PREDICTION, SIMULATION AND EVALUATION OF STAY BEHAVIOR IN PUBLIC SPACE INTEGRATED WITH MICROCLIMATE

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Abstract. As "users", individuals directly influence the use of space through their choices and decisions, ultimately determining the vitality of the space. Among these behaviours, stay behaviour significantly contributes to the dominance of space vitality due to its longer occupancy. Therefore, this study focuses on the stay behaviour in public spaces, with a specific emphasis on the choice and decision-making related to seating facilities. The study introduces a neural network model to analyse the influence weights of space and microclimate factors on the preferences of individuals. These weights are then integrated into a social force model to achieve the simulation and visualization of stay behaviour in public spaces. Building upon the results of behaviour simulation, the study evaluates the current utilization of seating facilities in existing public spaces. The original contribution of this study proposes a comprehensive workflow for the simulation of stay behaviour, encompassing "model construction - visualization - evaluation analysis - optimization." The aim is to provide insights for the quantitative analysis and rapid design of urban spatial environments.

Keywords. Public Space Analysis, Outdoor Activities, Behaviour simulation, Behaviour Prediction, Microclimate Perception

1. Introduction

Researchers widely acknowledge the advantageous role of vibrant public spaces in urban environments. However, it is imperative to recognize that the vitality of these spaces fundamentally relies on human interaction. The more effectively the design of public spaces meets human needs, the greater the attraction for pedestrians to visit and linger. A well-designed public space should possess a certain degree of "sticky", implying that pedestrians not only pass through the space but also choose to stay within it for extended periods (Zapata and Honey-Rosés, 2022).

Furthermore, researchers indicate that compared to dynamic activities, stay behaviours are more susceptible to the microclimate environment. Huang et al.

ACCELERATED DESIGN, Proceedings of the 29th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2024, Volume 2, 129-138.

proposed that during hot seasons, over 75% of users prefer to stay in shaded areas, resulting in longer stay times compared to sunny areas (Huang et al., 2015). Zacharias et al. emphasized that the quantity of seating arrangements is far less important than the factors of temperature and sunlight (Zacharias et al., 2004). Therefore, an optimal microclimate environment can effectively extend outdoor stay times for pedestrians, fostering the efficient utilization of outdoor spaces.

Urban public space construction and renewal often require extended periods. Therefore, researchers have begun to analyse existing urban public space usage data to identify patterns and analyse activity preferences, applying these findings in subsequent urban analysis and optimization efforts. Moreover, with the continuous advancement of technology, the acquisition of activity data in public spaces has evolved from basic mapping to macro-scale approaches such as Wi-Fi probes and big data. In comparison to traditional on-site surveys, methods utilizing Wi-Fi probes and big data can cover larger areas and span more comprehensive timeframes. However, these methods face significant limitations in capturing data details, individual pedestrian characteristics, and activity types. Understanding spatial attributes and related pedestrian activities often requires additional approaches. Behaviour simulation, on the other hand, introduces new possibilities for acquiring urban spatial data. Existing research on behaviour simulation has mainly focused on highly purposeful evacuation behaviours, while research and applications related to weakly purposeful, non-purposeful behaviours, and stay behaviours remain relatively limited.

Taking the example of pedestrian's selection of sitting spaces, this study aims to establish a visual simulation model specifically for stay behaviours in public spaces, breaking away from the predominant focus on purposeful behaviours in existing behaviour simulation research. Leveraging the complex characteristics of public spaces and pedestrian's choices of sitting behaviours, the study integrates physical space with microclimate factors to explore in-depth the multifaceted factors influencing choices of sitting spaces and their demands on public spaces. The workflow developed in this study is applied in the evaluation and optimization of actual public spaces. The research aims to incorporate behaviour simulation data as a supplement to both urban big data and small data, contributing to the quantitative analysis of urban spatial environments in the assessment and optimization processes.

2. Methodology

2.1. DATA ACQUISITION AND ANALYSIS

2.1.1. Data Acquisition

This study focuses on six riverside parks along the Huangpu River in Shanghai. A total of 117 seating facilities were selected as observation points, where 5821 pedestrians' stay strategies were observed. Data acquisition primarily involves two aspects: independent variables and dependent variables.

Firstly, independent variables include both physical spatial and microclimate data. Based on on-site investigations, spatial factor data for the site were summarized. Air temperature, relative humidity, and wind speed were measured 1.5 meters above the

ground using Testo 410-2, and solar radiation at the site was measured using TES-1333.

Secondly, the dependent variable in this study is the pedestrian's stay activity data. The method for acquiring behavioural data is through system for observing play and recreation in communities (Soparc) (McKenzie et al., 2006), which involves systematic and periodic observation of the target research area without disturbing the subjects. During the observation, direct data on the usage of community parks is collected, including environmental activities and relevant characteristics of facility users.

Considering the numerous and extensive sites involved in the research, evaluating them solely based on the number of facility users is challenging to truly reflect the decisions made by pedestrian in the space. Therefore, the probability of the pedestrian's choice of seating facilities is taken as the dependent variable, exploring the influence mechanism of spatial and microclimate perceptual factors on the pedestrian's facility selection and decision-making.

Additionally, there are significant differences in spatial preferences among different individual attributes. For instance, there is a significant correlation between the preferences of elderly individuals and females for shaded areas (Lee et al., 2020). Therefore, this study uses pedestrians' age as a control variable to systematically explore differences in their choices of seating facilities. Finally, based on the acquired data, the variable system for this study is constructed, as illustrated in Figure 1.

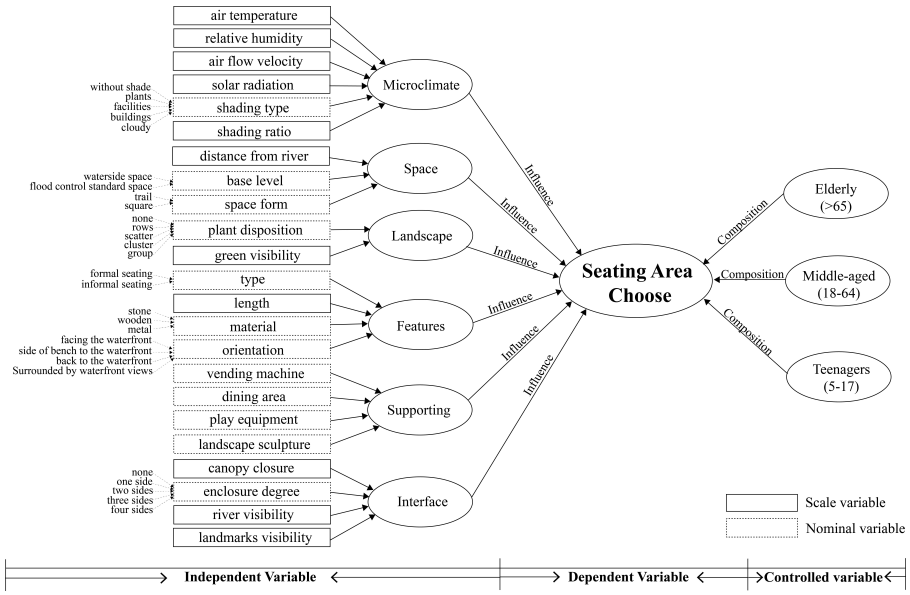

Figure 1. Variable system for this study

2.1.2. Data Analysis

This study explores the preferences of stay activities within the spatial range perceivable by the pedestrian. Hence, existing research has compared the predictive performance of various models on predicting different types of activity choices in public spaces. The study found that the nonlinear multilayer perceptron demonstrated

the best predictive capability (Liu et al., 2023). Multilayer Perceptron (MLP) is currently a widely used artificial neural network model in the built environment research, with a computational structure comprising input layers, hidden layers, output layers, and multiple levels of neural units. Therefore, this study similarly opts for the multilayer perceptron as the numerical analysis model to predict the influencing factors of pedestrian' choices regarding seating facility selection.

2.2. SIMULATION ENVIRONMENT CONSTRUCTION

2.2.1. Platform Construction

In this study, the Morpho plugin in Grasshopper was selected for simulating and analysing microclimate environments. By utilizing this plugin, microclimate simulation analysis can be performed on the 3D model created in Rhino using the Envi-met platform, providing corresponding microclimate conditions for behavioural simulation. Based on this foundation, it is linked with the behavioural simulation system (Pedsim) to achieve the interaction of different data.

2.2.2. Numerical Translation

In the simulation environment, agent particles are driven by a social force model, continuously changing their positions and continuously monitoring the surrounding environment through perception. Their choices and stay at facilities are determined based on the spatial and microclimate factors of the environment where the facilities are located. If the weight of each factor covered by the facility is defined as w_i, then the total weight W of the facility is given by Eq. (1):

$$W = \sum_{i=1}^{n} w_i \quad (1)$$

2.3. APPLICATION ANALYSIS

Based on the results derived from behavioural simulation and microclimate simulation in this study, five indicators—facility utilization rate, utilization balance, utilization balance in different bases, thermal comfort ratio, and the matching degree between thermal comfort and activities—are selected to evaluate the setting and usage of seating facilities within the site. Subsequently, optimization strategies are proposed on this basis.

3. Result

3.1. NUMERICAL PREDICTION MODEL

The predictive accuracy of the MLP model for seating facility choices among pedestrians is shown in Table 1. It can be observed that the model achieves a prediction accuracy of over 70% for the preferences of elderly and middle-aged. However, the accuracy for teenagers is limited. This limitation is attributed to the sparse data on teenagers' stay activities within the site.

Age Groups	Sample proportion		Relative error		R^2
	Training	Validation	Training	Validation	
Elderly	70%	30%	0.215	0.380	0.703
	80%	20%	0.701	0.770	0.305
	90%	10%	0.390	0.702	0.579
Middle-aged	70%	30%	0.287	0.397	0.682
	80%	20%	0.217	0.265	0.768
	90%	10%	0.239	0.146	0.770
Teenagers	70%	30%	0.960	0.958	0.045
	80%	20%	0.912	0.953	0.082
	90%	10%	0.983	0.988	0.032

Table 1. Prediction accuracy of MLP for seating facility choices among different age groups

3.1.1. Seating Facility Preferences of Elderly

An analysis of the importance of space and microclimate factors reveals that elderly tend to prefer environments with higher enclosure and density when selecting seating facilities. This preference provides stable shading conditions for seating facilities in such environments, creating a safer and more intimate atmosphere (Figure 2).

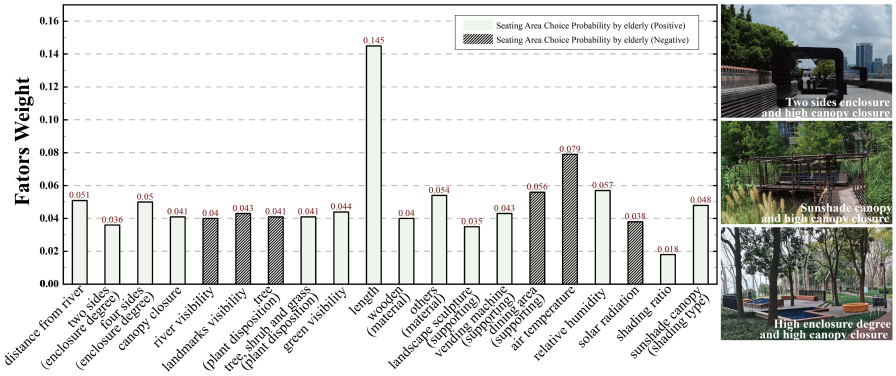

Figure 2. Seating facility preferences of elderly

3.1.2. Seating Facility Preferences of Middle-aged

As shown in the figure 3, the influencing factors for the seating facility preferences of middle-aged include the weights of building shadows, and air temperature, which are 0.08 and -0.079, respectively. It is evident that middle-aged adults also prefer cool and shaded spaces. The study reveals that, for middle-aged, the combination arrangement of seating facilities with other service facilities can better attract their choices. The combination weights are 0.084 for dining facilities, 0.071 for landscape sculpture, and 0.070 for play equipment.

3.1.3. Seating Facility Preferences of Teenagers

Based on the output weights of the independent variables, building shadows (0.114), shading structures (0.056), and seating facilities with high enclosure (0.089) provide cool and comfortable resting places for teenagers who enjoy playing. This can

effectively help teenagers lower their body temperature and regain a sense of comfort.

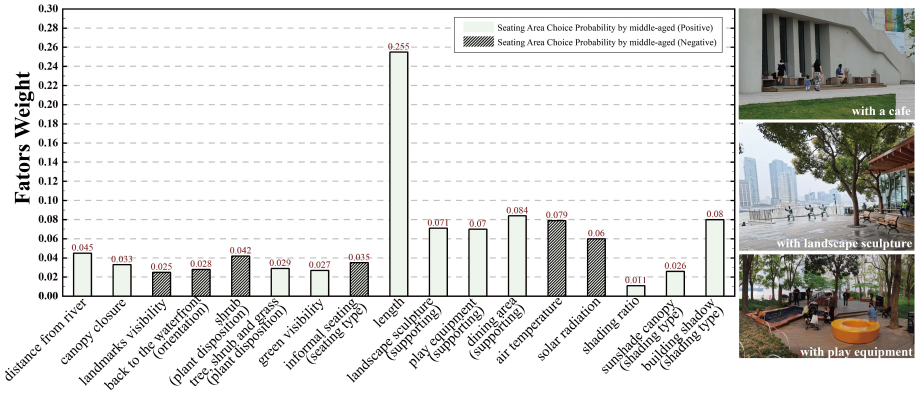

Figure 3. Seating facility preferences of middle-aged

3.2. BEHAVIOUR SIMULATION VALIDITY ANALYSIS

3.2.1. Site for Validity Verification

To ensure the authenticity and credibility of the constructed behavioural simulation method, this study selected six spatial segments within the site with a rich variety of seating facilities and ample spatial form and vegetation greenery for validation. The simulation was set for the corresponding microclimate conditions during the period with the highest occurrence of stay behaviour, on a leisure day from 14:00 to 17:00.

3.2.2. Seating Facility Weight Calculation

For pedestrians of different age groups, the weights represented by different types of seating facilities within each site were calculated according to Eq. (1). Based on this, agent particles were driven in the simulation environment to complete stay behaviours and decisions.

3.2.3. Validity Analysis Results

After translating the influence mechanisms obtained from the MLP into the simulation environment, the simulation results are shown in Figure 4. This study employed correlation analysis and linear regression fitting to validate the effectiveness of behaviour simulation (Table 2). It can be observed that the effectiveness of the first five sites is around 70%. However, the behaviour simulation results for Site F do not correlate with the actual survey. This is because, on the day of the survey, there was a significant flow of pedestrian in the area, and the seating facilities were in high demand. In this study, the modelling and prediction of stay behaviours are based on the preference choices of different age groups for facilities. If the number of spatial facilities is insufficient to provide preferences and choices for the pedestrians, i.e., special events cause the number of people in the area to exceed its capacity, the behaviour simulation method is no longer applicable.

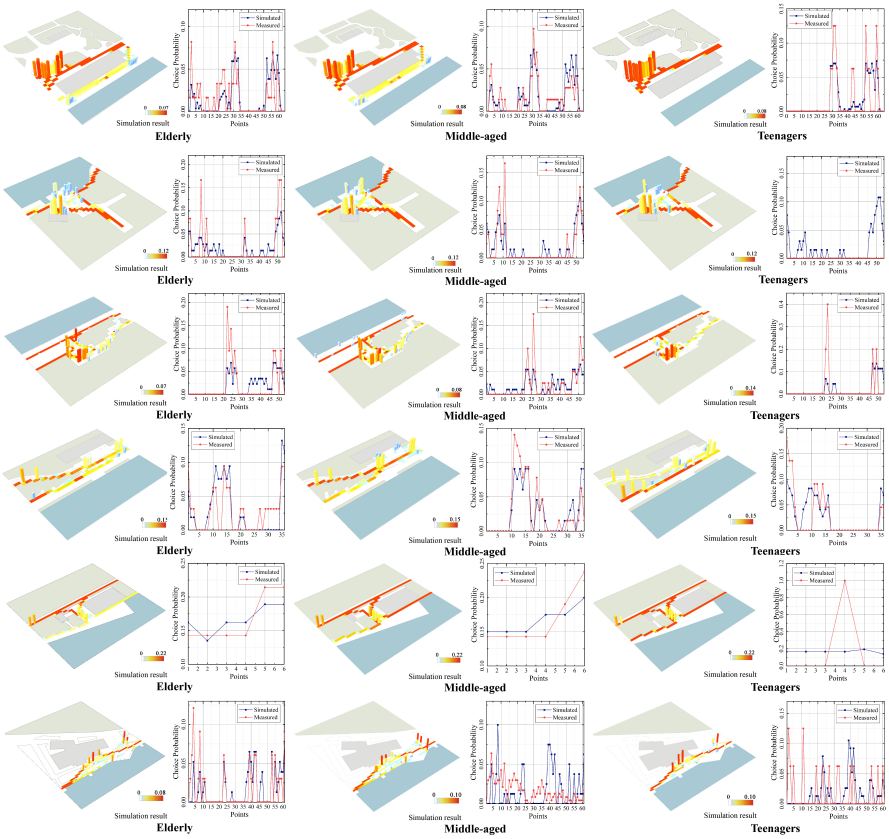

Figure 4. Behaviour simulation results and comparison

Site	Age group	Correlation Analysis	R^2	Site	Age group	Correlation Analysis	R^2
Site A	Old	0.733**	0.504	Site D	Old	0.654**	0.560
	Middle	0.660**	0.630		Middle	0.895**	0.741
	Young	0.681**	0.596		Young	0.743**	0.487
	Total	0.774**	0.701		Total	0.840**	0.759
Site B	Old	0.652**	0.654	Site E	Old	0.894*	0.735
	Middle	0.791**	0.695		Middle	0.822*	0.771
	Young	—	—		Young	—	—
	Total	0.775**	0.714		Total	0.845*	0.697
Site C	Old	0.707**	0.560	Site F	Old	0.731**	0.557
	Middle	0.743**	0.614		Middle	0.022	0.002
	Young	—	—		Young	0.127	0.024
	Total	0.750**	0.677		Total	0.070	0.005

Note: In the correlation results, **. is significant at the 0.01 level (two-tailed). The symbol "—" indicates that in actual research, the number of pedestrians of this type is very limited, leading to data gaps due to a lack of statistical significance.

Table 2. Validity analysis results

3.3. SITE ANALYSIS BASED ON BEHAVIOUR SIMULATION

3.3.1. Application Site

In order to illustrate the workflow of the behavioural simulation constructed in this study, a public space in the Xuhui Riverside area of Shanghai, China, was selected. Using the period with the highest activity flow from 14:00 to 17:00 as a basis, Envi-met simulation was first conducted to provide microclimate conditions for its seating facilities. Combined with spatial factors, the attraction features for different age groups were then formed.

3.3.2. Site Evaluation Based on Simulation Results

Through the organization and summary of behaviour simulation results, it can be observed that the evaluation of the current utilization of seating facilities in this public space is not high (Figure 5). During the simulation period, the overall utilization rate of facilities in the site is only 37.5%. Considering the simulation day is in the summer, neutral UTCI is set at 34°C as a reference, considering studies in the same climatic zone with similar air temperatures on the simulation date (Watanabe et al., 2014). It can be seen that only 22.8% of the facilities are in a state of thermal comfort. Moreover, the crowd is concentrated more on the flood control base of the waterfront public space, while the waterside base has few people staying due to high air temperatures and solar radiation. In this scenario, according to the simulation results, the current match between the potential stay activities and thermal comfort is only 37.1%.

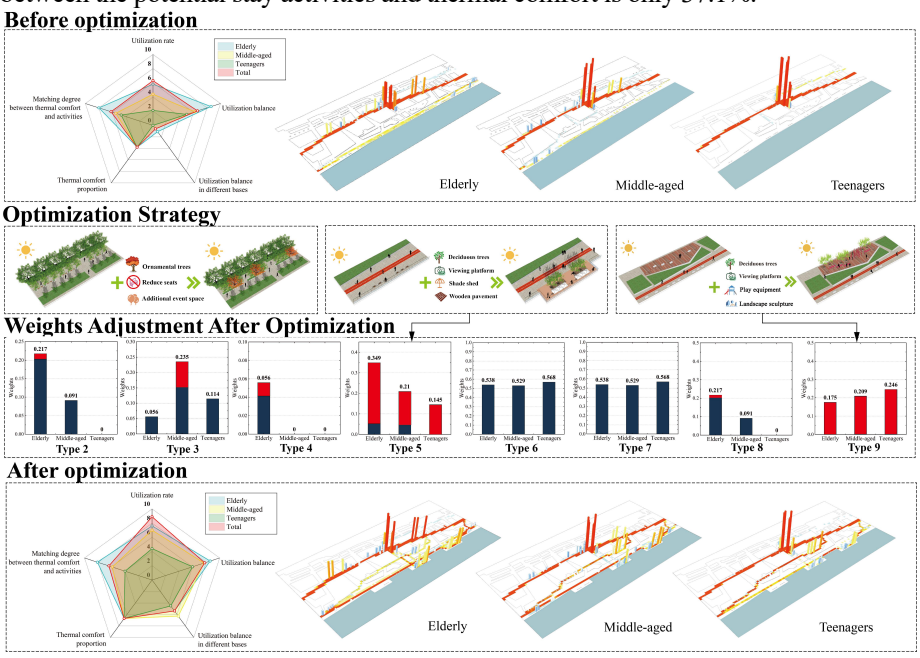

Figure 5. Site optimization based on simulation results

3.3.3. Site Optimization Based on Simulation Results

According to the simulation results, this study carried out certain optimizations for the site's seating facilities (Figure 5). Firstly, seating facilities with very low utilization rates adjacent to the street were replaced with ornamental plants, creating space for viewing activities. Secondly, shading facilities and tree planting were added to the waterside facilities with poor microclimate conditions, providing the possibility for prolonged stays. Finally, to enhance the attractiveness of less appealing node spaces, landscape sculptures and play equipment were added to provide support for a variety of activities while attracting people to stay.

After the optimization design, the weight adjustments of the facilities in the site are shown in the figure 5. After another round of simulation, the output data was evaluated, and it can be observed that all evaluation indicators showed a significant improvement.

4. Discussion

4.1. STUDY SIGNIFICANCE

In recent years, there has been a growing body of research focused on evaluating the use of urban built spaces. Researchers have gradually recognized that rapid urban development often leads to deficiencies at the human scale. The significance of this study lies primarily in two aspects. Firstly, it contributes to the micro-upgrading of urban public spaces. The construction of urban public spaces tends to prioritize systemic, connected, and rapid development, resulting in public spaces that do not fully meet the usage needs of the pedestrian at the human scale. This study explores the preferences of different age groups for seating facilities by examining multiple factors and integrating the influence of the physical environment. It constructs a behaviour simulation workflow to break through the traditional evaluation indicators and methods in behaviour simulation, which mainly rely on crowd path and density maps. Instead, it emphasizes the importance of residency behaviour as a vital indicator for evaluating the vitality of public spaces from multiple perspectives.

Secondly, the study is significant in terms of predicting urban built spaces. Retrofitting urban areas after problems arise from rapid development consumes significant human and financial resources. Moreover, traditional environmental behaviour studies often require extensive time for observation and research to gather on-site data. This study, based on real data, establishes a simulation of seating behaviour preferences with certain validity. This approach allows for a predictive understanding of public space cognition, design, and optimization, offering valuable insights before issues become prominent.

4.2. STUDY LIMITATIONS

Due to the limited scope of this study, the exploration of stay behaviours has primarily focused on pedestrians' choices and decisions regarding seating facilities. However, numerous other stay behaviours occur in public spaces, such as sightseeing, photography, and playing activities, all of which exhibit significant differences in stay time and spatial preferences compared to sitting behaviours. Future research could aim to provide a more comprehensive and systematic investigation into stay behaviours.

Furthermore, during the optimization and adjustment of the Xuhui Riverside site, we observed that the introduction of new types of cafes and popular stores had a significant influence on the pedestrian activity system in the area. This influence often stems not from the public space itself but more from the influence generated by these stores. The extent of this influence on public spaces requires more systematic research for confirmation.

5. Conclusion

This study, using the public spaces along the Riverside in Shanghai as a case study, started from real-world data. It analysed the influence mechanisms of public spaces on the selection of seating facilities by different age groups, integrating spatial elements with microclimate factors. Incorporating these influence mechanisms into a behaviour simulation system, the effectiveness reached between 0.677 and 0.759 under moderate pedestrian flow conditions. Applying this behaviour simulation workflow to real-world environments, the study analysed existing issues from five perspectives: facility utilization rate, facility utilization balance, balance of facility utilization in different surface spaces, facility thermal comfort ratio, and the matching degree of thermal comfort with residency behaviours. Subsequently, optimization strategies were proposed to enhance the utilization of site facilities.

The primary aim of this research is to delve into the preferences of long-term stay behaviours regarding the physical and environmental elements in urban public spaces. By applying these findings to a visualized simulation method, it aims to provide insights for the rapid design of urban public spaces, offering anticipatory guidance for the quantitative analysis of urban spatial environments.

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