Construction of Recreation Behavior Simulation Model of Public Space in Urban Waterfront—Taking Huangpu River in Shanghai as an Example

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Abstract. This study constructs a multi-agent behavior simulation model to explore the quantitative simulation method of waterfront public space. Taking 6 waterfront public space samples along the Huangpu River in Shanghai as research objects, this study first collects environmental data and pedestrian behavior data through field survey, and then analyzes and processes the data to obtain the Spatial Attraction Weight (SWA) that expresses the relationship between pedestrian behavior and spatial elements. Then, based on the Anylogic platform, the pedestrian agent particles expressing people's characteristics are placed into the simulation environment based on the social force model. They interact in real time to dynamically simulate the pedestrian's behavior. Finally, fitting verification of the preliminary model is carried out. The qualitative comparison and quantitative correlation analysis are combined to enhance the accuracy. The behavior simulation model of waterfront public space built in the study can more realistically represent the pedestrian's behavior. It can realize the scientific prediction of the future use of waterfront space and provide more detailed reference for problem diagnosis and optimization.

Keywords: waterfront public space · Recreation behavior · Micro-behavior simulation · Multi-agent

1 Research Background

As a unique space resource, urban waterfront has become an important recreational place in the city because of its continuous, open and water-friendly space characteristics. However, some extensive development and construction have made the urban waterfront public space low in vitality. The current problems are mainly manifested in improper connection of the base plane, single shoreline forms, limited public buildings, and dislocation of supporting facilities. The traditional small-sample survey, empirical design and pre-judgment make the allocation of spatial elements in waterfront areas not fully fit the user behavior preferences caused by waterfront characteristics. It is necessary to find more scientific, quantitative and intelligent analysis and simulation methods to guide the construction of urban waterfront space.

Multi-agent behavior simulation technology is a cutting-edge means of micro-behavior simulation. It considers the interaction between individuals and the environment, and is suitable for simulating individual behavior. It can realize full-time dynamic simulation, multi-plan comparison and virtual situation preview. Its full-time interactive dynamic simulation can better present the self-organized behavior of the pedestrian under the influence of complex environmental space elements in the urban waterfront, and the output simulation results can be used as the basis for evaluating the future use of public space.

2   Research Object and Research Path

Based on the Anylogic platform, this study constructs a behavior simulation model to simulate pedestrians' behavior in urban waterfron public spacet. It intuitively and dynamically presents the actual use of waterfront public space, and provides reference for the design, decision-making and management of waterfront public space. According to the principles of convenient accessibility, rich space, and open all day, this study selects six waterfront public space samples which are adjacent to each other in 3 pairs of the Huangpu River in Shanghai as objects for simulation. Six typical time periods (7: 00–9: 00, 9: 00–11: 00, 11: 00–13: 00, 13: 00–15: 00,15: 00–17: 00 and 17: 00–19: 00) are selected for the survey (Fig. 1).

Number	Six Samples	Surrounding Conditions
1	Minsheng Waterfront	Surrounded by commercial office area and residential area
2	Shipyard Waterfront	
3	Dongchang Waterfront	Surrounded by residential areas and tourist attractions
4	Laobaidu Waterfront	
5	Xuhui Waterfront	Surrounded by cultural exhibition venues and industrial relics
6	Longteng Waterfront	

Fig. 1. Six sample sites along the Huangpu River

The construction process of the behavior simulation model based on Anylogic platform includes four parts: basic data collection, data analysis and processing, simulation model construction and operation fitting adjustment (Fig. 2).
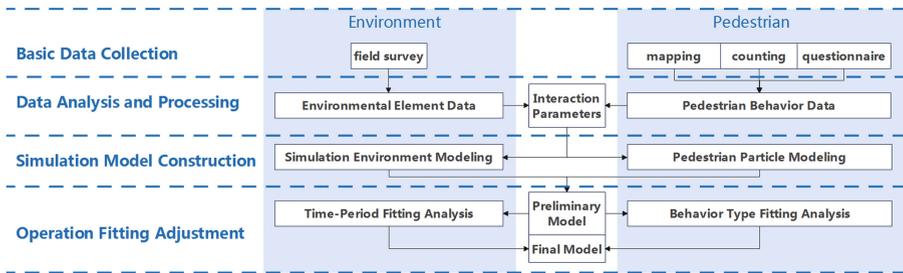
Fig. 2. Research framework

3 Research Key Links

Behavior simulation technology was initially widely used in the simulation of evacuation behavior in indoor spaces such as stations, airports, gymnasiums, etc. In recent years, it has been extended to the simulation of outdoor pedestrian spaces and commercial streets. Currently, most of the relevant studies are rarely applied to the simulation of outdoor public space and daily recreational behavior. In order to carry out targeted simulation research, the following three key links should be defined for the model construction of urban waterfront public space.

How to obtain and quantify the impact mechanism of the interaction between waterfront public space and pedestrian behaviors?

Firstly, types and characteristics of spacial elements should be analyzed through investigation. Then the classification of waterfront recreational behaviors and their basic characteristics, including pedestrian movement, vision, environmental response and other characteristics, are studied. On this basis, we should explore the impact of waterfront spacial elements on pedestrian behavior and consider how to convert them into impact weight that can be recognized by the model.

This study focuses on the pedestrian behaviors and distribution in a specific waterfront space environment, and uses the spatial element attractiveness weight (SWA), which is an important model construction parameter to quantify the relationship between spacial elements and pedestrian behaviors.

How to combine the advantages of agent model and social force model to build a behavior simulation model?

Commonly used micro-behavior simulation models include cellular automata model, social force model, agent model magnetic force model, etc. Most of the current research is based on existing models to simulate behaviors with obvious regularities in various spaces. In order to improve the precision of the simulation, some scholars have improved the existing models. For example, Chiung-Hui (2011) improved the agent model based on the theory of visual attention, and used the agent program to represent the shopping behavior rules. Based on the nonlinear exit allocation strategy, Song et al. (2018) improved the social force model to avoid problems such as hitting a wall and distortion of exit capacity in simulation. However, current research rarely combines the advantages

of each micro-behavior simulation model to construct a combined model and conduct targeted research. Meanwhile, research on the behavior simulation of complex urban public space lacks a mature combination model construction method.

In this study, the Anylogic platform that supports multi-method combination modeling is selected to build a combination model based on the advantages of the agent model and the social force model. The pedestrian path decision is dominated by the agent particles, which are placed in the simulation environment constructed based on the social force model, and the pedestrian path selection is expressed through the pedestrian behavior chain.

How to conduct fitting analysis and verify the validity of the model?

Fitting analysis is the key to verify whether the behavior simulation model can truly reflect the actual condition. The fitting method often uses an intuitive comparison between the measured and simulated results, and whether the fitting is effective depends on the empirical observation of the researcher. In recent years, quantitative fitting has gradually received attention, but more attention has been paid to the overall space, and there is a lack of fitting methods for local space. For example, Guo et al. (2014) applied Depthmap and SPSS correlation analysis software to fit the pedestrian behaviors in shopping centers under different spatial organization models. The model predicted the distribution of people flows in the overall space well, but the prediction accuracy of the distribution of local people flow in each layer did not meet expectations.

This study combines qualitative graphical comparison with quantitative correlation analysis, and takes the measured and simulated the number of people attracted by each attraction as the fitting basis to carry out sub-item simulation and fitting by time period and behavior type to improve the accuracy of the model.

4 Behavior Simulation Model Construction Process

4.1 Basic Data Collection

Basic data collection can be divided into environmental element data collection and pedestrian behavior data collection. This study classifies the diverse spatial elements of the waterfront public space into four categories of base plane, shoreline form, buildings, facilities and their subcategories. Using the method of field survey to collect the information of spatial elements. The record of the location and quantity of micro-spatial elements is especially paid attention. Pedestrian behaviors are divided into five categories of viewing, leisure, sports, entertainment, consumption and their subcategories. Pedestrians' waterfront recreation behaviors are diverse and random, with individual differences and obvious time differences. By means of mapping, counting and questionnaire, the information of pedestrian characteristics, behavior types, behavior locations, and behavior duration are obtained.

4.2 Data Analysis and Processing

Compared with commercial streets or other urban public spaces, the urban waterfront public space has more complex and diverse spatial elements. Pedestrian behavior is more

diverse and random due to the comprehensive influence of various environmental spacial elements. The distribution of pedestrian in waterfront shows that different spacial elements have distinct attraction to various pedestrian behaviors, that is, the probability of pedestrian choosing different spacial elements to carry out behaviors is different. The attraction weight of each space element expresses the relationship between spatial elements and pedestrian behaviors, which is an interactive parameter that can be identified by the model platform. This study adopts the Spatial Attraction Weight (SWA) in the waterfront public space to quantitatively express the regular relationship between the spatial elements and pedestrian behaviors in the waterfront public space, to establish the relationship between waterfront environment, pedestrian behaviors and the simulation model parameters. The calculation formula is as follows:

$$\mathbf{SWA_{(xy)}} = \frac{N_{(SA)}}{N_{(T)}}$$

$N_{(SA)}$ in x–y period, the total number of people of certain recreation behaviors in certain spatial elements.

$N_{(T)}$ in x–y period, the total number of people of all recreation behaviors in the waterfront public space.

4.3 Simulation Model Construction

Based on the Anylogic platform, the multi-agent behavior simulation model is constructed for six samples. Its modeling process can be divided into four parts: model operation process design, simulation environment modeling, pedestrian agent particles modeling and pedestrian behavior process modeling. Next, taking Dongchang Waterfront as an example, the model construction process is introduced in detail.

4.3.1 Model Running Process Design

The process of pedestrian recreation behavior in waterfront public space can be understood as a kind of space-time change, with the dual attributes of time and space. The waterfront recreation process of pedestrians has no relatively unified model, and their behaviors in the waterfront public space are full of randomness and diversity. Recreational behavior is not only a movement in space. In the process of being attracted to stay in some areas, pedestrians are actually engaged in recreational behavior although they do not move in space, which needs to be expressed through time changes.

The model operation process is divided into five parts: particle emission, direction determination, particle susceptibility determination, particle attraction determination and recreation end determination.

4.3.2 Simulation Environment Modeling

Firstly, the CAD base map is imported into the Anylogic platform, and various spatial elements of base level, shoreline form, buildings, facilities and their subcategories in the site are translated based on the spatial markup module (Space Markupin) of the Anylogic to build a simulation environment. As static agents, the spatial module has three basic attributes: service radius, pedestrian capacity and attraction weight, which are defined through the Parameter module of the Anylogic agent library (Fig. 3).
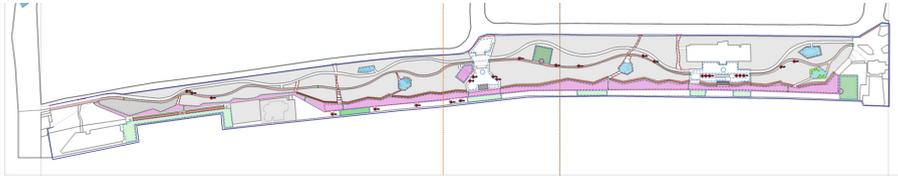
Fig. 3. Simulation environment of Dongchang waterfront

4.3.3 Pedestrian Agent Particle Modeling

In order to fully consider the characteristic differences of people, each pedestrian is simulated as a unique agent particle with its own attributes. Besides the three initial attributes of gender, age and behavior type, the pedestrian agent has four basic attributes: vision range, planned recreation time, basic speed and element perception radius. Pedestrian particles with different gender and age are given different basic attributes. In the Anylogic, the Parameter of agent library is used to express the four fixed basic attributes. Variable of agent library is used to express the dynamic attributes of pedestrian agent, such as moving speed, moving direction and moving time, which may change in the running of the model.

4.3.4 Pedestrian Behavior Process Modeling

Pedestrians' behavior process corresponds to the model operation process. Based on the behavior module of Anylogic, a pedestrian behavior chain that presents the behavior characteristics of random selection of pedestrians along the waterfront is constructed to express the path selection and decision-making process of pedestrians in the waterfront (Fig. 4).
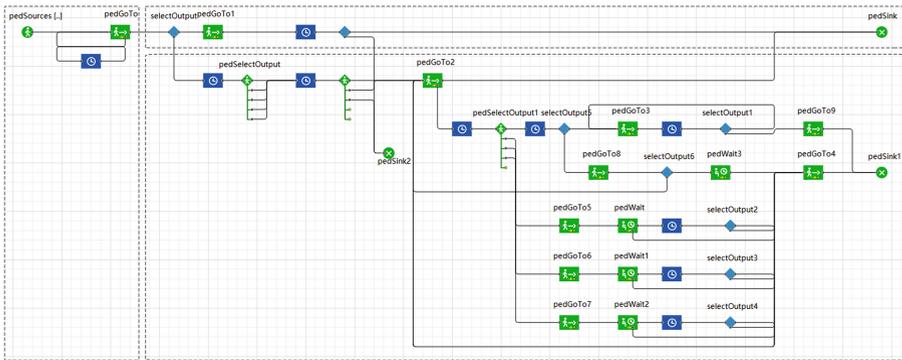
Fig. 4. Behavior chain

The pedestrian particles are put into the simulation environment built by the spatial markup module that based on the social force model. At each step of the continuous process, pedestrian agent particles can comprehensively simulate various attractions

and repulsion forces in the space and make autonomous behavior decisions. It dynamically presents the behavior process of pedestrian waterfront recreation and the spatial distribution of pedestrians.

4.4 Fitting Analysis and Validity Verification

On the basis of completing the preliminary construction of the combination model, the sub-item scenario simulation is carried out, and the results of the field survey are fitted by time period and behavior type.

4.4.1 Time-Period Fitting Analysis

In this study, the preliminary model simulation results are compared with the survey and measurement results, and Spatial Attraction Weight (SWA) of each element is adjusted through multiple simulations to make the simulation results highly consistent with the actual situation. The fitting method is the same for each time period, and the final result basically conforms to the actual situation is obtained through fitting (Fig. 5).
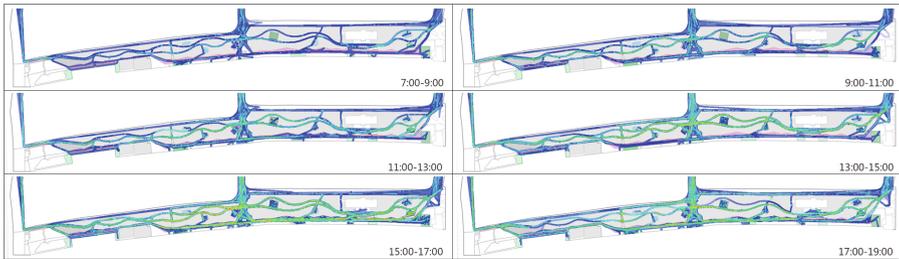
Fig. 5. Summary of simulation results of Dongchang waterfront in different periods

On the basis of qualitative fitting, quantitative fitting analysis is added to improve the simulation accuracy of local space. SPSS Statistics is used to analyze the bivariate correlation between the simulated data and the measured data of the attraction points in each period.

There are a total of 62 spatial attraction points in four categories in Dongchang Waterfront. The actual number of people attracted in the site survey and the simulated number of people attracted by the 62 attraction points in each time period are counted. The bivariate correlation analysis of the measured data and the simulated data of each attraction point in each time period is carried out through SPSS Statistics. The Pearson coefficient is the minimum of 0.840 (7:00–9:00) in the correlation analysis results. The maximum is 0.989 (17:00–19:00), which is greater than 0.6. And the significance level is 0.000, far less than 0.01, which proves that the model is effective (Table 1).

4.4.2 Behavior Type Fitting Analysis

On the basis of fitting analysis in different periods, the fitting of different types of behaviors is added. The model built in this study can simulate particles of a certain

Table 1. Correlation analysis of the number of people attracted by attraction points

7:00–9:00 (minimum)		Measured data	Simulated data	17:00–19:00 (maximum)		Measured data	Simulated data
Measured data	Pearson coefficient	1	0.840**	Measured data	Pearson coefficient	1	0.989**
	Sig		0.000		Sig		0.000
	Number	62	62		Number	62	62
Simulated data	Pearson coefficient	0.840**	1	Simulated data	Pearson coefficient	0.989**	1
	Sig	0.000			Sig	0.000	
	Number	62	62		Number	62	62
** Significant correlation at 0.01 level				** Significant correlation at 0.01 level			

type of behavior separately. We choose the 15:00–17:00 period with the largest number of people to compare the simulation results from the field survey results of each type of behavior. Taking the viewing behaviors as an example, the simulation results show that the viewing behaviors mainly take place at the wooden path, the rest platform and the cruise ship wharf on the concave shoreline, which is basically consistent with the measured results (Fig. 6).
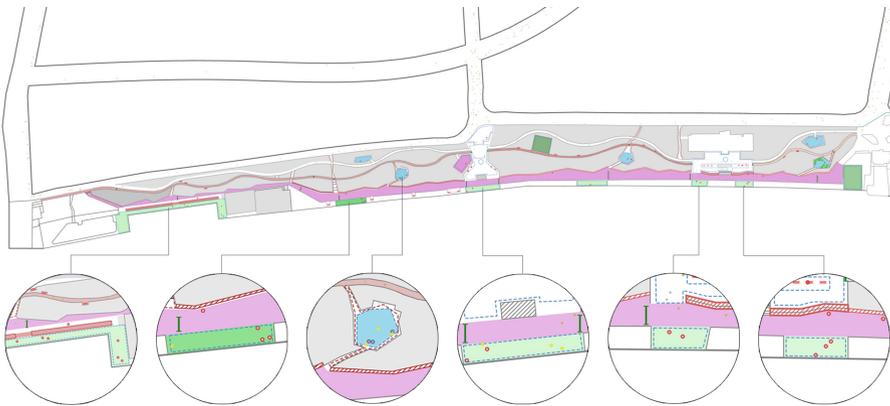
Fig. 6. Partial enlarged figure of viewing behavior particle simulation result

Similar to the time-period fitting, the actual and the simulated number of people attracted for different types of behaviors at 62 attraction points in Dongchang Waterfront during this period are counted and analyzed. The results show that the Pearson coefficient was 0.703 for viewing behaviors and 0.986 for leisure behaviors, both of which are greater than 0.6. The significance level is 0.000, which proves that the model is effective.

4.4.3   Model Validation

The adjacent Dongchang Waterfront, which is basically the same as the surrounding environment of Dongchang Waterfront, is selected to verify the effectiveness of the model. The Spatial Attraction Weight (SWA) of the spatial elements after fitting and adjustment is given to the spatial elements in the adjacent waterfront to verify model validation. The simulation results are highly correlated with the measured results, which prove that the model is effective. The Spatial Attraction Weight (SWA) obtained by simulation can provide reference for the simulation of other similar waterfront.

5   Model Application

Applying the above modeling methods, this study builds a behavioral simulation model for the waterfront section of the North Bund of Shanghai and carries out sub-scenario simulation. Firstly, the public space problem is diagnosed through simulation and optimization and improvement measures are proposed. Then this study improves the spatial elements such as various base planes, shorelines, buildings and facilities, and carries out the combination rehearsal and comparison, and puts forward the best recommendations with different orientations. Finally, an approximate combination is selected and compared with the reconstructed condition of the waterfront section of the North Bund which verifies the feasibility of the behavior simulation modeling analysis method (Fig. 7).
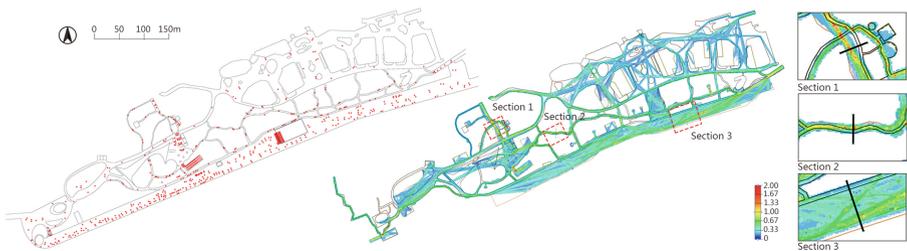
Fig. 7. Actually measured after transformation and pedestrian distribution of optimized and rehearsed before transformation

6   Conclusion

This research innovatively applies behavior simulation technology to the study of recreational behavior in urban waterfront public space, which extends the application scope of behavior simulation. The behavior simulation model constructed in this study can perform multi-scenario rehearsal for the allocation scheme of spacial elements in the urban waterfront, and realize scientific prediction of future use. It provides a more detailed design basis for diagnosis and optimization of waterfront. The scene preview of the optimization scheme can avoid inefficient repeated renewal to a certain extent.

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