dots,n)$ is the node directly connected to the i th node, d_{ij} is the shortest distance from the i th node to the j th node. n is the total number of nodes in the connection graph.

However, in practice, the concept of “average depth value” is often used, and the formula is shown below:

$$MD_i = \frac{\sum_{j=1}^n d_{ij}}{n-1} \quad (4)$$

where MD_i is the average depth value of the i nd node. $j(j=1,2,\dots,n)$ is the node directly connected to the i th node, d_{ij} is the shortest distance from the i th node to the j th node. n is the total number of nodes in the connection graph.

(5) Degree of integration or integration

Integration I_i is defined as the interrelationship between the i th node and all other nodes. In order to exclude the interference of spatial node number and size factors, topology asymmetry, etc., the integration degree is standardized using the relative asymmetry value (RA) and the true relative asymmetry value (RRA), which is numerically the reciprocal of the true relative asymmetry value RRA. The calculation formula is shown below:

$$RA_i = \frac{2(MD_i - 1)}{n - 2} \quad (5)$$

$$RRA_i = \frac{RA_i}{D_n} \quad (6)$$

$$D_n = \frac{2 \left(n \left(\log_2 \frac{n+2}{3} - 1 \right) + 1 \right)}{(n-1)(n-2)} \quad (7)$$

$$I_i = \frac{1}{RRA_i} \quad (8)$$

Where, RA_i is the relative asymmetry value of the i nd node and is the result of the first normalization using MD_i . RRA_i is the true relative asymmetry value for the i th node, which is the result of the second normalization using D_n . D_n is the normalization parameter, I_i is the integration of the i th node. MD_i is the average depth value of the i th node, and n is the total number of nodes in the connection graph.

Integration degree is generally categorized into global integration degree and local integration degree. The global integration degree indicates that the interrelationships between a space and all other spaces are considered globally. The local integration degree, on the other hand, indicates that the interrelationships between a space and all other spaces within a few steps of topological distance are considered only.

(6) Degree of Visual Area Concentration

The degree of view area clustering is defined as the degree to which the i th node is occluded and constrained. The formula is shown below:

$$Visual\ Clustering\ Coefficient_{(i)} = \frac{k}{k(k-1)} \quad (9)$$

Where, $Visual\ Clustering\ Coefficient_{(i)}$ is the clustering degree of the view area of the i nd node. k is the number of nodes contained in the region with the i th node.

(7) Synergy

Synergy is defined as the ratio of the linear correlation coefficient between the global integration degree and the local integration degree (the global integration degree is the X-axis and the local integration degree is the Y-axis), which is used to describe the interrelationship between the local space and the overall space. The formula is shown below:

$$R^2 = \frac{\left[\sum_{i=1}^n (I_3 - \bar{I}_3)(I_i - \bar{I}) \right]^2}{\sum_{i=1}^n (I_3 - \bar{I}_3)^2 (I_i - \bar{I})^2} \quad (10)$$

Where, R is the synergy degree of the i nd node. I_3 is the three-step integration degree of the i th node, \bar{I}_3 is the average value of the three-step integration degree of the total nodes, I_i is the global integration degree of the i th node. \bar{I} is the average value of global integration degree of total nodes, n is the total number of nodes in the connection graph.

(8) Intelligibility

Comprehensibility is defined as the ratio of the linear correlation coefficient between the global integration degree and the connection value (connection value is the X-axis, global integration degree is the Y-axis), which is used to describe the interrelationship between the local space and the overall space. The formula is shown below:

$$R^2 = \frac{\left[\sum_{i=1}^n (C_i - \bar{C})(I_i - \bar{I}) \right]^2}{\sum_{i=1}^n (C_i - \bar{C})^2 (I_i - \bar{I})^2} \quad (11)$$

Where, R is the comprehensibility of the i nd node. C_i is the connection value of the i th node. \bar{C} is the average of the connection values of the total nodes. I_i is the global integration of the i th node, is the average value of the global integration of the total nodes, and n is the total number of nodes in the connection graph the lower the sex.

(9) Human flow interface value

The human flow interface value is defined as the ratio of the linear correlation coefficient between the global integration degree and the selection degree. The formula is shown below:

$$R^2 = \frac{\left[\sum_{i=1}^n (C_i - \bar{C})(I_i - \bar{I}) \right]^2}{\sum_{i=1}^n (C_i - \bar{C})^2 (I_i - \bar{I})^2} \quad (12)$$

Where, R is the human interface value of the i nd node, C_i is the selectivity of the i rd node, \bar{C} is the average value of selectivity of the total nodes. I_i is the global integration of the i th node, \bar{I} is the average value of global integration of the total nodes, and n is the total number of nodes in the connection graph.

2.1.2. Applications in the environmental transformation of urban public spaces

Spatial syntax can both quantitatively describe urban linear space and analyze the transformation trend of nodal space. It combines people's behavioral activities and the conformational evolution of nodal spaces to guide the spatial environment transformation towards rationality and health by studying the degree of people's cognition of nodal spaces with public attributes.

The small-scale spatial image map of the city is analyzed on an axial map to derive a spatial picture between the elements. It shows the grouping relationship of the elements of the urban environment in this small-scale space, and the association and readability of the elements such as roads, boundaries, and areas can be seen through the analysis of the axial map.

(1) Roads, in the spatial syntax, the axes are used to simulate the configuration of the urban road system, which sees the urban roads as the main carrier of the citizens' movement to observe and experience the urban space.

In the spatial syntax data index system, axes represent the degree of road integration, and different axes represent different degrees of road accessibility and pedestrian flow concentration. Therefore, the road is a spatial form closely related to people's behavioral movement, and only on the basis of linear space can form the convex space in the spatial syntax.

(2) Boundary, spatial syntax of the boundary is categorized as a linear space category, the boundary space generally has a high degree of recognition, because of its nature is relatively single and lack of functional composite. The continuity of boundaries will often be integrated in spatial remodeling.

(3) Region, the region in the spatial syntax carries the psychological cognition of human space. After the axial map describing the domain is drawn, it will be able to fully explain the process of people's cognition of spatial features from the one-dimensional spatial level. Among them, the integration value is an important basis for extrapolating from the local space to the overall space. Only by clearly cognizing the relationship between local space and overall configuration can the stability and integrity of regional space be assessed, and the layout of node space in the region can be formulated more scientifically.

(4) Node, space syntax from the perspective of configuration put forward the concept of node space, which represents the transition of two spatial forms. In terms of data performance, nodes often have high integration characteristics, showing typical convex polygonal qualities and better visual area expression, such as public spaces in the city such as squares and parks.

2.2. Negative space

This paper argues that “positive spaces are those that are planned, satisfy human needs, and where people congregate, while negative spaces are those that are unplanned, develop naturally, and where people dissipate.” Disorder, marginalization, and lack of attention are the most prominent features of negative space. In the field of exterior space design, landscape elements are arranged and combined in a systematic way to form a favorite place with perfect functionality, that is, positive space. Positive and negative spaces can be transformed into each other with the changes of urban planning, where more attention should be paid to the behavior and subjective feelings of users.

2.3. Spatial dynamics

Urban vitality: “Vitality” characterizes the vitality of an organism, of which “people, activities and places” are the main components. Urban vitality is divided into four dimensions: environmental vitality, social vitality, economic vitality and cultural vitality.

Street vitality: it refers to the participation of people in a series of fixed or continuous activities in urban streets, which is the external manifestation of the vitality of urban society and the key and core of community planning and construction. Crowd density is the most intuitive criterion for judging the strength of street vitality, and its main manifestation is the gathering of people mainly for the purpose of slow-moving activities in the streets and the various activities they carry out. The “people” and “human activities” in the street are the key to evaluating the vitality of the street.

Jane Jacobs clarifies the position of people in urban construction, and points out that in order to increase the vitality of urban space, it is necessary to pay more attention to the characteristics of the diversity of urban space. He also put forward the theory of urban vitality and the four elements of urban vitality: (1) mixed land use, (2) small-scale neighborhoods, (3) the co-existence of old and new buildings, and (4) high population density.

3. Creating community vitality in residential environments based on spatial syntax

3.1. Study area and characteristics

In order to obtain intuitive and quantitative analysis results, spatial syntax theory was chosen as the main underlying theory of the study. The corresponding software for quantitative analysis of group structure by applying spatial syntactic variables is chosen to build and calculate the model, and field research is conducted to support the calculation results and to analyze the characteristics of pedestrian behavior in a more specific way. It is hoped that through the research, the problems existing in the current situation of urban public space will be explored in depth, and corresponding solutions will be found and optimization strategies will be proposed.

In this paper, the research object of the linear urban public space around the residential station in the city is mainly the streets within a radius of 500m around the rail station. The rail station is located in the central area of the city, and the research focuses on the spatial structural relationship of the urban public space around the rail station and the characteristics of human behavior it affects. By applying the corresponding calculation software of spatial syntax to establish an analytical model of the street axis, we quantitatively analyze the characteristics and interrelationships inherent in the spatial structure of the street, and then explore the behavioral patterns and laws of pedestrian activities based on this.

3.2. Evaluation of public use of negative space

Through the observation method and questionnaire survey method to analyze the characteristics of users' man-made activities, the corresponding satisfaction and activity preferences, to summarize the users' demand for the use intention of the linear urban negative space around the residential site, and to provide a realistic basis for the optimization and renovation strategy of the negative space proposed in the later section.

(1) The time schedule of the research related to public use evaluation is as follows:

Observe the behavioral activities of the crowd, randomly select a working day and a non-working day, and remove bad weather such as snowstorms and rainstorms to avoid the influence of weather on the activity time and characteristics of the behavior. Behavioral observation time periods: 7:00-9:00, 9:30-11:30, 14:30-16:30, and 17:00-19:00. (Peak working hours are 7:00-9:00 and 17:00-19:00, for a total of 8 hours per day).

The distribution of the research questionnaire was divided into two forms: online distribution and offline distribution. Three sites with relatively good spatial continuity of external negative space were selected for the study. A total of 450 questionnaires were distributed in the three sites, with 427 valid questionnaires and 94.9% validity rate of the questionnaires.

(2) Analysis of behavioral observation results

Based on the observation of the three typical negative spaces, it is concluded that the nature of people's activities can be categorized into necessity activities, spontaneous activities and social activities. Behavioral activities in the external space include playing, sitting, chatting, walking, stopping for a short time, singing and dancing.

(3) Analysis of questionnaire data processing

Negative space A, B, and C were taken as the main survey objects in this residential environment, in which the respondents evaluated negative space A as follows.

The statistics of the factors of the scale of negative space A are shown in Table 1. Respondents rated the fitness facilities, signage and guidance facilities, parking facilities, landscape facilities, plant species, and visual aesthetics of the area as low, and no more than four respondents rated the signage and guidance facilities, landscape facilities, and plant species as “very satisfied”.

Table 1. The factors of the scale of negative space a are calculated

	Evaluation factor	Very dissatisfied	Unsatisfactory	OK	Comparison satisfaction	Very satisfied
1	Leisure facilities satisfaction	56	47	32	10	9
2	Entertainment facilities satisfaction	35	45	21	15	12
3	Fitness facilities	47	20	25	8	5
4	Identification guide facility satisfaction	43	21	29	15	2
5	Parking facility satisfaction	49	36	15	17	5
6	The level of satisfaction of landscape facilities	43	15	21	14	3
7	Afforestation area satisfaction	14	9	21	13	10
8	Plant species satisfaction	16	11	21	14	2
9	Satisfaction of catering facilities	15	8	26	17	10
10	Degree of satisfaction of commercial facilities	14	35	10	16	8
11	Level of traffic environment	21	29	35	15	15
12	Satisfaction of road service	16	26	26	24	14
13	Environmental satisfaction of the street	32	27	32	19	9
14	Cultural guidance facilities satisfaction	8	15	18	18	12
15	Visual satisfaction	12	22	20	15	5
16	Accessibility facilities	23	15	24	21	7

Integrating respondents' ratings of the three typical negative spaces, the means and standard deviations of the three typical negative spaces are shown in Figure 1.

The mean values of negative space B are all relatively low. There are five factors, namely, rest facilities, recreational facilities, fitness facilities, street environment, and visual aesthetics, which are rated as “not very satisfactory” (score range: $2.5 > S \geq 1.5$). The lowest value was for rest facilities, with a mean value of 2.15 points. The remaining 11 factors were rated as “fair” (score range: $3.5 > S \geq 2.5$). The highest value was parking facilities, with a mean value of 3.33.

The mean value of Negative Space C is higher than that of the other two sites, with the mean value of the 13 evaluation factors greater than or equal to 2.71. 5 factors, namely, food and beverage facilities, commercial facilities, transportation environment, road pavement, and street environment, were evaluated to be “relatively satisfactory” (score range: $4.5 > S \geq 3.5$). The highest value was the transportation environment, with a mean value of 3.66. The remaining eight factors were rated as “average” in terms of satisfaction (range of scores: $3.5 > S \geq 2.5$), and the lowest value was the rest facilities, with a mean value of 2.85.

Integrating the 16 evaluation factors, the mean and standard deviation of the negative spaces A, B, and C are shown in the figure as 2.57 ± 1.132 , 2.68 ± 1.046 , and 3.25 ± 1.016 , respectively.

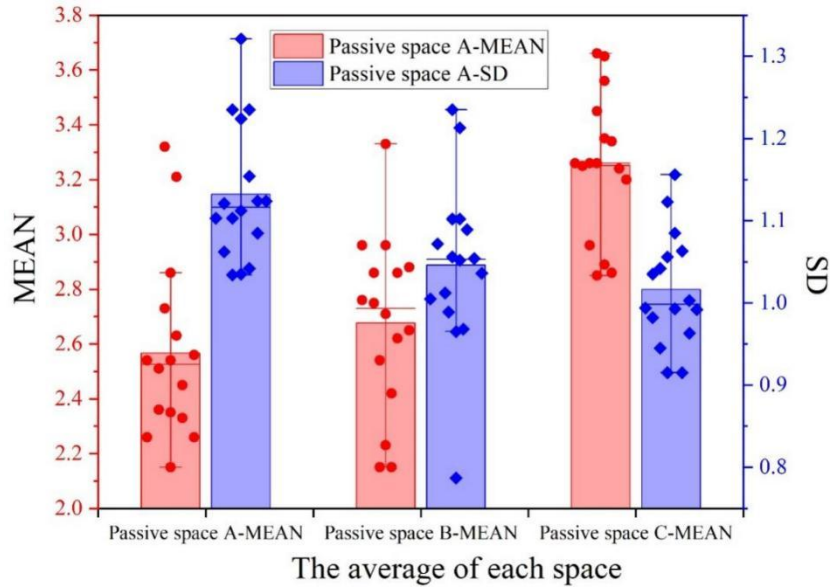


Figure 1. The mean and standard deviation of the three typical negative Spaces

3.3. Spatial Characteristics of the Living Environment and Spatial Vitality Associations

In order to further explore the influencing elements of community spatial vitality, this chapter uses the SPSS statistical analysis tool to do a correlation analysis between community spatial characteristics and spatial vitality [19].

Community spatial characteristics and spatial vitality indicators are shown in Table 2. The independent variables of residential space characteristics include accessibility, connectivity, detour coefficient, interface connectivity, interface transparency, boundary width-to-height ratio, sky area ratio, green visibility, walkability, functional density, and functional mixing degree.

Table 2. Spatial characteristics and spatial vitality indicators of the community

Spatial characteristics - self-variables	X1 accessibility
	X2 connection
Spatial dynamic dependent variable	X3 winding coefficient
	X4 interface continuous
	X5 interface transparency
	X6 boundary width high ratio
	X7 sky area rate
	X8 green vision
	X9 walkability
	X10 function density
	X11 function mixture
	Y comprehensive population density

3.3.1. Correlation analysis

SPSS was used to do correlation analysis on the spatial characteristics and vitality of the linear urban communities around the residential sites, and the coefficient r was used to reflect the degree of close correlation between the variables, which was calculated by the following formula:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (13)$$

In the formula r is the correlation coefficient and n is the number of samples in the study. x_i and y_i are bivariate. The larger $|r|$ is, the stronger the bivariate correlation is. Normally, a correlation coefficient of $0 < |r| \leq 0.1$ is a weak correlation. When $0.1 < |r| \leq 0.3$, it is a low correlation;

when $0.3 < |r| \leq 0.5$, it is a medium correlation; and when $0.5 < |r| \leq 0.8$, it is a high correlation. If $0.8 < |r| \leq 1$ it is significantly correlated, and $|r| = 1$ indicates perfect correlation.

The results of the above model correlation analysis are shown below. The results of the overall Pearson correlation analysis of community spatial vitality are shown in Table 3.

The correlation analysis results were tested for significance, if $P > 0.05$ indicates that the calculation results do not have significant correlation, do not have statistical significance, and the factor needs to be excluded from the linear regression analysis. $0.01 < P < 0.05$ indicates significant correlation, and $P < 0.01$ indicates extremely significant correlation.

Reachability, interface continuity, boundary aspect ratio, walkability and functional mixing passed the significance test, and the results of their quantitative analysis were reliable. The highest degree of correlation is accessibility, with a correlation coefficient of 0.752, followed by boundary aspect ratio, walkability, interface continuity, and functional mixing.

Table 3. The overall Pearson correlation analysis of community space

		Y comprehensive population density	Correlation degree
X1 accessibility	Correlation coefficient	0.752	Altitude correlation
	p value	0.000	
X2 connection	Correlation coefficient	0.035	Faintness
	p value	0.914	
X3 winding coefficient	Correlation coefficient	-0.294	Low correlation
	p value	0.213	
X4 interface continuous	Correlation coefficient	-0.637**	Altitude correlation
	p value	0.008	
X5 interface transparency	Correlation coefficient	0.328	Low correlation
	p value	0.203	
X6 boundary width high ratio	Correlation coefficient	0.713**	Altitude correlation
	p value	0.003	
X7 sky area rate	Correlation coefficient	0.154	Low correlation
	p value	0.569	
X8 green vision	Correlation coefficient	0.173	Low correlation
	p value	0.529	
X9 walkability	Correlation coefficient	0.705**	Altitude correlation
	p value	0.003	
X10 function density	Correlation coefficient	0.177	Low correlation
	p value	0.263	
X11 function mixture	Correlation coefficient	0.658	Altitude correlation
	p value	0.009	

3.3.2. Regression analysis

In order to further analyze the degree of influence of each street spatial carrier element on street vitality, multiple linear regression models are constructed for the factors that passed the significance test above. Multiple linear regression analysis can, on the one hand, distinguish the significance level of each spatial characteristic influence factor, and on the other hand, the standardized coefficients can reflect the specific degree of influence of the factors on spatial vitality. The city's residential environment community space integrated population density is set as the dependent variable, and the community space characteristics factors that have passed the significance test are set as the independent variables (and satisfy the principle of the least independent variable), and the multiple linear regression model is constructed.

The results of the multiple linear regression analysis of community space vitality are shown in Table 4. As can be seen from the table, the model formula is:

$$Y(\text{Aggregate population density}) = -15.965 + 18.454X1 - 6.792X4 + 3.055X6 + 4.127X9 + 5.103X11 \quad (14)$$

The model R^2 value is 0.973, which means that X1 accessibility, X4 interface continuity, X6 boundary aspect ratio, X9 walkability, and X11 functional mixing explain 97.3% of the variation in the Y composite population density. A F -test was conducted on the model and it was found that the model

passed the F -test, $F=41.297$, $p=0.000$. i.e., it indicates that at least one of X1 accessibility, X4 interface continuity, X6 boundary width to height ratio, X9 walkability, and X11 functional mixing will have an impact on the Y composite population density. To summarize the analysis, it can be seen that accessibility, boundary aspect ratio, walkability, and functional mixing will have a significant positive influence on spatial vitality. As well as interface continuity will have a significant negative impact on spatial vitality.

Table 4. The results of the multi-linear regression analysis of community space dynamic

	Nonnormalized coefficient		Normalization factor	t	p	VIF	R^2	Adjust R^2
	B	Standard error	Beta					
constant	-15.965	5.041	-	-5.662	0.005**	-		
X1	18.454	4.126	0.425	5.891	0.005**	1.524		
X4	-6.792	1.899	-0.332	-5.713	0.003**	1.369		
X6	3.055	0.875	0.294	5.034	0.004**	1.724		
X9	4.127	1.413	0.231	3.428	0.032*	1.508	0.973	0.925
X11	5.103	1.769	0.268	5.489	0.005**	1.367		

Dependent variable: y comprehensive population density
D-W value:4.582
 $F(6.57)=41.297$ $p=0.000$

3.4. Spatial optimization of residential environment based on spatial syntax

The research process is shown in Figure 2. Through the quantitative calculation of spatial grouping guided by the theory of spatial syntax to analyze the inherent logical relationship of spatial form, and through the research, questionnaires, interviews and other forms of analysis of human psychological cognition under the role of environmental conditions guided by the theory of environmental behavior, the combination of the two, and ultimately arrive at the problems of the urban public space around the city's residential rail stations, and then explore the solution strategy.

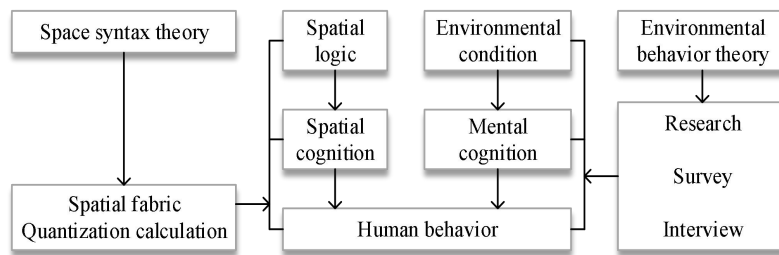


Figure 2. Research process

3.4.1. Problems

After observing the quantitative analysis of the spatial configuration of the 12 residential rail stations, it can be summarized that there are problems in the accessibility and legibility of the linear urban public space, which directly lead to the degradation of the quality of the pedestrian transportation system, resulting in the limitation of pedestrian activities.

(1) The form of local blank link refers to the urban residential area surrounded by streets, but there is no city street to reach or pass through, interrupting the connectivity of the street network and forming a blank area in the street network.

This form is mostly found in the street network of urban public space around modern residential rail stations, due to the fact that most high-end residential areas cover a wide area. And limited entrances and exits are gated, non-district vehicles or residents are prohibited from entering. Therefore, such residential areas have become “islands” in the urban street network system, seriously affecting the connectivity of the roads around the neighborhood, resulting in reduced regional accessibility.

(2) The local cluster connection pattern refers to the urban residential area in the street road network density, complex connection status, the direction of the relative chaos, the formation of disorderly clusters of dense pattern.

This pattern is mostly seen in the street network of the urban public space around the courtyard type residential rail station. As the courtyard type of residential form is no longer a traditional form of residence, more and more building additions, alterations, demolitions and the situation of the

compound mixed multi-family living situation cause the original old hutongs composed of the urban texture has been seriously damaged. The many residential corridors that have emerged to increase connectivity have become new urban street networks, but these new streets are not a continuation of the old form, and are internally disorganized and externally connected to a limited number of streets with a higher degree of overall integration. Except for the permanent residents, it is impossible to distinguish the location by the spatial form alone, and the recognizability is very low.

3.4.2. Optimized design

(1) Accessibility is one of the most important attributes of urban public space around the rail station, which comes from the transportation function of the rail station itself, a large number of pedestrians move to their destinations through the rail transportation in the city, and the accessibility of the pedestrian transportation system within a reasonable walking range after leaving the station directly determines the convenience of the pedestrians to reach their destinations. Therefore, the improvement of accessibility of linear urban public space around residential rail stations is the most important optimization demand.

From the analysis of syntactic variables in spatial syntactic theory, it can be seen that increasing the degree of connectivity between streets is the most effective way to improve the relative depth value and the overall integration value, which directly determine the accessibility level. The accessibility of a well-connected pedestrian transportation system will meet the needs of pedestrians and give full play to the role of the rail station to drive the development of the surrounding area.

(2) Good legibility is also one of the important attributes of urban public space around rail stations. One of the key points of good recognizability is that the urban public space system is clear, with a high degree of integration and synchronization of local space and overall space. That is to say, the information that people receive from the local space can make them recognize and perceive the convenience of the whole spatial system. Therefore, the morphology optimization of the street network structure is an important optimization strategy to improve the legibility of the pedestrian transportation system, clear hierarchy, the urban public space with rigorous logic of the form will have a high degree of legibility, and it is convenient for the users to grasp the information brought by the space they are in at any time.

4. Optimizing design effects in urban living environments

4.1. Community space optimization analysis based on spatial syntax

In the previous paper, the spatial syntax method was used to analyze and optimize the linear urban public space around the residential stations in the city in a more comprehensive and detailed way, and in the next section, the optimization results of the spatial syntax method on the linear urban public space around the residential stations in the city will be summarized and evaluated from the overall space and the local space, respectively.

4.1.1. Overall space

The overall spatial axis analysis data of the study area is shown in Table 5, and the spatial syntax analysis shows that the comprehensibility value of the linear urban public space around the residential-type sites in the city is 0.89, and the overall performance is high recognizability.

After the optimization of the linear urban public space around the residential-type sites in the city, most of the spaces have a high degree of integration and accessibility, while the road network is set up more freely. Exercise facilities and activity spaces are mainly fitness equipment and open communication spaces, so the area has a high spatial utilization. The spatial nodes have good accessibility and close connection with the surrounding space, and as the shared interaction space for citizens, they have strong openness, and the lawn area is the largest, which is easy to attract a lot of young people and middle-aged people to go to gather activities.

Through the analysis of the optimized residential environment synergy R^2 value is 0.83, a high value, indicating that the overall space and local space development is consistent, the correlation is significant, so the park space has high accessibility and the road system is smooth.

Table 5. The overall spatial axis analysis data of the research area

Parameter	Max	Avg	Min	Std Dev
Degree of conformity	0.81	0.55	0.36	0.05
Local conformity	2.63	0.17	0.43	0.21

Synergies	Global integration ratio and local integration ratio $R^2=0.83$			
Comprehensibility	Ratio of connection degree to conformity $R^2=0.89$			
Selectivity	65548	5360	0	8963

4.1.2. Local space

The local spatial visual field analysis data of the study area is shown in Table 6, with the negative space ABC as the local spatial visual field, the negative space A optimized by spatial syntax is the most attractive, the control value of the various road intersections is higher, the overall control of the site is strong, and the value of each parameter is the highest in the four scenic areas. The integration degree (feasible layer average and visual layer average) is 8.56 and 9.14 respectively.

Table 6. Local spatial view analysis data of the research area

Quantitative parameter/functional area	Passive space	Passive space	Passive space
	A	B	C
Conformity (the average of the feasible layer)	8.56	8.81	8.05
Conformity (visual layer average)	9.14	8.54	9.02
Control value (the feasible layer average)	0.98	1.00	0.98
Control value (visual layer average)	0.99	0.97	0.95
Concentration coefficient (the feasible layer average)	0.93	0.81	0.87
Concentration coefficient (visual layer average)	0.89	0.85	0.81

4.2. Quantitative analysis of community vitality after optimized design

In order to be able to clarify the degree of influence on community vitality centers of linear urban public spaces around residential-type sites optimized based on spatial syntax, this paper uses the vitality parameter formed by multiplying the spatial morphology variables of integration and selectivity as an indicator to measure the spatial vitality within a community. The values of the vitality parameter of the community vitality centers identified in the three cases including the internal road network of the open park and without the internal road network of the open park were compared.

The comparison of the vitality parameter values of the community vitality centers before and after the optimization of urban residential space is shown in Table 7.

It can be seen that comparing the vitality parameter values of the vitality streets identified without including the internal road network of open parks, after including the internal road network of open parks, the vitality parameter values of these vitality streets have increased to some extent, and the growth rate of the composite parameter can reach up to 92.38%. This indicates that the addition of the internal road network of the open park can lead to an increase in the vitality parameter values of some of its neighboring streets, i.e., the accessibility of the neighboring streets, as well as the potential for pedestrian traffic to pass through them, is increased.

In addition, among these vitality streets, the vitality parameter values of these streets increased significantly after the inclusion of the internal road network of the open park compared to those without the inclusion of the internal road network of the open park. For example, Longjiang Street, Wohexin Street, and Hengdao Street showed increases of 81.09%, 92.38%, and 73.40%, respectively. At the same time, the street locations of community vitality centers before and after joining the open park also changed, which indicates that when the value of a vitality parameter in the study area is increased to a certain extent, the vitality of the street will change from quantitative to qualitative change, and the location of the vitality center of the area will also change.

Through the comparative analysis of the changes in the location of community vitality centers and the changes in vitality parameters, it can be concluded that open parks have a very important influence on the vitality of community vitality centers and their layout in the community, which also shows that the internal road network of open parks has a very important influence on the overall pedestrian network of the community.

Through topological operations, the inclusion of park sub-networks can affect the overall network structure in the community, which in turn affects the spatial distribution of vitality in the community. The validity of the spatial syntax approach to the problem of the impact of open parks on community vitality centers is verified.

Table 7. The optimization of the dynamic parameter values was compared

Study case names	Street name	Whether it includes an open park network	IN*Choice(R=1000)	Growth rate(%)
Beixiu park	Corporate street	No	3562251	0.1076
		Yes	3945684	
Children's park	Dragon river street	No	401207	0.8109
		Yes	726534	
	Guogeli street	No	466934	0.4995
		Yes	700152	
Qingbin park	Hexing three streets	No	338899	0.9238
		Yes	651983	
	Zhongxing street	No	409124	0.0000
Yes	409124			
Shangzhi park	Cross street	No	782536	0.7340
		Yes	1356925	
	Xiangfang street	No	923651	0.1369
		Yes	1050084	

5. Conclusion

This paper obtains the public's subjective evaluation of negative spaces and analyzes the relationship between spatial characteristics of residential environments and spatial vitality. Combining the effects of accessibility, boundary width-to-height ratio, and walkability on spatial vitality, the spatial syntax method is applied to optimize the vitality of linear urban public spaces around residential sites.

Three negative spaces outside the sites with relatively good spatial continuity are selected for fixed-point analysis, and the mean scores of each evaluation factor for the three typical negative spaces are 2.57, 2.68, and 3.25, respectively. The problems of poor signage and guiding facilities, and the lack of landscaping facilities and plant species are mainly found in the negative space A. The negative space A is mainly characterized by poor signage and guiding facilities, and lack of landscaping facilities and plant species.

The spatial characteristics of residential environments in terms of accessibility, boundary aspect ratio, walkability, and functional mix can positively generate spatial vitality. The accessibility and legibility of the linear urban public space around the residential site is optimized by spatial syntactic modeling. The optimized comprehensibility value of the area is 0.89, and the R^2 value of the synergy of the residential environment is 0.83, which indicates that the overall space and the local space are developed in a consistent manner, with high identifiability and spatial accessibility, and a smooth road system. The values of the community vitality parameters of the residential environment of the urban negative space optimized by the spatial syntax method are all improved to some extent, and the growth rate of the composite parameter can reach up to 92.38%.

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