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Research on the Correlation Mechanism between Street Space Quality and Walking Behavior in Data Environment

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ABSTRACT: It is of great significance to explore the correlation mechanism between urban street space quality and residents' walking behavior for rational and effective allocation of street facilities resources and promotion of healthy and green travel. Taking Qiguitang block in Hefei as an example, the streetscape image is crawled through Python, and the elements of street spatial quality are quantified by a machine learning algorithm, spatial syntax, and ArcGIS. Get travel data through behavior observation, and then build a multiple linear regression model for the correlation study of spatial quality and behavior characteristics to summarize the interaction degree and mode of various influencing factors. The research shows that there is a specific mathematical relationship between walking behavior and street space elements, among which functional formats, walking width, and interface openness have a more significant impact on walking behavior. Accordingly, the optimization strategy of street space in the old city area is proposed to provide a reference for the formulation of Hefei street design guidelines.

KEY WORDS: big data; street space; walking behavior; street view pictures

Introduction

As my country's urbanization process continues to advance, the "car-oriented" urban space expansion model has led to a lack of walking space for residents, prompting academia to rethink and improve street space [1-2]. Its quality improvement and refined design are increasingly attracting attention[2].Street design guidelines, as a novel area of research on road spaces, have been emerging in both domestic and international cities in recent years[3]. This study, from the perspective of street space quality, investigates the correlation between its spatial characteristics and walking behavior[4-7],explores the space quality features that influence residents' walking behavior[7-8], and has significant implications for improving environment quality, promoting green and healthy travel[6],and enriching the content of street design guidelines.

The research on the correlation between street space and walking activities started from the material space level, and scholars at home and abroad have achieved quantification of qualitative research. In traditional research, William White used behavioral observation to count crowd behavior, which promoted the study of the relationship between material space and behavior.[1] Huang Jianzhong established a comprehensive measurement method for the built environment that includes multiple dimensions such as accessibility, convenience, comfort, and safety[2] . In

[The format of citation in this article]
XUAN Wei, PENG Kang, ZANG Chuanyun. Research on the Correlation Mechanism Between Street Space Quality and Walking Behavior in Data Environment[J].Journal of South Architecture, 2025(1): 60-80.

• **Fund Projects**: Natural Science Foundation of China (52008143); Natural Science Foundation of China (52478050).
Document Identification Code A **DOI** 10.33142/jsa.v2i1.15474 **Article number** 1000-0232(2025)05-060-21

addition, under the background of new data environment support, the relevant research on streets has gradually broken through the limitations of traditional field measurement and collection. The emergence of new technologies and new methods has helped to solve the previous relatively vague and subjective evaluation of urban space quality, as well as the current situation of too large scale and unclear indicators due to the limitation of data acquisition conditions[8] .Long Ling, Hao Xinhua, Tang Jingxian, Xu Leiqing, and others used street view image data and machine learning algorithms to construct a street space measurement method based on visual morphological indicators such as sky visual index, green view index, and street color pleasure index from a human-centered perspective[4-12] .From the perspective of research methods, existing studies mainly rely on theoretical perspectives such as environmental behavior, sociology, and street morphology aesthetics to conduct analysis. The methods used can be divided into classification description, subjective preference, and correlation analysis.[13] Early studies were mostly based on environmental behavior, summarizing the internal laws by observing street space and classifying behavior,[14-15] but it is difficult to quantify accurately. The subjective preference method needs to be analyzed with the help of statistical methods such as the analytic hierarchy process[16] , semantic differential method [17] ,and factor analysis[18] .To further quantify the differences in the impact of each indicator, the quality of samples and data is very crucial. The correlation analysis method mainly uses mathematical statistical methods such as correlation analysis and regression analysis to explore the mutual influence mechanism between behavior and space quality. Due to its objective, intuitive, and sophisticated characteristics, it has been widely used in related research in recent years.

In the past two years, with the development of technology and its dissemination in the world academic community, a large number of quantitative studies in urban-related fields have emerged. However, the proportion of quantitative research on street space quality at the human scale is relatively low, and the traditional methods commonly used in the research process have problems such asbeing time-consuming and inaccurate. In the context of the new data environment, the perspectives in quantitative research mostly focus on urban space at the macro level, and the research content mostly focuses on the spatial form and land use composition of the streets. There is a lack of quantitative research on the micro characteristics of street space quality, and the impact of human behavior on street space quality is ignored. The few studies on quantitative street space quality mostly use descriptive induction and lack the use of mathematical models to quantify the coupling mechanism between street space quality and behavior.

Therefore, this study is guided by environmental behavioral theory and supported by a new data environment. It takes the correlation mechanism between street space and walking behavior as the research object and explores the interaction patterns and degree of influence among various factors from a human-centered perspective. By measuring street space quality and studying the correlation between street space quality and behavior, we can understand the mutual needs and connections between pedestrians and various elements of material space and clarify the difference in intensity of significant influencing factors of various behaviors. Finally, based on the perspective of street space quality, the study offers suggestions for optimizing the street design guidelines for the old city area of Hefei.

1 Research design and indicator system construction

1.1 Research scope and sample selection

The old city area of Hefei (within the first ring road) has a long history and profound cultural heritage. It was once the political, economic, and cultural center of Hefei. It is also the place that best reflects the daily life of Hefei citizens[19] . With the evolution of the spatial functions of the old city, the changes in history, and the promotion of "urban dual repair"[20] the development history of the historical streets (Table 1) such as Hongxing Road, Women's Street, and Renmin Alley in the Qiguitang Block (Figure 1) represents a microcosm of urban renewal and construction history of the old city. Research on the street space quality of the Qiguitang Block is of great significance to the improvement of street quality and optimization of guidelines in Hefei.

The road network coordinate information within the blockis selected, and 146 sampling points are established on the road network with a sampling interval of 0.0005 degrees of longitude and latitude (about 30 meters) (Figure 1). The spacing is based on the theory of the human scale of external space.[21] It not only reduces the repetitiveness of street view content but also ensures the acquisition of refined and perceptible results while also taking into account the quality of behavioral data obtained by video shooting. The large-scale and high-precision sampling point setting ensures the diversity and authenticity of the research data.

Through the study of the phenomenon of Qiguitang Street in Hefei City, the built-up situation of the street space characteristics of the oldcity area of Hefei City is summarized, and the causes, impacts, and corresponding optimization methods of the built-up environment problems are deduced. Then, specific renewal ideas are developed to improve street space quality and promote healthy travel.

Table 1 Overview of typical streets

Street Name	Characteristics	Business Composition	Era	Street Length
Women's Street	Commercial pedestrian street	Dining, shopping, leisure	1990s	~ 270 meters
Hongxing Road	Cultural and artistic street	Shopping, leisure, residential	1980s	~ 1,700 meters
Renmin Alley	Dining and service street	Dining, convenience services, residential	1960s	~ 500 meters
Yimin Street	Clothing and service street	Shopping, residential	1960s	~ 500 meters
Lujiang Road	Food and service street	Shopping, residential	1960s	~ 1,500 meters
Dingjia Alley	Convenience service street	Convenience services, residential	1950s	~ 260 meters

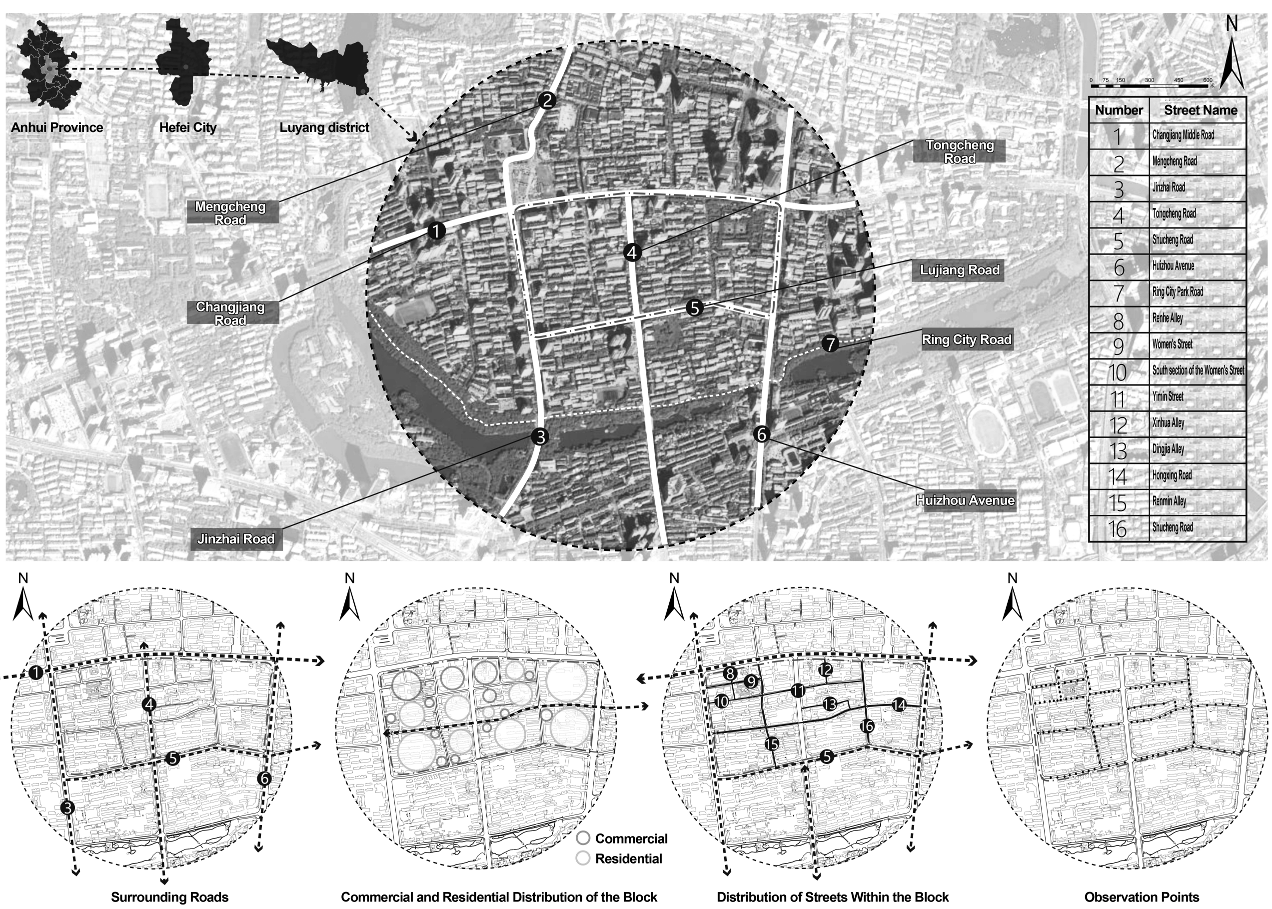

Figure 1 Research scope and observation point locations

1.2 Research Methods

Firstly, street space quality characteristics are extracted through multi-source big data relying on machine learning algorithms, and then a street space quality evaluation index system is constructed; secondly, behavioral observation is used to obtain the specific spatiotemporal characteristics of pedestrian behavior; then, a multivariate linear regression model for the study of the correlation between space quality and behavior is constructed, which includes comfort, convenience, safety, richness and four behavioral characteristics, as well as a corresponding measurement index system of 12 variables, and the degree and mode of interaction between the influencing factors are summarized based on the data processing results. The purpose is to provide precise support for the construction of high-quality block spaces by objectively analyzing the relationship between street space elements and walking behavior based on the urgent needs of urban micro-renewal and high-quality development of street guidelines.

1.3 Indicator selection

1.3.1 Review of existing research

The street space quality covers both objective material space and subjective psychological feelings[12].Its improvement and exploration have always been a hot topic of research. By reviewing classic urban design theories and sorting out relevant literature, we have concluded that (Table 2): 1. The indicator characteristics are not only continuous but also continue to expand in depth and breadth. 2. The research on space quality has gradually shifted from early qualitative analysis to comprehensive quantification, and the source of measurement data has also shifted from traditional, small sample data to multi-source big data.

Most of the current quantitative studies on street space quality use relatively subjective analysis methods, ignoring the relevant characteristics of street space quality from a human-centered perspective. The street space quality includes both objective material and psychological feelings. Different disciplines analyze it from different perspectives. Its connotation is complex, so it is necessary to adopt a comprehensive quantitative measurement method. The new data environment brings new possibilities in terms of scale, dimension, and content of analysis. It can obtain multi-source data on street material space and users' subjective psychological feelings at a human scale, providing strong support for multi-scale and high-precision evaluation of street space quality.

Table 2 Summary of research on street space quality characteristic factors

Period	Research content	Main characteristic factors	Data Sources and Research Methods	Research Scholar	Major references
1950—1999	Objective material space	Street form, color, landmarks, etc.	Observation and interviews	Lynch K	Good City Form
		Accessibility, density, mix of uses	Observation and interviews	Jacobs J	The Death and Life of Great American Cities
		Urban texture and architectural interface	Research and interviews	Trancik R	Finding Lost Space: Theories of Urban Design
		Pedestrian-friendly, moderately built-up, mixed-use	Research and photo documentation	Katz P	The New Urbanism: Toward an Architecture of Community
		Building form, green view index street furniture, human-centered scale, mixed functions, etc.	Literature Summary	Montgomery J	Making a City: Urbanity, Vitality and Urban Design
	Subjective psychological feelings	City intention	Observe and record	Lynch K	City Sense and City Design
		Safety, security, continuity, comfort, attractiveness	Observe and record	Fruin JJ	Pedestrian Planning and Design
		Intentionality, readability, diversity, street vitality	Literature summary	Montgomery J	Making a City: Urbanity, Vitality and Urban Design

(Continued)

Period	Research content	Main characteristic factors	Data Sources and Research Methods	Research Scholar	Major references
2000—2010	Objective material space	Street width, sidewalk width, street greenery, street-to-wall ratio, sky visibility, street furniture, street color, building visibility	Questionnaire Scoring	Ewing R	Measuring the Unmeasurable: Urban Design Qualities Related to Walkability
		Street business density and functional density	Research and statistical analysis	Xu Leiqing et al.	The impact of commercial street space and interface characteristics on pedestrian stay activities: a case study of Nanjing West Road in Shanghai
	Subjective psychological feelings	Intentionality, enclosure, human-centered scale, transparency, complexity, safety, comfort, fun, walkability	Questionnaire Scoring	Ewing R	Measuring Urban Design: Metrics for Livable Places
		Resident satisfaction, sense of security, etc.	Questionnaire Survey	Chen Yong	Analysis of pedestrian-friendly environment and influencing factors in rail transit station areas: an empirical study of 12 residential areas in Shanghai
2010 to present	Objective material space	Street width, street function density, functional mix, etc.	0SM map, POI data	Long Ying et al.	Quantitative evaluation of street vitality and analysis of influencing factors: A case study of Chengdu
		Green view index, street interface openness index, spatial enclosure index, and vehicle interference index	Street view images, ScgNct image segmentation, subjective scoring	Ye Yu et al.	Measuring street space quality at this scale: a large-scale, high-precision evaluation framework combining streetscape data and new analytical techniques
		Street function density and mix	Social networking site points of interest and check-in data	Shen Y	Urban Function Connectivity: Characterisation of Functional Urban Streets with Social Media Checking Data
		Street Greening and Accessibility	0SM Maps, Google Street View, Space Syntax	Tang Jingxian et al.	Measurement of street space quality in the central area of a megacity: A case study of the second and third ring roads in Beijing and the inner ring road in Shanghai
		Street length, width, height, cross-section ratio, street wall continuity	ESRI data, basic engineering ArcGIS platform measurement data	Harvey C	Streetscape Skeleton Measurement and Classification
		Accessibility of street space	Line segment model and natural street model, space creation evaluation	Batty M	Building a Science of Cities
		Street Space Quality and Accessibility	Street view image data, machine learning algorithms, ArcGIS data	Ye Yu et al.	Measuring street space quality at this scale: a large-scale, high-precision evaluation framework combining streetscape data and new analytical techniques
		Street space quality and pedestrian flow	Axwoman63 quantitative data 0SM map, street view pictures Pearson related	Zhao Xiaolong et al.	Study on the correlation between residential street space characteristics and pedestrian flow based on multi-source open data
		Convenience of life	0SM data, POI data, bus stop data	Fan Jun et al.	Multi-dimensional evaluation and control strategies of slow-moving street quality: integrated analysis based on multi-source urban data

1.3.2 The measurement indicators of street space quality

By reviewing classic urban design theories and sorting out the measurement indicators proposed by relevant researchers[20-26] , the objective material space and subjective psychological feelings of space quality characteristics are divided into four analytical dimensions: safety, convenience, comfort, and richness according to Maslow's needs theory (Figure 2). Therefore, the indicators are further subdivided based on these four dimensions. Additionally, an analysis is conducted on machine learning algorithms represented by SegNet[27], DeepLab[28], YOLO [29], etc., to identify the key factors that existing analysis techniques can support for measurement. Ultimately, 12 spatial feature indicators are determined (Figure 3, Table 3).

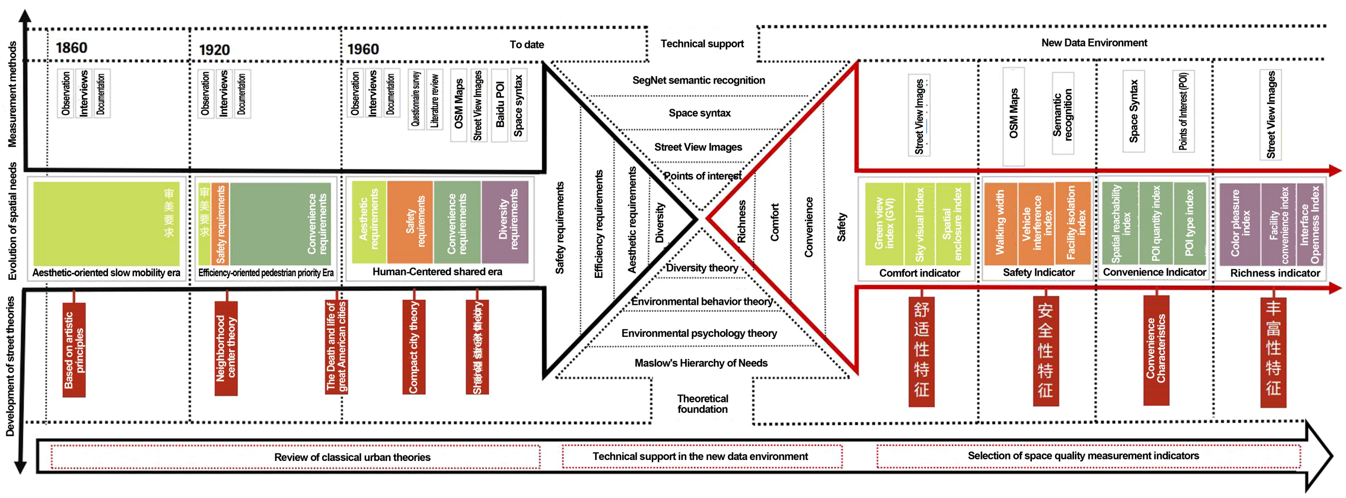

Figure 2 Roadmap of indicator screening technology

(1) Comfort characteristics: refers to the ability of street space to provide users with a comfortable and relaxing walking experience and visual perception. Among the many factors that affect spatial comfort, landscape greening and the openness of space have the most direct and universal impact on walking comfort[12] .Based on this, combined with existing analysis techniques, green view index, sky visual index, and spatial enclosure index are selected as measurement indicators. (Figure 4)

(2) Safety characteristics: The establishment of safety facilities is intended to ensure the safety of pedestrians. This is an active process. Only when users can gain a sense of active protection from the street material space for their travel can the construction of street safety be achieved. Therefore, the street safety discussed in this study mainly refers to the sense of security actively provided by the street material space[30] .Vehicle interference index, walking width, and facility isolation index are selected to quantify street safety.

(3) Richness characteristics: refers to the rich and layered visual experience that street elements bring to users, including the rich visual experience brought by the types of facilities, shop windows, and colors. Loveland (1998) pointed out that the most direct manifestation of beauty is the color observed by people, and visual color will directly affect people's preference for street space [12] .In summary, this article selects facility convenience index, color pleasure index, and interface openness index to further quantify the richness of the streets.

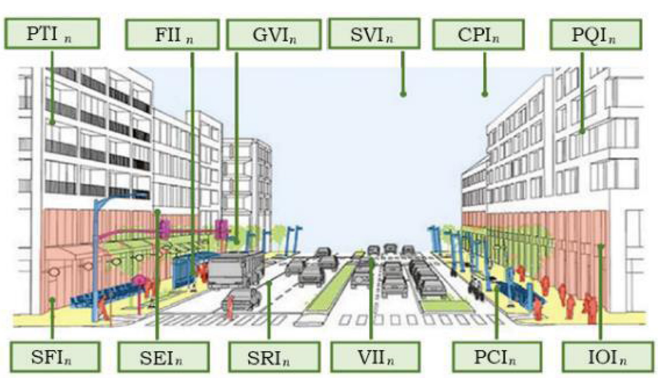

Figure 3 Street space quality index measurement chart

(4) Convenience characteristics: refers to the potential for a street to provide sufficient number of street services

and spaces for surrounding residents and pedestrians to meet the needs of users. From the perspective of street functional carrying capacity, it can be divided into two aspects: business function and traffic accessibility. This article selects POI business data and spatial reachability index to quantify street convenience.

Table 3 List of street space quality measurement indicators

Target layer	Analysis Dimensions	Measurement indicators	Collection method	Quantitative Model
Street space quality	Comfort	Green Viewindex (*GVI*)	Use Python to crawl street view data and use SegNet to cut and classify features.	Green plant pixels /total image pixels
		Skyvisual index (*SVI*)		Sky visible pixels/total image pixels
		Spatial enclosure index (*SEI*)		Building pixels/total image pixels
	Safety	Sidewalk footpath index(*SFI*)	Quantitative measurement based on OSM open data	Sidewalk footpath
		Facility isolation index (*FII*)	Use Python to crawl street view data and use SegNet to cut and classify features.	Isolation Facility Pixels/Total Image Pixels
		Vehicle interference index(*VII*)		Vehicle pixels/total image pixels
	Richness	Color pleasure index (*CPI*)	Identify the type of factors through semantics and calculate the numer of factor types.	Use the Simpson index to calculate
		Interface openness index (*IOI*)	Use Python to crawl street view data and use SegNet to cut and classify features.	Open interface pixels/total image pixels
		Facilityconvenience index (*FCI*)		Total number of facility categories
	Convenience	Spatial reachability(*SRI*)	Quantitative measurement based on ArcGIS\ Axwoman63	Space syntax calculation
		POI quantity index (*PQI*)	Baidu Map Open POI Capture\ ArcGIS Calculation.	Total PQI
		POI type index(*PTI*)		Number of PTI

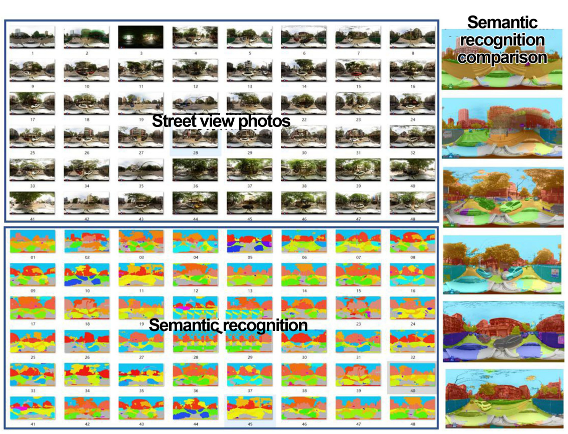

Figure 4 Semantic recognition results

1.3.3 Walking behavior

The selection ofwalking data is based on environmental behavioral theory, and its diversity is the result of the role of specific street space factors. As a representation of street space quality, walking data is extracted based on the classification of outdoor activities in *Communication and Space*.[21] Through on-site video recording and behavioral annotation, walking activities within the street area are captured. Subsequently, walking behaviors are categorized into four major types: sightseeing, leisure, consumption, and passing, which serve as the outcomes of spatial characteristics-driven behavior.

Sightseeing behavior mainly refers to the active behavior of users towards space under the influence of visual factors such as landscape, signs, and facilities, reflecting the ability of space to attract people. It mainly includes stopping to watch, taking photos, and admiring the buildings.

Leisure activities mainly refer to leisure activities that seek physical and mental adjustment and relaxation through various forms of "playing" during non-labor and non-working hours, with the purpose of achieving physical and mental health[31]. It specifically includes chatting, playing, sitting and resting, etc.

The consumption behavior in this study refers to the purchasing transactions of pedestrians attracted by the business formats along the street, including dining, shopping, etc.

Passing behavior refers to the behavior of the absolute and relative displacement of two points within a certain spatial range[32], reflecting the accessibility and continuity of the space. It specifically includes pedestrians walking, brisk walking, jogging, etc.

1.4 Data Processing

Walking behavior data: using a combination of video recording and behavior annotation. The recording spanned four days in total, including two weekdays and two rest days, with observation periods from 7:00 AM to 7:00 PM. Data is recorded for 0.5 hours every two hours. During recording, devices are placed diagonally at both ends of the observation space to avoid errors caused by perspective distortion and occlusion.

OSM open road network data is an open source world map that is freely used under an open license agreement. It contains information such as roads, green spaces and water systems, and is widely used in the study of space quality. Road network datais obtained by crawling Baidu Map raster images and performing vectorization processing using ArcGIS.

Street view data: By calling the Baidu Map API through Python, four street view pictures are captured at each sampling point with vertical and horizontal viewing angle, and then the SegNet machine learning algorithm is used to semantically recognize the target elements in the image to achieve accurate extraction of street space quality indicators.

Baidu POI business data: Pythonis used to crawl the Baidu map within the block. Based on the street scale and the combination of street-facing shops, a 20m radius buffer zone centered on sampling points is created using ArcGIS. Within these buffer zones, a total of 1,579 POIs are covered and calculated.

Based on space syntax theory, the Axwoman63 plugin for ArcGIS is used to calculate the spatial reachability index within the street area[33], explaining the potential that space can reach.

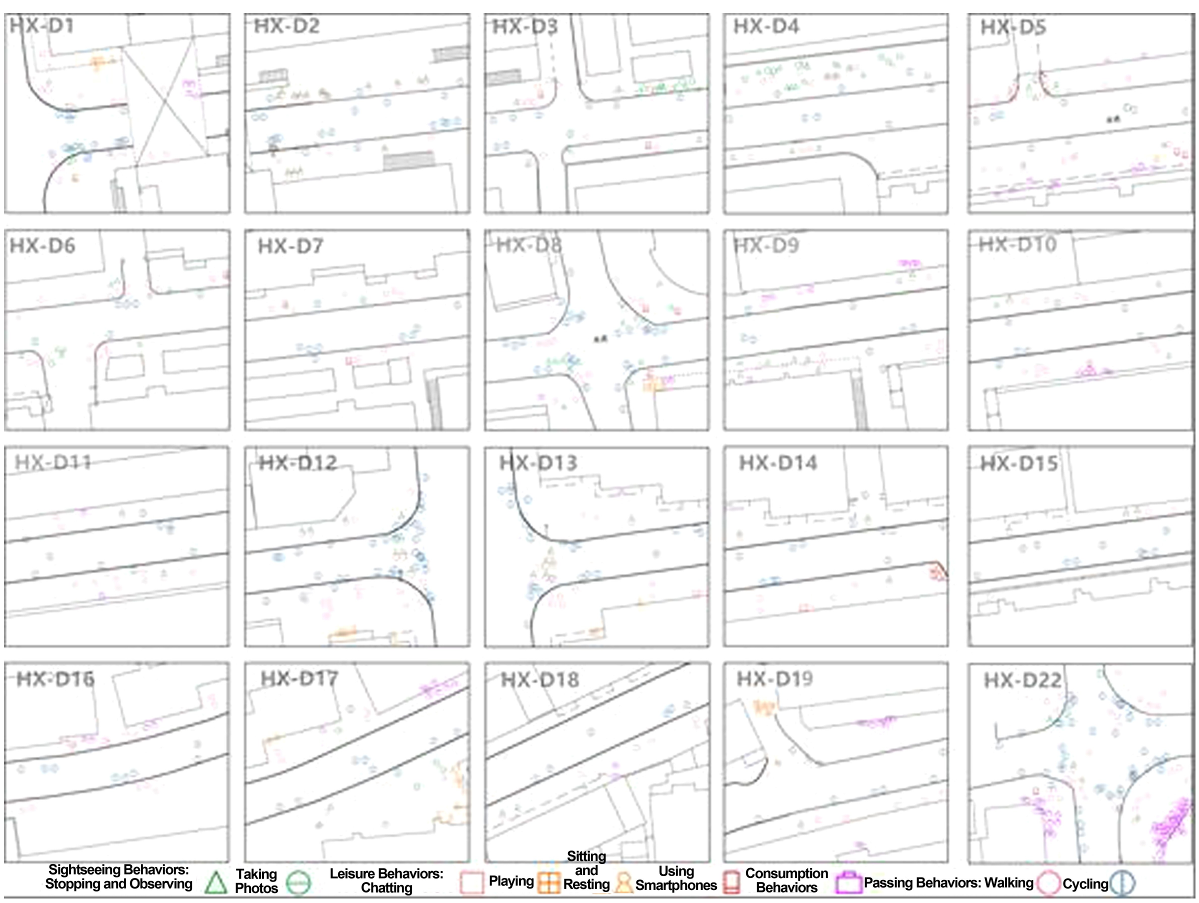

Figure 5 Behavior distribution diagram (partial)

2 Empirical research

2.1 Characteristics of Pedestrian Walking Behavior Data

According to statistics (Figures 5 and 6), people tend to choose spacious areas for walking and talking, while the narrow side is mainly for passing through and less spontaneous behavior; people will be attracted to look at the dazzling windows on both sides of the street, and will also look at the sudden road forks. When the spatial interface undergoes major changes, it is easy for people to observe out of curiosity or safety awareness; the beautiful street environment and interesting street facilities will attract pedestrians to take pictures. These findings suggest that specific pedestrian behaviors are influenced by environmental factors, and conversely, specific environmental elements guide pedestrian behaviors.

Based on ArcGIS kernel density analysis, the behavioral data from 146 observation points in the block across six time periodsare analyzed to obtain the kernel density map of the usage patterns of each sample space in the block in each time period (Figure 6), which shows that the density of user groups follows a trend of initial increase, subsequent decline, and final resurgence. In general, the flow of people in the morning period is higher than that in the afternoon, and the high density is scattered, with the main behavior being walking around, and there is no obvious aggregation. From the perspective of space usage, after 15:00, the spatial aggregation effect continues to expand over time from a scattered point-like distribution to a surface-like distribution fixed in a few places in the block.

By classifying and summarizing the behavioral data of the observation points, we obtained the behavioral characteristics to form a bar graph (Figure 7). The overall number of behaviors is uneven, with high-value fluctuations in the periphery and low-value continuity in the center, revealing that the difference in street space quality inside and outside the block leads toan uneven distribution of behaviors. The total number of behaviors and consumption behaviors in the behavior composition of Xinhua Alley and Dingjia Alley are far lower than the overall block level. It is found that the space quality indicators of the two are also lower than the overall level (Figure 8). On the contrary, Women's Street has high spatial vitality and high space quality. Therefore, the improvement of the internal vitality of the block requires the improvement of spatial quality as an internal driving force.

Based on this, there is a correlation between street space quality andwalking behavior. And what is the interaction between space and behavior? What is the extent of the influence of each factor? Studying the mathematical correlation mechanism between the two is of great significance to improving street quality and promoting healthy walking travel.

2.2 Spatial Data Characteristics

Based on the ArcGIS analysis platform, the quantitative data of 12 spatial characteristic indicators in four dimensions correlates with the sample space, and then a visual analysis is obtained through kernel density calculation (Figure 8).

2.2.1 The analysis of spatial characteristics of comfort

The environmental comfort indicators within the block exhibit two distinct patterns. The green view ratio and sky openness demonstrate a hollowing-out distribution pattern (Figure 8), with higher values near main roads and lower values in the block interior, indicating relatively limited green visibility and sky openness in the inner areas compared to the periphery. This reflects the compact spatial configuration and insufficient landscape vegetation in the old urban district's interior blocks. Conversely, the artificial comfort indicator -spatial enclosure index - shows an inverse pattern with lower values in the interior and higher values towards the periphery (Figure 8). This distribution characteristic shows that the building layout density and height inside the block also show a pattern of decreasing from the center to the periphery.

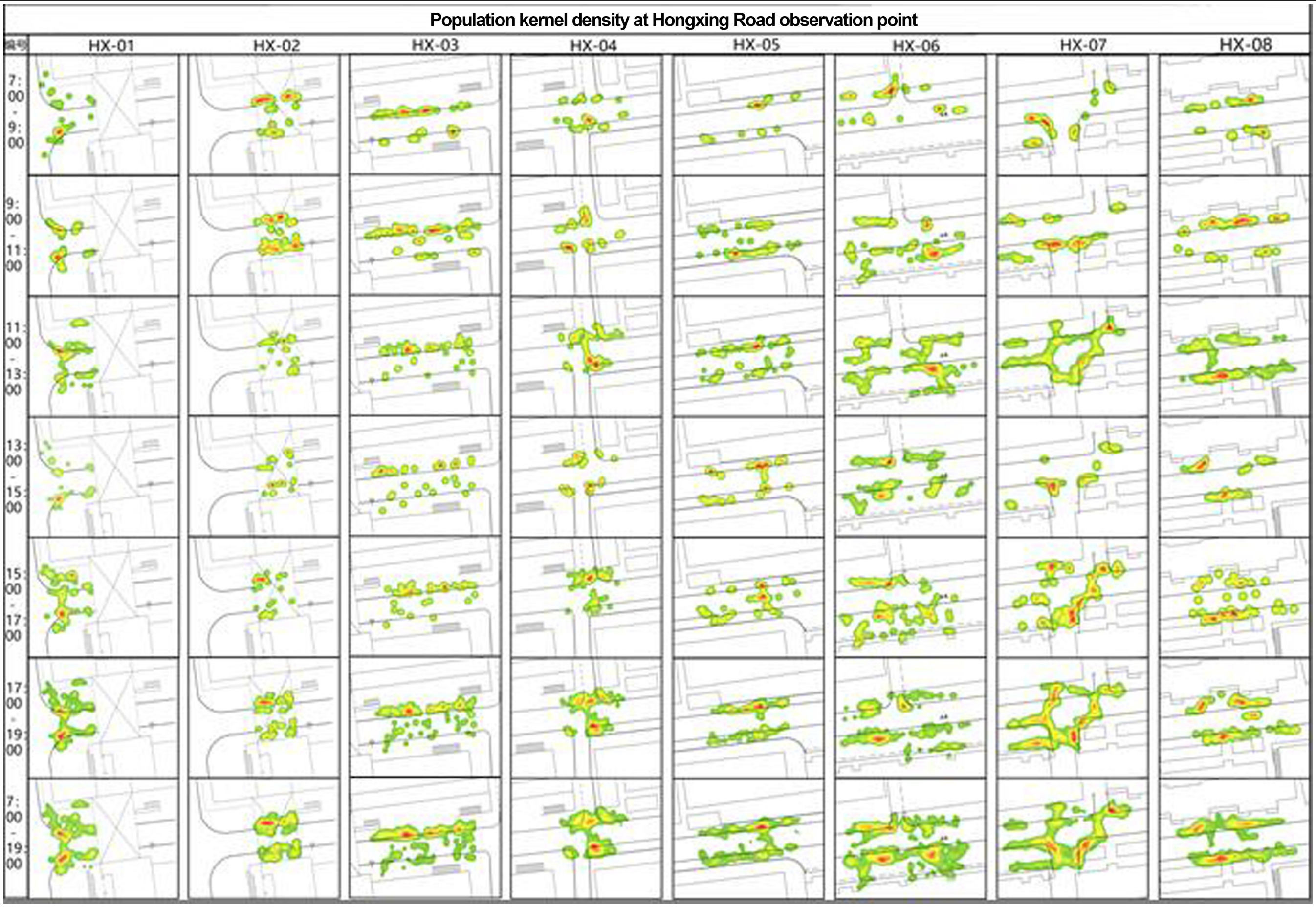

Figure 6 Kernel density map of behavior distribution (red star section)

Women's Street performs better than other streets in terms of comfort indicators, with a relatively suitable sense of enclosure and a relatively good green landscape. Other typical street data all clearly lean towards one indicator. The Renmin Alley has high sky visual index and spatial enclosure index, but the street's green view index has large areas of zero values. On the other hand, Hongxing Road shows a mixed pattern with both high and low values across the three indicators. Yimin Street has high green view index and low spatial enclosure index, reflecting a noticeable uneven distribution of current comfort levels across the streets in the old city area.

2.2.2 The analysis of spatial characteristics of safety

The quantitative results of various street safety indicators generally show a characteristic of being high outside and low inside (Figure 8), indicating that there are differences in the material space inside and outside the block, which in turn leads to the destruction of safety. From the analysis ofwalking width index and vehicle interference index (Figure 8), the vehicle interference index reflects the traffic conditions of the block; the walking width reflects the size of the walking space; the comprehensive measurement results of the two indicators show that the walking width presents a high value at the periphery and a low value in the center; the vehicle interference index presents a high value at the periphery and continuous holes in the inner core (Figure 8); therefore, the motor vehicle flow in the entire block is high, and the internal roads are narrow, and the pedestrian right of way is encroached, resulting in poor safety. Therefore, the balance between driving and walking is particularly urgent in the optimization of streets in the old city. The quantification of facility isolation index shows high values concentrated at the periphery, with a mixed pattern of highs and lows in the interior. Reasonable configuration of isolation facilities is conducive to ensuring smooth and safe travel for people and vehicles[32].

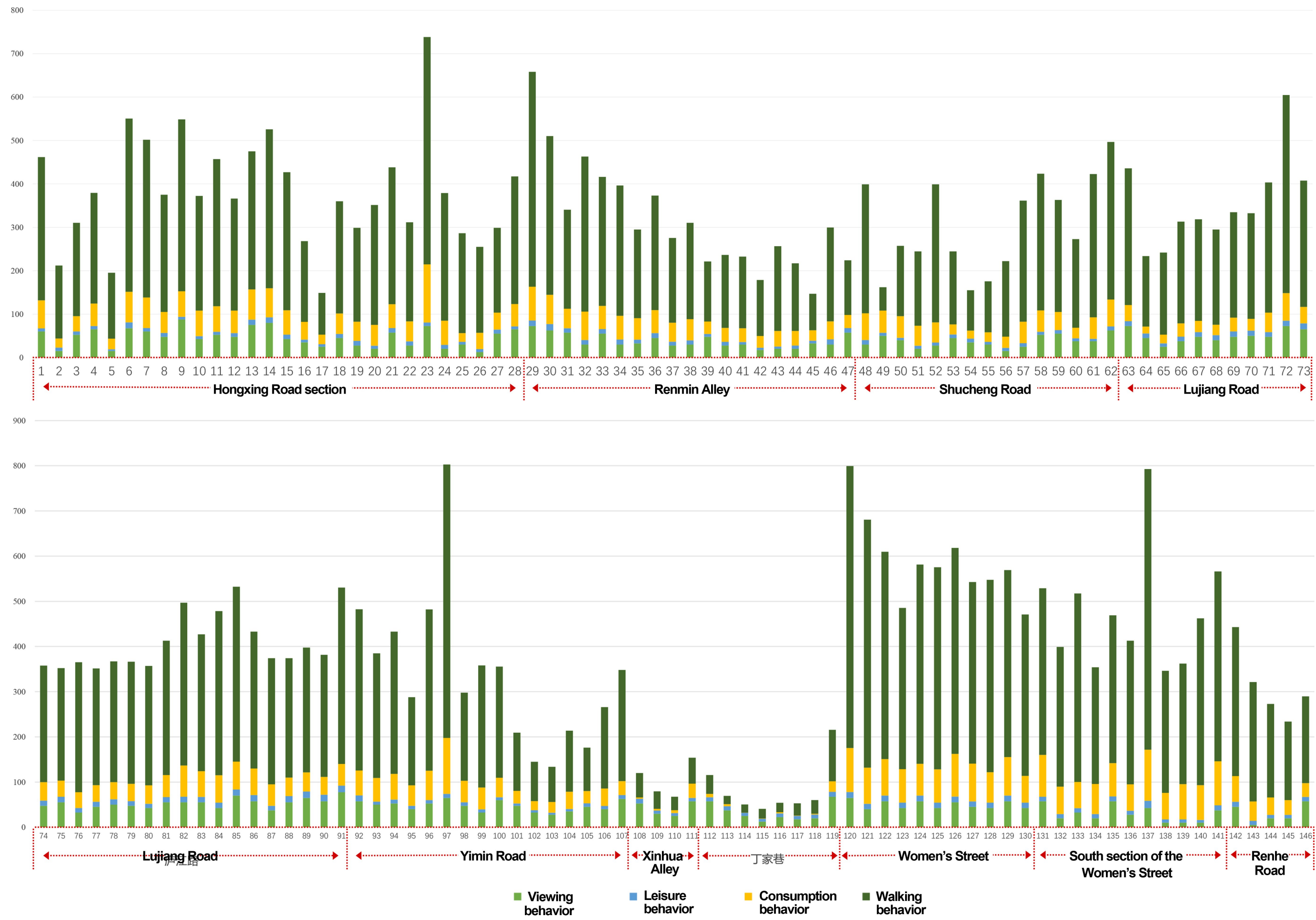

Figure 7 Bar graph of behavior characteristics composition

Based on the measurement results and the survey situation, Women's Street and Dingjia Alley are pedestrian streets and, therefore, have the best safety conditions. Hongxing Road's condition is relatively poor, with many entrances and exits. The walking width and facility isolation index are discontinuous, which affects the smoothness and safety of walking. The distribution of motor vehicles is staggered with intersections, indicating that there are many static parkings on the road, revealing the shortage of parking space in the block.

2.2.3 The analysis of spatial characteristics of richness

The overall color pleasure index and interface openness index of the blocks show the characteristics of multi-core scattering in the north, staggered highs and lows in the center, and low and continuous values in the south (Figure 8). They are greatly affected by the distribution of business types. The higher the commercial vitality is, the higher the interface openness index and the variety of colors are. Therefore, the measurement results indicate both the lack of street interface richness and the uneven distribution of business vitality. The facility convenience index is characterized by multi-core continuous distribution and central low-value point distribution, indicating that the overall distribution of facilities in the block is too balanced and unchanged, and there is a lack of intrinsic exploration of different types of street spaces, such as pocket parks, corner squares, street entrances, and other spaces for walking and leisure, interactive fun, and cultural improvement.

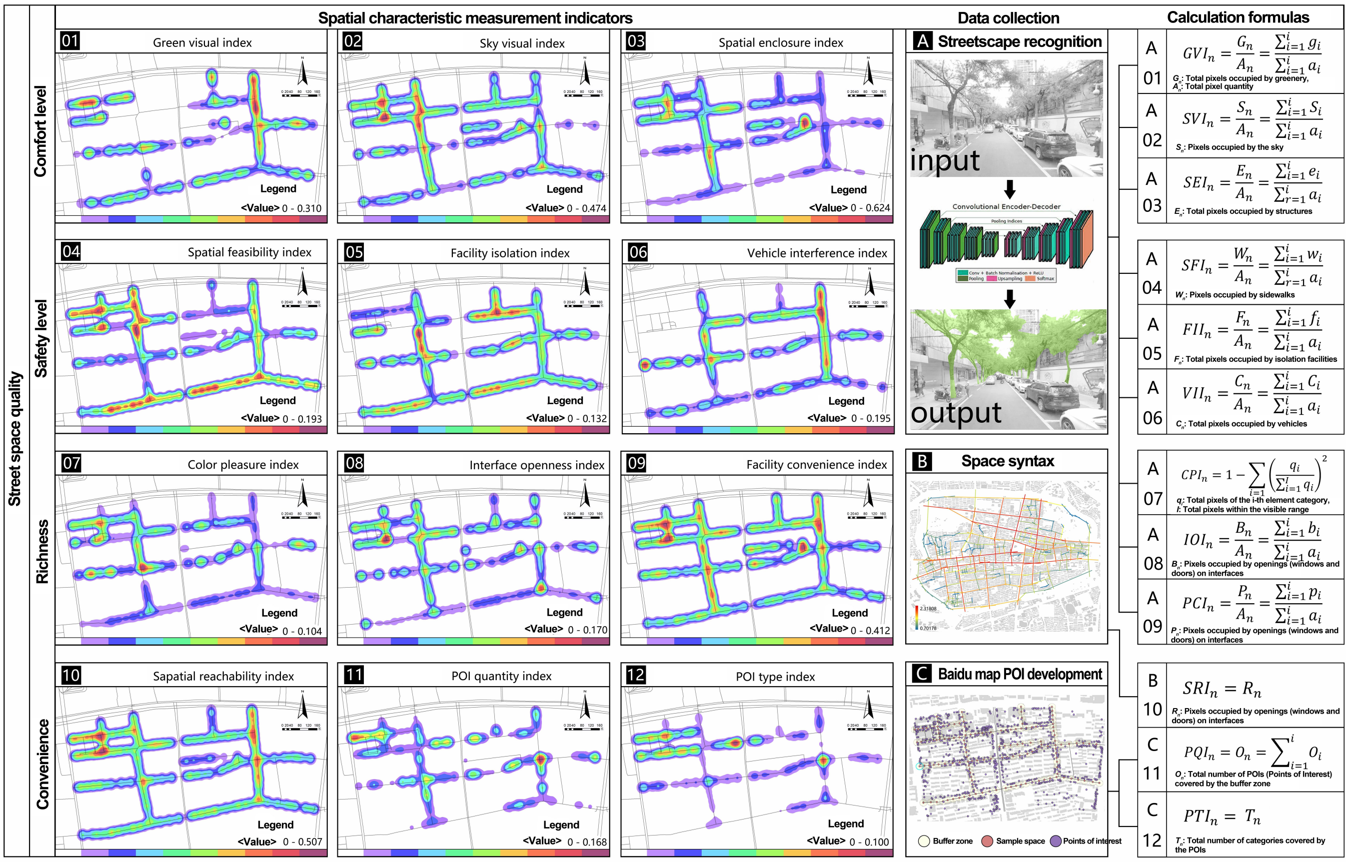

Figure 8 Measurement method and visualization of street space quality index

2.2.4 Analysis of spatial characteristics of convenience

Convenience index reflects the convenience level of the space in the entire space, which includes both the functional business types of the space and the accessibility potential of the space. There are differences in the distribution characteristics of the two. The overall distribution of POI types and numbers of the functional business convenience index is measured to show a multi-core dispersion, with high values extending from the north to the south (Figure 8). That is, high values spread from the center of the old city to the surrounding areas, reflecting the agglomeration and uneven distribution of business functions. Therefore, it is necessary to insert functions according to local conditions to activate the vitality of the block. The integration degree of the spatial reachability index is characterized by high values in the periphery and low values in the center, and the closer to the main road, the higher the integration degree. Most of the streets in the old city have similar characteristics and rules. The key to solving the problem is how to improve the attractiveness of the street space based on the existing spatial organizational relationship.

2.3 Results of correlation data analysis

Considering that the relationship between street space characteristics and behavior is relatively complex, the value of the behavior variable is not uniquely determined by the variable of a certain spatial characteristic. There may be multiple variables interacting with each other, and the degree of interaction between variables varies. Therefore, based on the SPSS data analysis platform, this study constructed a multiple linear regression model to study the association between space quality and behavior, including comfort, convenience, safety and four behavioral characteristics.

2.3.1 The impact of street space characteristics on various behaviors

(1) Constructing an impact mechanism model Based on the SPSS analysis platform, with street space quality characteristics as independent variables and the number of various behaviors distributed in the street space as the de-

pendent variable, a model of the impact mechanism of street space characteristics on life behaviorsis established, showing the quantitative relationship between various behaviors and street space characteristic indicators.

Table 4 Results of multiple regression analysis of sightseeing behavior and spatial characteristics

Level 1	Level 2	Standardized coefficient			Collinearity statistics		Adjusting R^2	F
index	index	Beta	t	p	Tolerance	VIF		
	constant		−3.087	0.00**				
Comfort	Green view index(GVI)	0.172	2.355	0.020**	0.349	2.865		
	Sky visual index(SVI)	−0.044	−0.740	0.460	0.518	1.930		
	Spatial enclosure index(SEI)	0.013	0.192	0.848	0.378	2.647		
Safety	Sidewalk footpath index (SFI)	0.254	4.147	0.000**	0.496	2.014		
	Facility isolation index (FII)	0.013	0.221	0.825	0.577	1.733		33.609
	Vehicle interference index(VII)	0.072	1.422	0.157	0.718	1.394	0.730	p= 0.000
Richness	Color pleasure index(CPI)	0.215	4.016	0.000**	0.651	1.537		
	Interface openness index (IOI)	0.586	10.593	0.000**	0.609	1.642		
	Facility convenience index (FCI)	0.357	7.907	0.000**	0.914	1.094		
Convenience	Spatial reachability index(SRI)	−0.036	−0.490	0.625	0.346	2.886		
	POI quantity index(PQI)	−0.065	−0.985	0.326	0.432	2.317		
	POI type index(PTI)	0.014	0.194	0.846	0.365	2.742		
DW value= 2.289								

* p< 0.05, ** p< 0.01

Table 5 Results of multiple regression analysis of leisure behavior and spatial characteristics

Level 1	Level 2	Standardized coefficient			Collinearity statistics		Adjusting R^2	F
index	index	Beta	t	p	Tolerance	VIF		
	constant		0.272	0.786				
Comfort	Green view index(GVI)	0.013	0.332	0.740	0.349	2.865		
	Sky visual index(SVI)	0.002	0.067	0.947	0.518	1.930		
	Spatial enclosure index(SEI)	0.014	0.387	0.700	0.378	2.647		
Safety	Sidewalk footpath index (SFI)	0.810	25.453	0.000**	0.496	2.014		
	Facility isolation index (FII)	−0.002	−0.052	0.958	0.577	1.733		154.584
	Vehicle interference index(VII)	−0.431	−16.286	0.000 **	0.718	1.394	0.927	p= 0.000
Richness	Color pleasure index(CPI)	−0.003	−0.104	0.917	0.651	1.537		
	Interface openness index (IOI)	0.212	7.375	0.000 **	0.609	1.642		
	Facility convenience index (FCI)	0.328	13.992	0.000 **	0.914	1.094		
Convenience	Spatial reachability index(SRI)	−0.043	−1.122	0.264	0.346	2.886		
	POI quantity index(PQI)	0.036	1.044	0.299	0.432	2.317		
	POI type index(PTI)	0.015	0.414	0.680	0.365	2.742		
DW value = 1.946								

* p< 0.05, ** p< 0.01

Table 6 Results of multiple regression analysis of consumption behavior and spatial characteristics

Level 1	Level 2	Standardized coefficient			Collinearity statistics		Adjusting R^2	F
index	index	Beta	t	p	Tolerance	VIF		
	constant		−4.753	0.000**				
Comfort	Green view index(*GVI*)	−0.046	−1.611	0.110	0.349	2.865		
	Sky visual index(*SVI*)	0.070	2.994	0.003**	0.518	1.930		
	Spatial enclosure index(*SEI*)	0.087	3.174	0.002**	0.378	2.647		
Safety	Sidewalk footpath index (*SFI*)	0.244	10.192	0.000**	0.496	2.014		
	Facility isolation index (*FII*)	−0.062	−2.807	0.006**	0.577	1.733		281.941
	Vehicle interference index(*VII*)	0.031	1.547	0.124	0.718	1.394	0.959	p= 0.000
Richness	Color pleasure index(*CPI*)	0.009	0.434	0.665	0.651	1.537		
	Interface openness index (*IOI*)	0.210	9.729	0.000**	0.609	1.642		
	Facility convenience index (*FCI*)	−0.023	−1.278	0.203	0.914	1.094		
Convenience	Spatial reachability index(*SRI*)	0.206	7.193	0.000**	0.346	2.886		
	POI quantity index(*PQI*)	0.386	15.028	0.000**	0.432	2.317		
	POI type index(*PTI*)	0.393	14.083	0.000**	0.365	2.742		
DW value= 0.876								

* $p< 0.05$, ** $p< 0.01$

Table 7 Results of multiple regression analysis of passing behavior and spatial characteristics

Level 1	Level 2	Standardized coefficient			Collinearity statistics		Adjusting R^2	F
index	index	Beta	t	p	Tolerance	VIF		
	constant		−8.543	0.000**				
Comfort	Green view index(*GVI*)	0.026	0.762	0.447	0.349	2.865		
	Sky visual index(*SVI*)	0.148	5.285	0.000**	0.518	1.930		
	Spatial enclosure index(*SEI*)	0.162	4.932	0.000**	0.378	2.647		
Safety	Sidewalk footpath index (*SFI*)	0.359	12.539	0.000**	0.496	2.014		
	Facility isolation index (*FII*)	−0.108	−4.072	0.000**	0.577	1.733		193.953
	Vehicle interference index(*VII*)	−0.005	−0.201	0.841	0.718	1.394	0.941	p= 0.000
Richness	Color pleasure index(*CPI*)	0.028	1.137	0.258	0.651	1.537		
	Interface openness index (*IOI*)	0.224	8.655	0.000**	0.609	1.642		
	Facility convenience index (*FCI*)	−0.005	−0.228	0.820	0.914	1.094		
Convenience	Spatial reachability index(*SRI*)	0.330	9.632	0.000**	0.346	2.886		
	POI quantity index(*PQI*)	0.512	16.687	0.000**	0.432	2.317		
	POI type index(*PTI*)	0.039	1.156	0.250	0.365	2.742		
DW value= 1.790								

* $p< 0.05$, ** $p< 0.01$

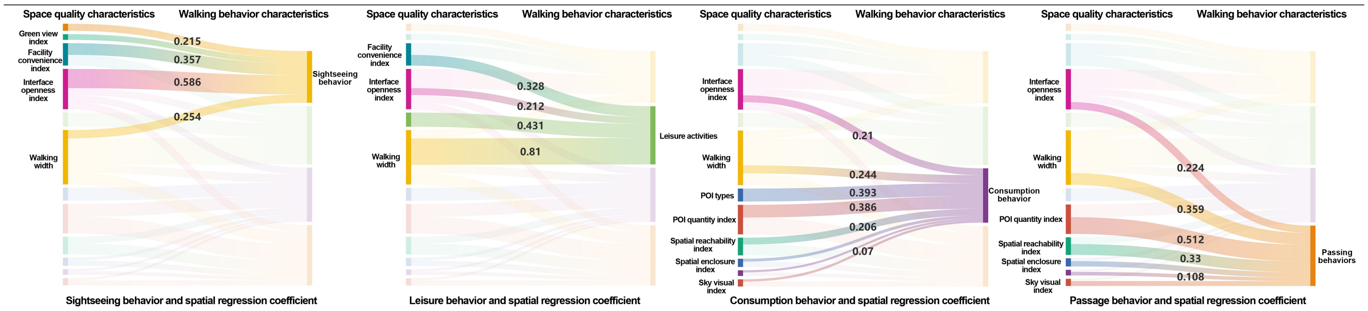

Figure 9 Multiple regression Beta value quantification chart

2.3.2 The influence of street space characteristics on various behaviors

On the basis of clarifying the influencing mechanism of each behavior and spatial characteristics, the P value is used to screen out the significant influencing factors, and the influence of each spatial characteristic on each behavior is analyzed by comparing the Beta value. (Figure 9)

(1) The influence of street space characteristics on sightseeing behavior. As shown in Table 4, the adjusted R-squared of the model is 0.730, indicating a good fit. The model passes the F-test (F= 33.609, P< 0.001), suggesting that the fitted equation is statistically significant; the VIF values of the independent variables are all less than 5 and the Debin-Watson test value of this study is 2.289, indicating that the observations in the study are independent of each other. By screening P values and comparing Beta values, the influence of various factors on sightseeing behavior in streets, ranked from strongest to weakest, is as follows: interface openness index (*Beta*= 0.586), facility convenience index (*Beta*= 0.357), walking width (*Beta*= 0.254), color pleasure index (*Beta*= 0.215), and green view index (*Beta*= 0.172). That is, interface openness index has the greatest impact on sightseeing behavior in living streets. Following that, facility convenience index, walking width, and color pleasure index play major roles, while green view index also promotes sightseeing behavior.

The richness index of street space has an important impact on viewing behavior. Among them, improving the interface openness in street space and reasonably arranging street furniture and facilities are important means to promote sightseeing behavior; spacious walking space, rich and diverse street colors and dense greenery are also space characteristics that attract pedestrians to stop and watch.

(2)The impact of street space characteristics on leisure behavior. As shown inTable 5, the model fits well, the fitted equation is statistically significant, and the observations in the study are independent of each other. By screening P values and comparing Beta values, the influence of various factors on leisure activities in streets, ranked from strongest to weakest, is as follows: walking width (*Beta*= 0.810), vehicle interference index(*Beta*= −0.431), facility convenience index (*Beta*= 0.328), and interface openness index(*Beta*= 0.212). That is, the walking width has the greatest impact on leisure behavior in living streets, and spacious pedestrian spaces are conducive to promoting the mixing and interaction of ground-floor commercial spaces. Following that, the impact of vehicle interference index is also significant and has an inhibitory effect on leisure behavior. In other words, the greater the number of motor vehicles in street spaces, the lower the likelihood of leisure activities. On the other hand, facility convenience index and interface openness index have a positive effect on leisure behavior.

Spacious pedestrian space has an important impact on leisure behavior. Improving the utilization rate and quality of pocket squares in blocks is an important design point to promote leisure behavior. Parking of motor vehicles in blocks and reasonable planning of motor vehicle lanes are also effective measures to encourage leisure behavior.

(3)The impact of street space characteristics on consumer behavior. By screening the P value and comparing the Beta value(Table 6), the influence of various factors on consumer behavior in streets, ranked from strongest to weakest, is as follows: POI type index(*Beta*= 0.393), POI number index(*Beta*= 0.386), walking width (*Beta*= 0.244), interface openness index(*Beta*= 0.210), spatial reachability index(*Beta*= 0.206), enclosure index(*Beta*= 0.087), sky visual index (*Beta*= 0.070), and facility isolation index (*Beta*= －0.062). That is, the types and number of POIs have the greatest impact on consumer behavior. Following that, the influence of walking width, interface openness index and spatial reachability index plays a major promoting role on consumer behavior. The enclosure index, sky visual index, and facility isolation index also have an impact on consumption behavior to a certain extent, and the facility isolation index is negatively correlated with consumption behavior, which has a certain inhibitory effect.

In the influence relationship of consumer behavior, the higher the convenience of the street space, the more corresponding consumer behaviors will occur. Street space with high convenience characteristics can better stimulate people's consumer behavior. For example, the types and number of POIs on Hongxing Road and Women's Street are higher than those on the surrounding streets, and the number of consumer behavior distributions is also obviously high in the entire block.

(4)The impact of street space characteristics on passing behavior. By screening the P value and comparingit with Beta value(Table 7), the influence of various factors on passing behavior in streets, ranked from strongest to weakest, is as follows: PQI (*Beta*= 0.512), walking width (*Beta*= 0.359), spatial reachability index(*Beta*= 0.330), interface openness index(*Beta*= 0.224), spatial enclosure index(*Beta*= 0.162), sky visual index(*Beta*= 0.148), and facility isolation index(*Beta*= - 0.108). That is, PQI, walking width, and spatial reachability index have the most significant impact on passing behavior. Interface openness index, spatial enclosure index, and sky visual index have important impacts on passing behavior. The facility isolation index has a certain inhibitory effect on traffic behavior.

In general, street spaces with high convenience often havea large flow of people and are accompanied by a concentration of business types, such as Women's Street and Hongxing Road; there are also street spaces with high accessibility and low functional density, such as Lujiang Road. This shows the important influence of the convenience index on traffic behavior. Walking width reflects the accessibility of the street and the road grade. The higher the street grade and the better the accessibility, the more conducive it is to facilitating residents' travel.

3 Street guideline optimization strategy based on space-behavior correlation

Summarizing and sorting out the research findings of current street optimization strategies: (1) The proposed strategies do not fully consider the regional characteristics of the research objects. (2) Most of the strategies are proposed through qualitative analysis and empirical analysis, and there are few studies that propose strategies based on quantitative relationships. (3) The research on street design guidelines is in the ascendant, and it is meaningful to provide suggestions for the optimization of guidelines from the perspective of street space quality[3].

Therefore, in the process of optimization and transformation, in addition to considering objective material factors, we should also pay attention to combining it with its unique regional characteristics[34-36]. This study fully considers the existing situation of the old city of Hefei and, based on the mathematical relationship between space and behavior, puts forward suggestions for optimizing street guidelines from the perspective of street space quality.

3.1 Optimization strategies based on comfort

3.1.1 Create a green ecology and comfortable and pleasant interaction

The green view index of the blocks in Hefei's old city shows a hollow distribution, and the street space resources are unevenly allocated. In addition, how to reasonably and effectively allocate them under the contradiction of compact spatial layout is the key to the design. We should focus on the multi-dimensional expansion of green open spaces and combine them with commercial spaces [34]; fully explore the compound utilization of the remaining space on both sides of the street, and coordinate pocket parks, street corner squares, and other spaces. The reasonable layout of green plants in street space and increasing street greening in various ways can effectively regulate street microclimate and play the role of street shading, dust filtering, and noise reduction in hot summer [37] . Therefore, island flower beds and tree pools can be used to form the vitality tentacles of green ecology, which can not only create the possibility of intermittent stop and sightseeing for people's necessary activities but also create conditions for people to pass through traffic and penetrate natural landscapes[38].

3.1.2 Create a pleasant space and a rhythmic interface

Thespatial enclosure index has different degrees of influence on consumption behavior and traffic behavior, and the relationship is positively correlated. The appropriate spatial enclosure index is conducive to creating an orderly, comfortable, and pleasant street space. Street spaces should be reasonably organized to form a rhythmic and orderly spatial interface through the alignment of street-facing buildings, street trees, and walls while encouraging the creation of a multi-layered street interface[37].

3.2 Spatial optimization strategies based on safety

Ensuring pedestrianpassing safety is the primary issue in improving the quality of street space. The sections of Hongxing Road, Renmin Alley, and Yimin Street tend to gather a large number of commercial and crowd activities and also serve as important transportation carriers within the neighborhood. Currently, the shops along both sides of Hongxing Road, Renmin Alley and Yimin Street have developed to a certain scale, but this has also caused a contradiction between traffic safety and crowd gathering activities.

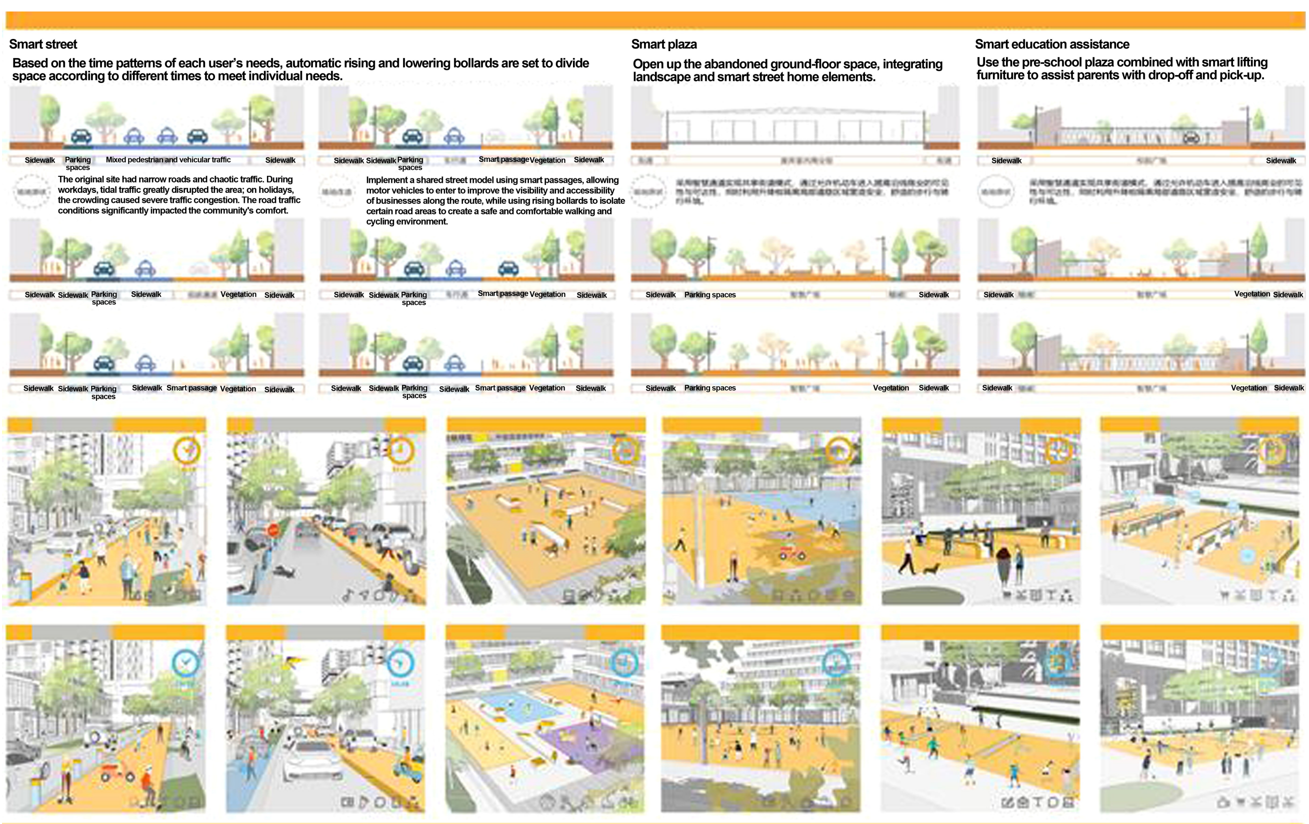

Figure 10 Tidal Street Strategy

3.2.1 Smarttidal streets and shared mixed spaces

Expanding pedestrian spaces plays an important role in improving travel safety. Currently, there are periods of congestion in both motor vehicle spaces and sidewalks in urban streets, creating safety hazards and inconveniences for pedestrians, especially in the Hongxing Road section, RenminAlley section, and Yimin Street section. Research has shown that traffic congestion in the inner districts typically only occurs during peak hours, with lighter traffic during off-peak periods. Moreover, the well-developed surrounding road network helps alleviate urban traffic pressure during off-peak times. Based on this, we propose the concept of tidal streets: During off-peak periods, smart rising bollards are used to convert part of the vehicle lanes into pedestrian spaces, significantly improving the utilization of street space. This expansion of pedestrian areas ensures walking safety while not interfering with motor vehicle traffic flow, thus revitalizing the street (Figure 10). During peak hours, smart rising bollards will be lowered to restore space on motor vehicle lanes and ease urban traffic pressure.

3.2.2 Appropriate division and isolation to strengthenthe functional connection

While ensuring pedestrian safety, the economic and social benefits generated bypassing and consumption behaviors in the block should not be overlooked. Excessive implementation of unnecessary isolation measures may lead to negative consequences[38]. For instance, in the case of the North and South sections of Women's Street and the East and West sections of Yimin Alley, excessive isolation under similar conditions has resulted in significant reduction in commuting and consumption activities. Therefore, the accessibility to commercial and residential spaces should be achieved through an integrated design that connects pedestrian spaces with parking areas and transit stations, rather than complete segregation from vehicular spaces. Practical solutions should be developed based on existing conditions, emphasizing enhanced connectivity with other public open spaces to strengthen functional integration throughout the block.

3.3 Spatial optimization strategies based on richness

3.3.1 Improve street facilities and strengthen characteristic guidance

The facility convenience index plays an important role in promoting sightseeing and leisure behaviors. The current distribution of facilities within the block exhibits low-value scattered patterns, indicating limited variety and monotony. Given the concentration of historical buildings and interconnected alleys in Hefei's old city, the key challenge lies in improving facilities while preserving and enhancing historical characteristics. The difficulty of the renovation is how to improve the facilities, strengthen the characteristics, and continue the rich history of the streets. During the design and renovation process, in addition to focusing on the design of areas close to people, using awnings and spaces along the edges to provide shade, improving furniture items for people to rest, and selecting various paving materials to enrich the horizontal interface of the street; it is also possible to strengthen the guidance of street advertising slogans, facade window designs, cultural wall displays and block colors, which can help strengthen pedestrians' overall cognition of the block and form a unique cultural image.

3.3.2 Grasp the reality and virtuality of the facade and enrich the visual experience

The interface openness index is mainly affected by the transparency of the street facade. Attention should be paid to the virtual-real relationship of the ground floor facade along the street to avoid large areas of solid walls. Excessive use of highly reflective glass is unnecessary and will affect the walking experience of pedestrians. Buildings along the street are encouraged to provide exquisite and rich details, the design of building entrances should form a rich image, and the walking speed should be catered to form a rich visual experience.

3.4 Spatial optimization strategies based on convenience

3.4.1 Enriching business functions and facilitating the neighborhood

According to the theory of space syntax, the interaction between space, function, and human flow will produce a multiplier effect. That is, the high accessibility of the street often attracts people to gather, and the dense human flow activities promote the development of business along the street. The rich and diverse business functions promote the increase of road network density, thus forming a sound cycle of coordinated development between space, function, and human flow.[35] Taking Yimin Street as an example, this type of street has a dense number of business functions but low accessibility, resulting in insufficient street space quality. To this end, while maintaining the original street mechanism, we can properly clear the relationship between the internal alleys and main streets within the block and effectively optimize the organization of traffic and functions, thereby attracting more people flow and a mix of functions.

3.4.2 Combine land use functions and strengthen characteristic themes

The land use structure in Hefei's old city is complex. The core of the problem is how to extract the unique cultural intentions and connotations of the streets and continue the city's regional characteristics.

We need to understand each street in depth, explore its characteristics and connotations, and divide the streets into theme streets according to their functions. For example, the surrounding land occupied by Nanmen Primary School can be used to create a vibrant campus theme section; the old residential areas around the land can be combined with the unique courtyard culture of the old city to create a city life theme section; the commercial functions of Hongxing Road are concentrated to create a creative commercial section, etc.

Centered around the core functions of various street themes, diverse commercial activities should be introduced. Through the development of street themes, the unique culture of the street can be highlighted, catering to different types of people with varying needs. This approach maximizes the cultural imagery and cultural connotation of the streets[34].

4 Summary and discussion

This article obtains space characteristics data through a multi-source big data collaborative machine learning algorithm, combines the behavioral observation method to obtain behavioral data, and explains the relationship between street space and walking behavior based on mathematical models. The study found that there is a specific mathematical influence relationship between walking behavior and street space elements, among which functional business types, walking width, and interface openness have a more significant impact on overall walking behavior. Based on this, the strategy for street optimization and renovation should be tailored to local conditions based on the characteristics of street space quality under different behavioral needs.

Due to the limitations of multi-source data acquisition, the quality characteristics of some factors have not been taken into account for the time being due to the difficulty of obtaining and converting them. As a result, the variables affecting walking behavior are still not perfect, such as the sense of harmony, microclimate, soundscape, traffic flow, and social factors of travelers. In addition, due to the limitations of the scope of walking behavior collection and the effort required to organize the behavioral observation method, the size and number of statistical blocks cannot be too large, which in turn affects the sample size and data quality. In subsequent research, we can try to use machine learning algorithms and WIFI data to obtain travel data characteristics to improve the richness and efficiency of data analysis.

The correlation mechanism between street space quality andwalking behavior can provide a strong basis and support for scientifically diagnosing urban built environment problems and optimizing travel experience. It can also provide new solutions for the rational allocation of facilities, the promotion of low-carbon travel, and the formulation of Hefei street design guidelines.

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All figures and tables are made by the author

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