APPLICATION OF MULTI-AGENT SYSTEM IN URBAN RENEWAL DESIGN

Dissertation for the degree of
Doctor of Liberal Arts (DLA) in Architecture

LIANG ZIXIN

UNIVERSITY OF PÉCS
Faculty of Engineering and Information Technology
Breuer Marcel Doctoral School

Supervisor:
Dr. GÉZA VÁRADY
Dr. MÁRK BALÁZS ZAGORÁCZ

Pécs, Hungary
May 2023

Abstract

As cities expand, many old towns face the threat of being renovated or demolished. In recent years, the drawbacks of extensive urban renewal have become increasingly apparent, and the focus of urban development is gradually shifting from efficiency to quality. This study aims to combine urban renewal with Multi-Agent System (MAS) to address the dilemma between efficiency and quality in urban renewal. Modern design disciplines frequently use more effective intelligent technologies and complicated computers due to the advancement of information technology. In order to provide clients additional value-added services, the industry for urban and architectural design has been transformed attributable to the research of intelligent technologies. While computer design techniques have achieved success, there is still untapped potential for MAS in urban and architectural design. The study found that algorithm models based on graph theory, topology, and shortest path principles neglect the influence of internal states and visual features on pedestrian activity, resulting in lower simulation accuracy. Although incorporating internal states and visual features into the core of the algorithm has further improved simulation accuracy, the model operates in a 3D environment with lower efficiency. To address the problems of insufficient simulation accuracy and low efficiency, this study proposes a dynamic pedestrian activity model based on a MAS and incorporating visual features. The model simulates pedestrian daily activity paths using pheromones and virtual sensors as the core, and it was found that using Visibility Graph Analysis (VGA) can accurately divide pheromones in the environment, thus obtaining more accurate simulation results. Subsequently, based on the optimized pedestrian model's agent activity rules and dynamic pheromone theory, a model for automatically generating road paving in urban renewal projects was developed, and the generated results were verified for their rationality through design practice. This technology can effectively promote urban renewal and the preservation of historic neighborhoods, providing technical support for achieving sustainable urban development.

Table of contents

Chapter 1: Introduction

1.1 Research background

According to the United Nations, the proportion of the global urban population to the world population was 56% in 2021, and it is expected to increase to 60% and 68% respectively by 2030 and 2050. Among them, China's urbanization trend is particularly evident, and researchers predict that the total urban population in China will increase by 255 million by 2050 [1]. As urbanization continues to develop, the function of urban renewal is becoming increasingly prominent. It is considered an effective method for increasing land value, improving environmental quality, and strengthening social connections [2]. Faced with limited productivity and the rapid growth of urban renewal projects, some cities in China blindly pursued design efficiency and extensively adopted the approach of massive demolition and reconstruction to update the outdated urban areas [3]. In recent years, the drawbacks of extensive renovation methods have become increasingly apparent in urban renewal, such as erasing historical memory [4], polluting the environment [5], damaging social stability [6], and wasting resources [7]. China's urban development is gradually shifting from a focus on quantity to quality [8,9], which has led to an increased emphasis on urban renewal and preservation as important factors for evaluating urban quality [10]. However, traditional design methods limit design efficiency. With increasing work pressure, designers have no extra energy to improve the design quality of projects, leading to a dilemma between protection and reconstruction in urban renewal [11].

The fourth industrial revolution has brought about significant changes to people's lifestyles and work patterns [12]. This study aims to combine urban renewal with emerging technologies to address the dilemma between efficiency and quality in urban renewal. Huang used a wind environment model based on the relative warmth index to analyze the thermal comfort of the Qi-lou column space in Nanning. He started from aspects such as building materials, structure, and layout, effectively improving the thermal comfort of the research object [13]. Bazazzadeh investigated the impact of spatial visual attributes on human perception and proposed the use of a Visibility Graph Analysis (VGA) to optimize spatial layout for improving user perception and promoting sustainable development of industrial heritage sites [14]. Rao used the spatial syntax of the "all line" to analyze the spatial layout and usage characteristics of Huzhai, a traditional building in Eastern Zhejiang, under the influence of the clan system [15]. The combination of computer models and urban renewal has to some extent promoted the development of both the renewal and preservation of outdated urban areas [16].

1.2 Research objectives

The methods used by researchers to create scientific models have undergone significant changes as a result of the advancement of computer technology, and scientists have become able to investigate models that are more complex. Minsky (1988), proposed that complex systems are made up of various, precisely defined, tiny agent units. In the simulation process, multiple agents are act autonomously, all the agents are updated asynchronously in parallel. A bottom-up logic can be seen in how the dynamics of the entire system change over time [17] (*Fig. 1-1*). Simple agents are capable of creating complex structures, and intelligence can be explained as the result of a combination of non-intelligent agents. This complex structure is referred to as a Multi-Agent System (MAS) [18]. MAS is influenced by the modeling concepts of complex systems, artificial intelligence and artificial life, and uses computers to simulate and provide decision-making recommendations, and has recently become a popular technique for simulating complex systems. It can be used to automatically generate new complex systems and investigate the functioning of existing complex systems in nature [19].

Now, agent-based pedestrian behavior simulation is mainly used in urban planning, evacuation research and building evaluation. These research methods are mainly used in urban simulation in the macroscopic field and building simulation in the microscopic field [20]. In terms of micro-simulation, current simulation systems are usually related to user behavior, such as pedestrian flow or evacuation simulation. Penn and Turner's model which based on Space Syntax Theory of VGA proposed that stopping and congestion would affect the agent motion simulation. Turner also introduced a dynamic agent model, which derives aggregate spatial analysis from the visibility of the built environment [21]. In 2004, Kitazawa and Batty have applied the agent model to the field of micro-behavior simulation. The agent model uses the shortest-path model as one of the evaluation criteria of Genetic Algorithms, and uses the agent model to simulate the behavior of consumers [22]. In addition, some agent models are developed and formed on the basis of fluid dynamics, particle systems and self-organization theory [23]. Sehnaz Cenani conducted an experiment involving the basic concepts and rules of a shopping mall simulation model. Research emphasizes the importance of building a memory system and simulation learning ability during simulation [24].

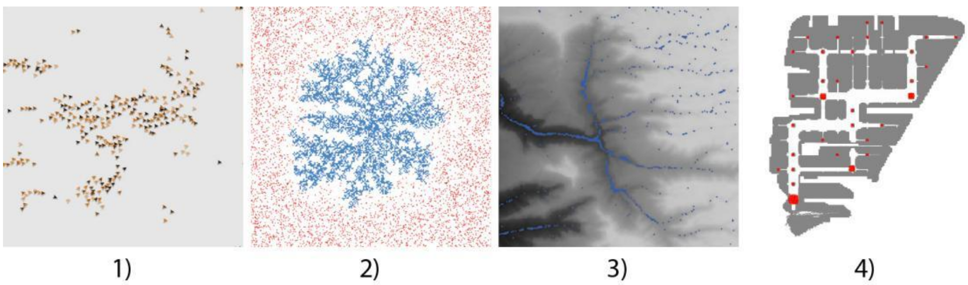


Fig. 1. 1-1) Artificial bird flock, 2)DLA model, 3) stream model, 4) Nordhavnen model
(Source: drawn by author)

1.3 Research significance

MAS modeling, may find unique intelligent models for resolving difficult design issues. Furthermore, the system functions as a decentralized, bottom-up, self-organizing dynamic modeling approach, which is well-suited to modeling the complex, decentralized, and dynamic nature of human activity [25,26]. Compared with traditional machine learning, MAS may have higher efficiency in urban environment design. However, most research needs to be completed on existing analysis software platforms. These static models based on graph theory [27] and topology

[28] can only output fixed results, lacking creativity [29]. Building a dynamic model with automatic generation capabilities is of great significance for improving the efficiency of designers.

Currently, most dynamic multi-agent models are used to predict macro-level changes in urban development [30,31], but overlook the potential application of this technology in micro-level urban construction, such as streets, public spaces, and green landscapes. Evacuation models are most commonly studied at the micro-scale, with the shortest path algorithm as the core representation of activities, ignoring the influence of internal states and vision on activities [32] (*Fig. 1-2*). Therefore, Karoji developed and improved a pedestrian simulation model for commercial environment simulation and integrated the dynamic internal states of pedestrians into the simulation model [33]. Based on the concepts of prospect and refuge, Hwang [34] proposed a computational algorithm for 3D visual simulation and privacy quantification based on the Grasshopper platform. Incorporating internal states and visual characteristics into pedestrian models further improves the simulation accuracy [33], but building the required 3D environment for simulation and slow analysis speed increases the workload of designers. Moreover, the above models still belong to the category of evaluation and analysis and cannot automatically generate corresponding design results.

To address the issues of inadequate accuracy in evacuation model simulations and low efficiency in 3D modeling, this study proposes a dynamic pedestrian activity model based on a MAS that incorporates visual features. The research first conducts a survey of pedestrian activity paths in historical blocks to identify the significant influence of visual factors on pedestrian behavior. The survey results serve as the foundation for model development and also as a critical reference for verifying simulation accuracy. By comparing simulation results under different parameters with actual pedestrian activity paths and using VGA to refine static information in the simulation environment, the study obtains simulation results that closely match reality paths. Subsequently, based on the optimized agent activity rules of the pedestrian model and dynamic pheromone theory, the study develops a model that automatically generates design result in urban renewal projects. By constructing a simulation environment conducive to agent interaction through dynamically distributed pheromone, the model achieves its goal through competition, stimulation, and optimization. The study ultimately verifies the rationality of the generated results through design practice and demonstrates that the automatic generation model is more efficient, cost-effective, and widely applicable than traditional design methods. This technology can effectively promote urban renewal and the preservation of historical blocks and provide technical support for achieving sustainable urban development.

Fig. 1-2. Pedestrian activity simulation based on PedSim Pro (Source: https://3d1.com.br/noticia/68586)

Chapter 2: Literature review

2.1 Definition of model

Scientific modeling is created to study complex systems and gain insight into reality, and it is frequently an abstraction of real-world phenomena (Lynch 1981) [35]. There are various forms of models for different purposes and usage scenarios such as a flexible language model, a rigorous mathematical formula (Scholl 2001) [36], a physical equation reflecting real-world movement, a statistical formula expressing social development (Gilbert and Terna 2000) [37], a virtual or physical building model that conveys design concepts and effects, an algorithmic model that analyzes site conditions and evaluates design effects, or a computer intelligence model for automatic design generation. Models come in various styles, but their purpose is to offer a clear and visual representation of a theory or concept (Skyttner 1996) [38].

For architecture, the transition boundary between virtual and reality largely depends on the visualization of architectural design and the materialized construction process of architecture. Architectural visualization is a medium between virtual design and physical construction, which is used to convey abstract concepts, describe design information, and guide architectural construction, and materialization technology is the key to transforming visual information into physical construction. At the same time, the intelligent building technology based on the highly integrated cyber-physical system makes performance visualization and building materialization present an unprecedented interaction [39]. An information system is a "pure form" with generating potential, and developing an intelligent model is a process of information visualization. This kind of thinking with information as the driving factor of generation is completely different from the top-down aesthetic logic of traditional architecture. Neil Leach distinguishes between the definitions of form and information, where form represents a static concept largely influenced by aesthetics, while information represents a dynamic concept defined by a series of factors with formal meaning [40]. The advanced nature of MAS is also reflected in its dynamic simulation process. Dynamic simulation is the most essential difference between intelligent models and traditional models. Advanced algorithmic models allow researchers to explore more complex models (Holland 2000) [41], and model functions shift from reflecting the real world to promoting thinking (Resnick 1999) [42]. According to Haggett and Chorley (1969), computer models emphasize the development process rather than the final form [43], and they also facilitate the study of decentralized systems (Resnick 1997) [44].

2.2 Types of algorithm model

Models of various types will be classified in this part based on four characteristics:

Physical models are often scaled down to represent a specific aspect of a system or to recreate reality in a physical medium (*Fig. 2-1*). The virtual model, also referred to as a digital model, employs computer programs as a medium and converts an object's key information into binary form, making it much better equipped to handle information than a physical model (Castle and Crooks 2006) [45]. Contemporary philosopher Slavoj Žižek believes that the virtual does not have a material form, but the real material form is the external manifestation of the pure form of the virtual. The reverse thinking that the virtual exists prior to the real makes the virtual intelligent, which shows that the pure form of the virtual has the ability to organize the real world [46].

The biggest difference between a dynamic model and a static model is that the former is a model about the behavior of objects and the interrelationships between these objects, while the latter is mainly aimed at describing objects and understanding the structure of the system. Dynamic models can simulate and reflect the behavior of systems over time, making them well-suited for examining speculative situations, while static models are often used for impact, vulnerability, and sensitivity testing (Javier 2007) [47]. In modeling complex systems and conducting related comparative studies, the openness of the dynamic model enables researchers to observe the behavior of the model under different conditions by adjusting parameters (Batty 2005) [48].

Fig. 2-1. Physical models (Source: designed and drawn by author)

A simple dynamic system is inseparable from a motion agent, and a more complex model system is also formed by mutual organization on the basis of multiple simple models. The integrated model and the individual model are distinct from each other, yet they are also connected. Integrated model aggregates the behavior of individuals and models the behavior of the entire system as a whole (Castle and Crooks 2006) [45]. Holland (2000) notes that population simulations and cluster models are among the most typical models used in this regard, as they possess predictive capabilities [41].

Digital models in urban design can be categorized into macro and micro models. Macro models assess urban spatial layout and road structure (*Fig. 2-2*), whereas micro models simulate pedestrian activity, viewshed analysis, and evacuation routes. While space syntax axis analysis is commonly used for macro analysis, it has limited predictive ability, which can be unhelpful for designers. In contrast, microsimulations use probabilistic models that introduce randomness, allowing for optimization and providing valuable suggestions and inspiration (Williams 2005) [49].

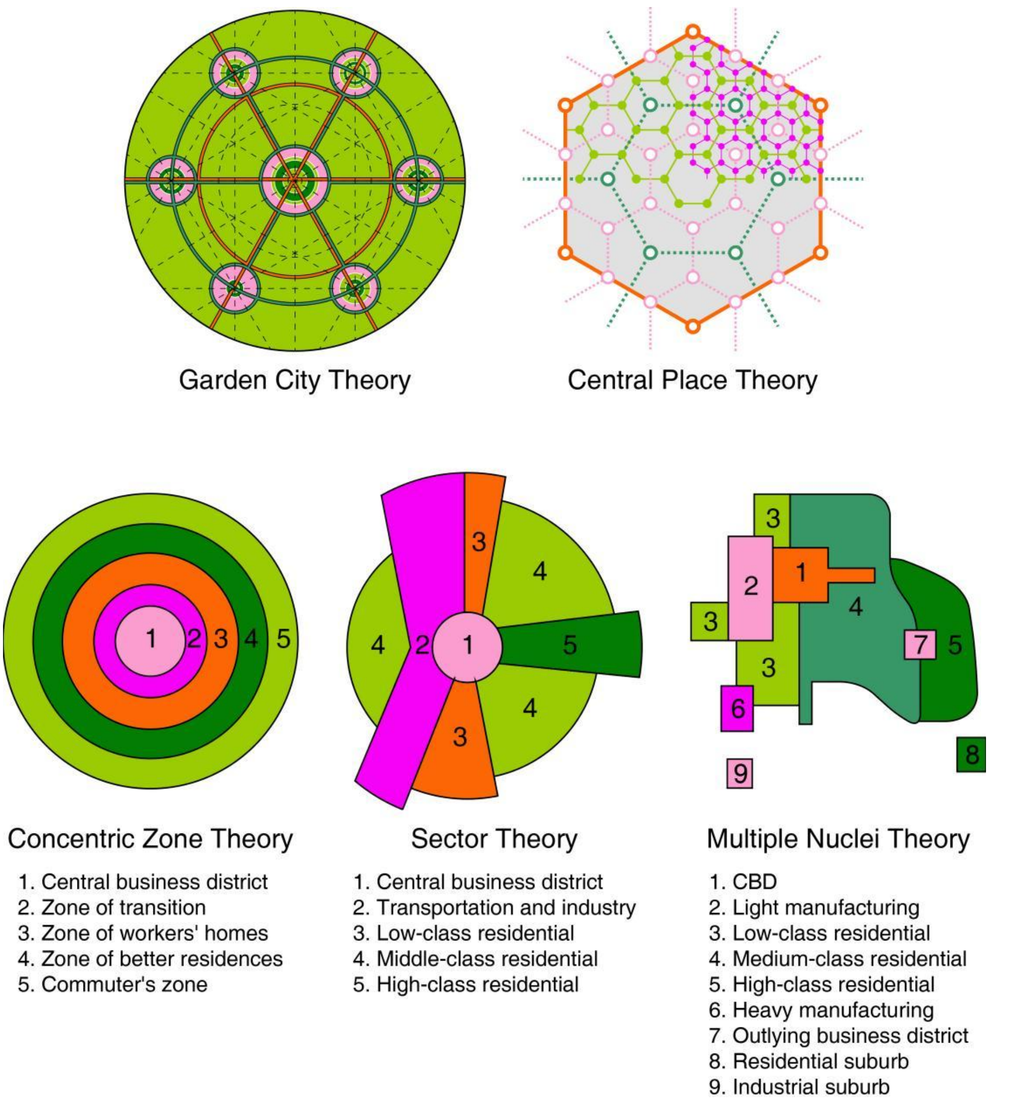


Fig. 2-2. Urban models (Source: drawn by author)

2.3 Urban design with MAS

Minsky proposed that complex systems are made up of various, precisely defined, tiny agent units. In the simulation process, multiple agents are act autonomously, all the agents are updated asynchronously in parallel [17]. Simple agents are capable of creating complex structures, and intelligence can be explained as the result of a combination of non-intelligent agents. This complex structure is referred to as a MAS [18]. The history of programmable agents dates back to 1951, when John von Neumann introduced the concept of Cellular Automata (CA) to elucidate neural processes in the brain [49]. While his automata models were less complex than biological systems, studying living organisms contributed to the advancement of more sophisticated automata models [50]. Building on von Neumann's theory, John Conway developed the first implementation of CA in the 1960s, which became known as the famous Game of Life (Adamatzky 2001) [51] (*Fig. 2-3*). The Game of Life can generate remarkably intricate and enduring dynamic patterns through the basic and systematic switching of cells. According to Rodrigues and Raper (1999), the concept of CA shares many similarities with the concept of agents. On one hand, the cells of a CA can be seen as stationary agents within a static network that respond to stimuli in their vicinity. On the other hand, the lasting pattern of a CA can be considered a self-replicating agent within the cellular space. As a result, CA can be categorized as a subtype of Agent-Based Models (ABM) [52].

Russel and Norvig (1995) define an agent as something that can perceive and act [53], while Wooldridge (1999) describes an agent as a computer system located in an environment in which it can act independently to achieve its design objectives [54]. MASs exhibit several characteristics, including autonomy, adaptability, intelligence, reactivity, initiative, social competence, and goal orientation. The versatility of MASs in addressing distributed problems in dynamic scenarios has led to their widespread adoption across diverse fields [55]. These applications can be broadly categorized as models for simulating and comprehending natural systems, and models of artificial systems for resolving complex problems and generating solutions [56]. Therefore, CA have also been used for optimization in urban growth models. Feng proposed that incorporating a spatial heterogeneity-weighted neighborhood into CA could effectively simulate dynamic urban growth [30]. Later, he also suggested using CA and particle swarm optimization rules to model dynamic urban growth [57]. Liu used long short-term memory network models and CA to simulate dynamic urban expansion under ecological constraints [31].

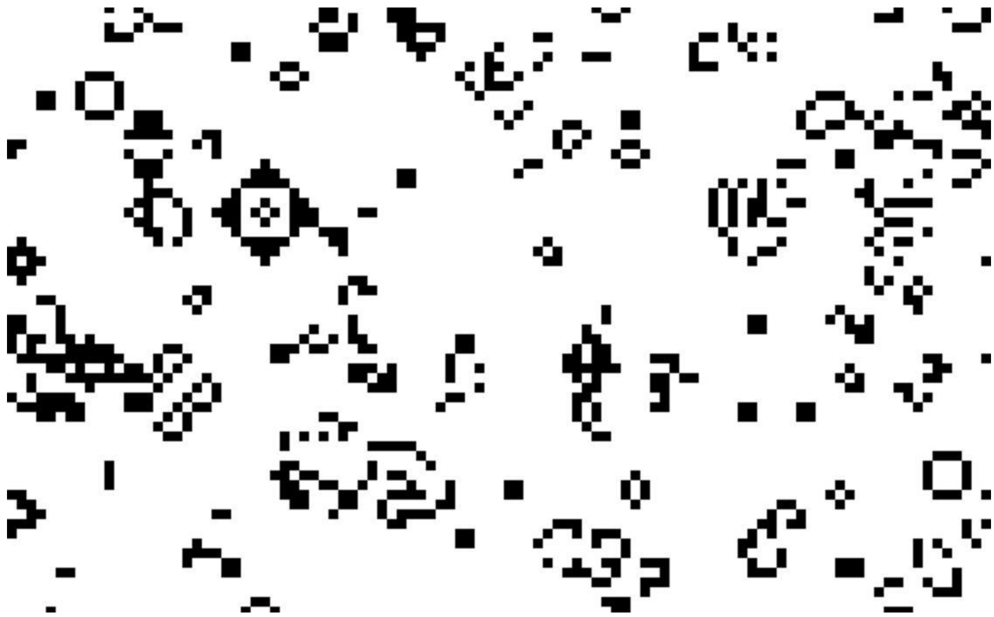


Fig. 2-3. Game of Life base on CA (Source: drawn by author)

Raisbeck acknowledges the potential of MAS in urban design, which allows for bottom-up modeling of cities through simulation and optimization of motion, structure, and pattern formation. However, he notes that MAS is still in an exploratory stage and its most successful applications have been in pedestrian movement and evacuation studies [58]. These research methods are mainly used in urban simulation in the macroscopic field and building simulation in the microscopic field. In terms of micro-simulation, current simulation systems are usually related to user behavior, such as pedestrian flow or evacuation simulation [59]. Penn and Turner's model which based on Space Syntax Theory of VGA proposed that stopping and congestion would affect the agent motion simulation. This research improves the similarity between model simulations and consumers movement patterns. Turner also introduced a dynamic agent-based model that enabled visual analysis of aggregated spaces in architectural environments [21]. Kitazawa and Batty have applied the agent model to the field of micro-behavior simulation. The agent model uses the shortest-path model as one of the evaluation criteria of Genetic Algorithms, and uses the agent model to simulate the behavior of consumers [22]. In addition, some agent models are developed and formed on the basis of fluid dynamics, particle systems and self-organization theory [23]. Resnick, based on the turtles language, invented a simple and powerful application combining mobile agents and

CA-StarLogo [43]. StarLogo is the predecessor of NetLogo. As a common MAS construction and operation platform, NetLogo has been widely used in various fields (*Fig. 2-4*).

Currently, most dynamic multi-agent models are used to predict macro-level changes in urban development [30,31], but overlook the potential application of this technology in micro-level urban construction. Evacuation models are most commonly studied at the micro-scale, with the shortest path algorithm as the core representation of activities, ignoring the influence of internal states and vision on activities [32]. Although there are many analytical MAS models related to pedestrian movement, evacuation, and crowding, there is a growing trend to use agents in the generative design process [29].

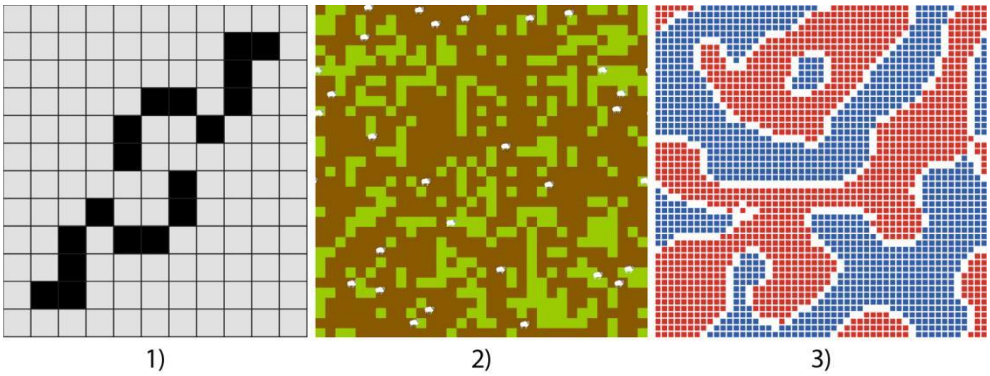


Fig. 2-4. 1) Game of Life, 2) Sheep Grazing Game, 3) Schelling model (Source: drawn by author)

Chapter 3: Master design 1 - application of 3D visual quantification in historic district renewal

This paper explores a MAS-based pedestrian activity model that can be applied to urban renewal and commercial environment design at the microscale. In existing research, traditional evacuation models neglect the influence of external environment on people's vision and psychology, resulting in inaccurate predictions. In the daily activities of pedestrians, the surrounding environment affects the internal state of pedestrians through visual elements, and affects pedestrian activities and behavioral decisions. Therefore, visual factors have an important impact on pedestrian activity, and it is necessary to establish an algorithm centered on human perception to dynamically reflect the internal state of pedestrians by collecting visual information. In this chapter, the Minzhu Road historical district in Zhanjiang is used as the research object to develop a visual quantification tool for the three-dimensional space of the historical district, exploring the relationship between perception, visual simulation, and behavioral simulation. Meanwhile, the visual quantification model is used to evaluate the commercial value and renovation value of different locations in the district, effectively promoting the commercial layout, resource allocation, cultural preservation, and regional renewal of the historical district.

3.1 Site analysis

Minzhu Road historic district is located in Chikan District, Zhanjiang City, Guangdong Province (*Fig. 3-1*). The pedestrian district consists of four main streets with an area of approximately 1 square kilometer. A hundred years ago, it was an important freight port for foreign trade in Zhanjiang City (*Fig. 3-3*). However, due to the expansion of the city and land reclamation projects, the area has become completely inland. The historic district is located in the core area of Chikan District, with 11 primary and secondary schools, parks, sports fields, hospitals, and other important urban facilities within a kilometer radius (*Fig. 3-2*). Therefore, the historic district has a good location advantage. However, due to its location in the old city area, the infrastructure is relatively backward, and the surrounding roads are mostly narrow one-way streets, making transportation inconvenient.

Fig. 3-1. Project location (Source: designed and drawn by author)

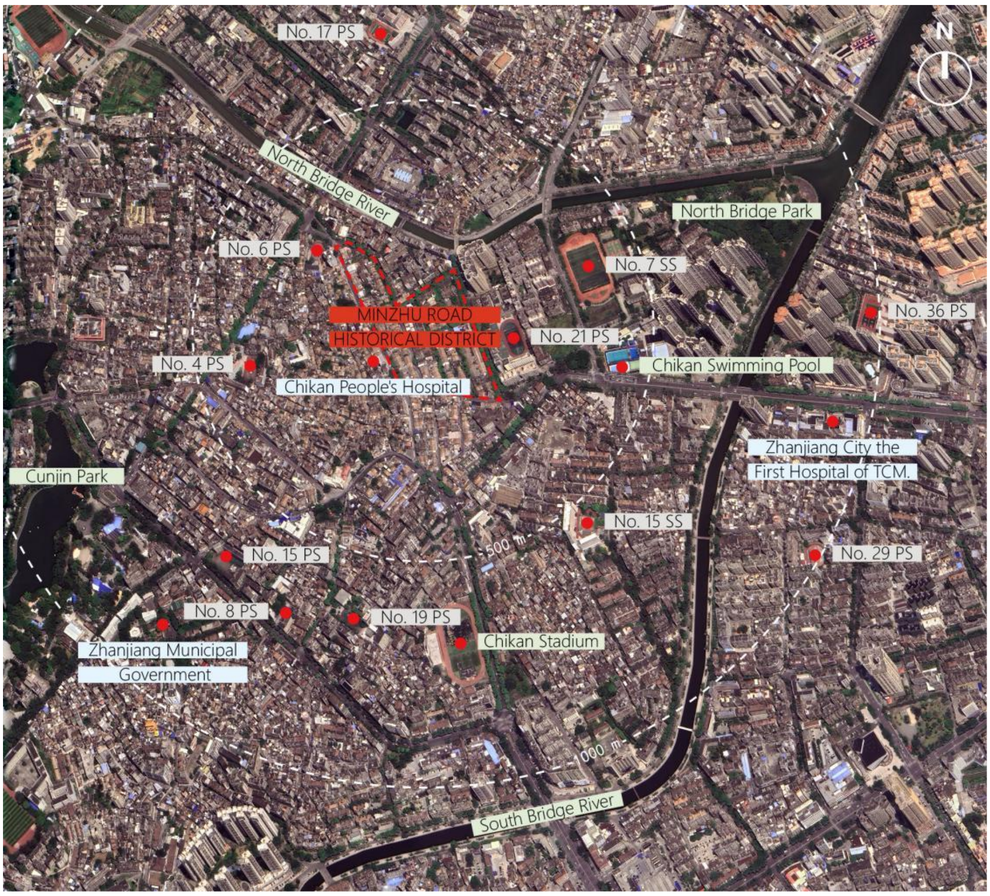


Fig. 3-2. Minzhu Road historical district location (Source: designed and drawn by author)

With the development of society and the change of urban renewal concepts, the transformation of outdated urban areas has shifted from demolition and reconstruction to the protection of historical heritage. Therefore, the government of Zhanjiang plans to carry out protective renewal in this area, and while presenting preliminary design concepts to society, it is also soliciting relevant opinions [60]. According to the relevant documents released by the government, based on the characteristics, structures, history, and current situation of more than 100 existing buildings in the historic district, three different renewal methods need to be adopted: preservation, renovation, and demolition [61]. Most of the preserved ancient buildings with shops on ground floors and residential on the upper floors. Their characteristic is that the corridor part facing the street is an extending to the store. In China, this arcade-style building is called "Qi-lou". As Zhanjiang has a subtropical climate, it is hot and rainy all year round. People walking in the corridor can avoid wind, rain, and sun. These buildings were established in the 1820s, when Zhanjiang was occupied by France. Under the influence of French culture, these buildings presented a combination of French style and local style (*Fig. 3-3*). At the end of the 20th century, Qi-lou could not meet people's daily needs, they were abandoned quickly, and the preservation of these buildings was terrible. These buildings were used as electrical stores, furniture stores, breakfast stores, variety stores and antique stores, which is undoubtedly a kind of waste of historical buildings (*Fig. 3-4*). Moreover, the shopkeepers partitioned the interconnected corridor areas and occupied the public area of the corridor as a private store area. This situation damaged the structural characteristics of historical buildings. Some old buildings have collapsed, and their owners have built new buildings on the ruins. This kind of architectural form that conflicts with the overall landscape of the historical district is also a negative impact on the environment.

Fig. 3-3. 1) Qi-lou commercial street, 2) Qi-lou office, 3) Chamber of Commerce, 4) Consulate, 5) Naozhou Lighthouse, 6) Minzhu Road Pier (Source: drawn by author)

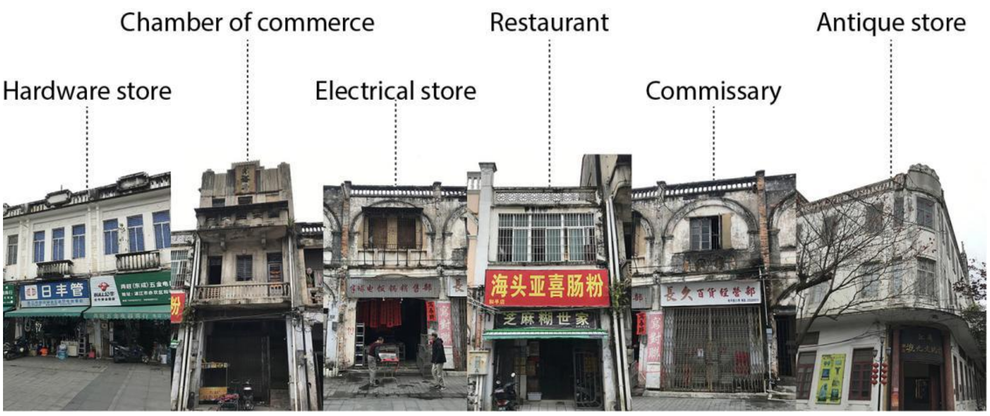


Fig. 3-4. Minzhu Road Qi-lou status (Source: designed and drawn by author)

3.2 Model construction

Minzhu Road historic district is located at the core of the city and has important historical value, which has attracted significant attention from the public regarding its protection and renovation. In order to further protect the historical buildings on both sides of the street, all four roads in the area have been completely closed to vehicles, and are only open to pedestrians (*Fig. 3-5*). Therefore, in the renovation design, it is necessary to fully consider the relationship between pedestrians and the surrounding environment. The complexity of the historical building structures, as well as the interference of trees, streetlights, and power poles in the district, make it difficult to quantify pedestrian visual perception.

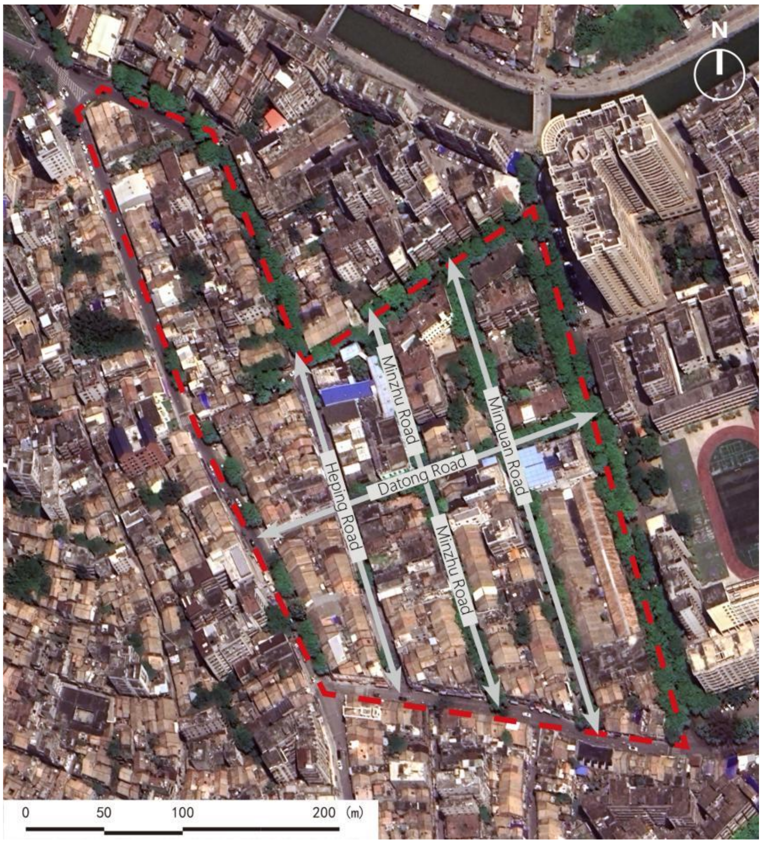


Fig. 3-5. Pedestrian streets in Minzhu Road historical district

(Source: designed and drawn by author)

This study developed a visual quantification model that can be used in three-dimensional space. It can reflect the visibility and commercial value of each store, and different types of stores can be arranged according to the evaluation values of different areas to achieve effective allocation of resources. In the field of digital media, Chen Jianhui [62] has conducted several studies on agent-based interfaces. His research indicated that future researches may incorporate 3D space to examine the impact on visible areas of attention. The establishment of a 3D model that truly reflects the situation of the project, and the classification of visual elements on this basis, is one of the requirements for using agent to simulate the reality [34]. Stores can use visual elements to influence whether pedestrians enter the store. These factors have both positive and negative effects. For example, visual elements like billboards, posters, windows, and entrances showing the characteristics of the stores would attract peoples. However, corridor columns, street lights, trees, and devices would hinder people's activities and reduce the attractiveness of shops (*Fig. 3-6*). In addition, the models of streets, buildings, and other objects are simplified. For example, in terms of buildings, mainly structural features are retained in the modeling, and most of decorative details are omitted, so as to ensure the running speed of the simulation model.

Fig. 3-6. Obstructions on the street (Source: photo by author)

In the 3D model, some Observation Points (OP) are set up according to people's activity routes to realize the visualization and quantification of the influence of the store view objects. The area is divided using a grid composed of squares with a width of 1 m. The agent walks on the grid, and the points on the grid are used to record the agent's walking route. The agent's activities are simplified from 360° to 8 directions: east, south, west, and north, southeast, northeast, southwest, northwest (*Fig. 3-7*). According to the path, a camera with a lens length of 28 mm in Rhino is placed on each OP with a height of 1.5 m. Then, the eye height of the observer can be simulated, and the state of the observer viewing the building horizontally and collecting images is represented. Besides, the field of view and the focal length are set to 75 degrees and 20 meters, respectively. Afterward, 108 rays are emitted from camera and use Grasshopper platform to calculate the number of rays projected on the target. The score of Evaluation Visibility (EV) is defined as the ratio of the number of rays hitting the view objects [33]. The Evaluation Visibility Ratio (EVR) is the ratio of the visible area inside the building to the area of the façade (*Table 1*). Moreover, the greater the EVR score, the higher the visibility inside the store, and the greater the attraction of the store to pedestrians. The smaller the EVR score, the higher the privacy of the interior space of the store.

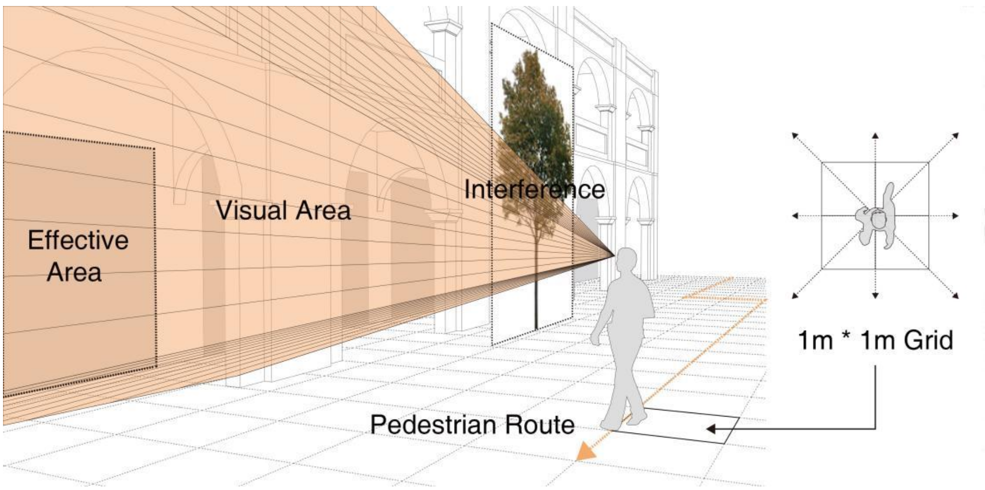


Fig. 3-7. Visual quantification process (Source: designed and drawn by author)

Table. 1. Model design and value input (Source: designed and drawn by author)

Pedestrian Route selection (PR)			
PR^1	Route anchor	A square grid with a width of 1 m divides the area	
PR^2	Route direction	Simplify 360 degrees into 8 directions	
Observation point selection			
OP^1	Number of observation points	Number of grid points on the route	17
OP^2	Observer height	Z coordinate direction of observation point	1.6 m
Observer parameters			
OP^1	Camera position	Observer position	1-17
OP^2	Lens length of camera		28 mm
OP^3	Viewing angle of camera		75°
OP^4	Focal length of camera		20 m
Visual Simulation (VS)			
VS^1	Number of ray for simulation	Rays projected on the object	108
VS^2	Visual Object Score (VOS)	Rays projected on the visual object	
VS^3	Building Score (BS)	Rays projected on the building	
VS^4	Object visibility ratio	$EVR = VOS/BC \cdot 10$	

3.3 Visibility evaluation analysis

The visualized area ratio of the store can be exhibited through the visual simulation model. These figures illustrate the undisturbed EVR and the EVR affected by trees and street lights when the store does not hang advertisements (ads) on the building. In the first case, the visibility of the internal of the store changes less frequently, and the visible time of the interior is continuous (*Fig. 3-8*). In the second case, people's attention to the shop fluctuates significantly due to the disturbance. Because of the lack of coherent attention, such shops are easily overlooked. (*Fig. 3-9*).

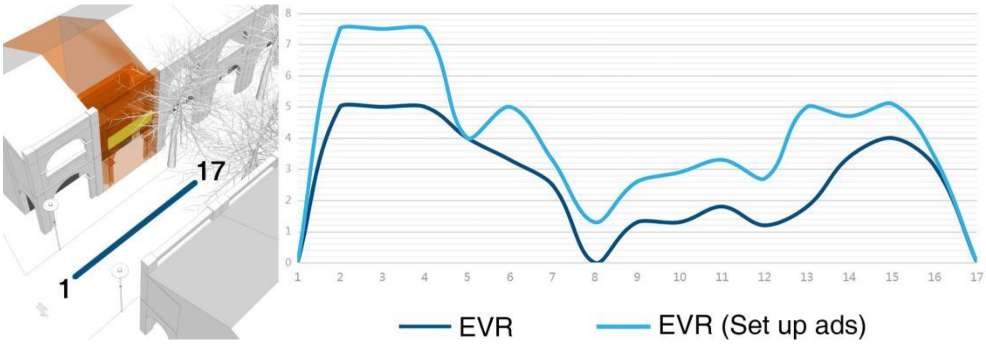


Fig. 3-8. EVR for setting up ads without interference (Source: designed and drawn by author)

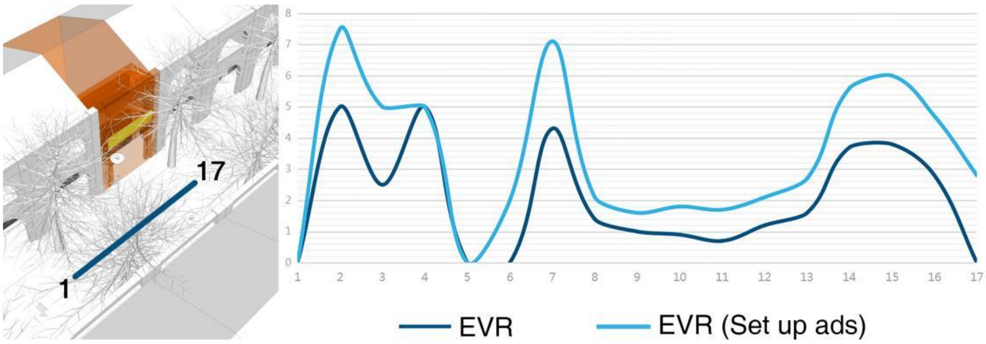


Fig. 3-9. EVR for setting up ads under the influence (Source: designed and drawn by author)

3.4 Historic district renewal strategy

The author aims to optimize the tourist and commuting experience, and enrich the business environment of the historic district through its renovation. As an important city for art exams in Guangdong Province, Zhanjiang cultivates a large number of students in art-related fields every year. It can be seen from *Fig. 3-10* that Zhanjiang’s 2018 art candidates accounted for 13.5% of the province’s total, the highest number in the province. The number of ordinary candidates in Zhanjiang only accounted for 7.7%. Compared with the general college entrance examination, the proportion of art candidates is higher.

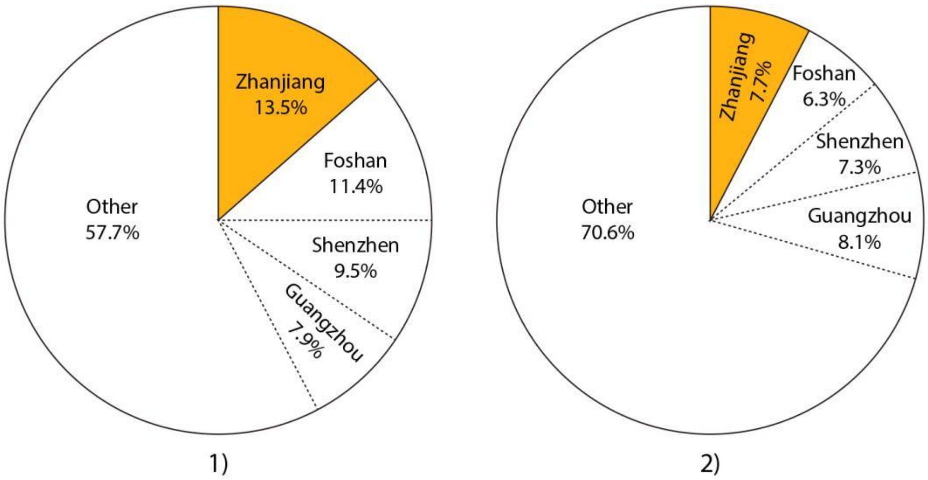


Fig. 3-10. 1) Proportion of art candidates, 2) Proportion of ordinary candidates
(Source: designed and drawn by author)

Fig. 3-11. Art education (Source: drawn by author)

However, private art training institutions are scattered throughout the city, and lack communication and cooperation with each other. Therefore, the author uses the historic district to create teaching conditions and an environment for mutual exchange and learning for these art training institutions. Art students need more than half a year of intensive and closed training. A large number of art students can significantly increase the flow of people, improve the utilization efficiency of the area, and promote the development of supporting industries, such as stationery shop, restaurant, commissary, etc (*Fig. 3-12*). At the same time, the products of art institutions can be sold in the shops of the historic district, not only gaining economic benefits but also enhancing the cultural atmosphere of the historic district, forming a positive cycle (*Fig. 3-13*).

Fig. 3-12. Supporting industries (Source: drawn by author)

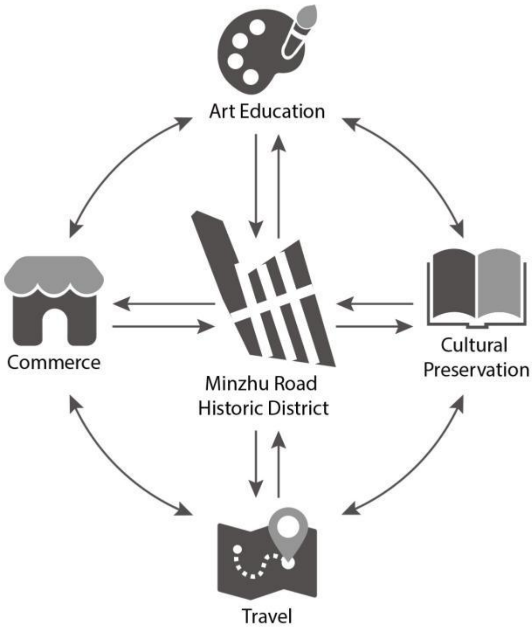


Fig. 3-13. Industrial structure (Source: designed and drawn by author)

The EVR is calculated by the visual simulation model can evaluate the visibility of different stores, including the visibility of interior and external publicity of the store. Through the evaluation, the store can be divided into three categories according to the visibility score: continuous visual elements, affected visual elements and trivial visual elements (*Fig. 3-14*).

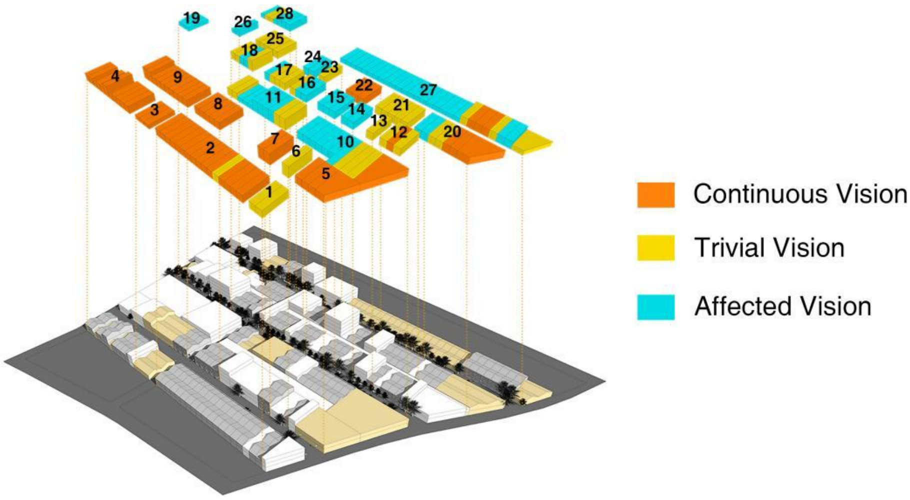


Fig. 3-14. Visibility evaluation of historical buildings (Source: designed and drawn by author)

Firstly, restaurants and specialty shops do not have fixed consumer groups, and they are mainly for foreign tourists. Therefore, such stores need to have higher exposure to attract more customers, and they have higher requirements for the visibility of internal space and advertisements. Secondly, the buildings' visual elements are affected; they are set as art materials stores, stationery stores, and antique stores. Consumers in such stores basically have a clear shopping purpose. For example, customers who go to art material stores and stationery stores are generally students from surrounding art training institutions. Because of the shortage of these materials, they will go to the store to purchase, so they are purposeful, and they will actively look for these stores. This kind of store can be planned in areas where the visibility is disturbed by some influencing factors, and even this arrangement will not have a major impact on the store's business. Thirdly, buildings with trivial visual elements are designed as art training institutions, Chinese medicine hospitals and kindergartens. These buildings do not have high requirements for the display of internal space and the high flow of people. Their users are stable and require a quiet and safe space (*Fig. 3-15*).

Fig. 3-15. Site plan of Minzhu Road historic district (Source: designed and drawn by author)

Fig. 3-16. Functional positioning of different building blocks (Source: designed and drawn by author)

3.5 Buildings renewal design

In the renovation of historical buildings, the visual types of different buildings should correspond to the functional characteristics of the store. According to the buildings preservation, they are divided into three types: preservation, renovation, and demolition. If the building structure was too old to support subsequent renewal work, these buildings are demolished. Besides, the other buildings should be preserved. This renovation project is mainly divided into three aspects:

First, this renovation project should achieve a balance between the historicity of the old building and the functionality of the modern building. For general historical buildings, the most common protection method can be used to change the original use. This not only protects the buildings, but also gives them new life through industrial transformation. Most Qi-lou will be used as stores in the future, and how to promote themselves will become the focus of businessmen. Therefore, it is necessary to consider how to set up ads in stores without destroying the appearance of historical buildings. Design team uses visual simulation models to analyze and evaluate different forms of advertisements. The number of rays projected on the facade of the building is called building score. Under the influence of obstructions, the number of rays projected on visual objects that can reflect store characteristics is called visual object score. EVR is a numerical value for evaluating the visibility of store promotion factors The following table can reflect the changes in EVR under different influencing factors with people's activities, and when the value is higher, the effective field of view area is also more obvious (*Table 2*). The EVR in different situations can be compared through visual simulation when ads are set up. This research shows that the proper placement of ads on the facades of historical buildings can effectively expand the scope of publicity of the store and extend the perception time of pedestrians. Compared with uncovered stores, those covered by trees and street lights have a more significant effect on brand promotion by setting up ads. The conclusion is that the reasonable display of ads without destroying the structural characteristics of Qi-lou should be encouraged and supported (*Fig. 3-18*).

Table 2. EVR in different situations (Source: drawn by author)

EVR in different situations													
Moving distance (m)	0	1	2	3	4	5	...	11	12	13	14	15	16
EVR without interference													
Building score	4	4	4	4	5	6	...	52	62	62	45	32	18
Visual object score	0	2	2	2	2	2	...	6	11	21	18	10	0
EVR (=VOS/BC*10)	0	5	5	5	4	3.3	...	1.2	1.8	3.4	4	3.1	0
EVR for setting up ads without interference													
Building score	4	4	4	4	5	6	...	52	62	62	45	32	18
Visual object score	0	3	3	3	2	3	...	14	31	29	23	11	0
EVR	0	7.5	7.5	7.5	4	5	...	2.7	5	4.7	5.1	3.4	0

Fig. 3-17. Advertisement settings reference (Source: https://www.gooood.cn/yongqing-fang-lab-dh.htm)

Fig. 3-18. Advertisement settings for store (Source: designed and drawn by author)

Second, the renovation project realizes the coexistence of order and variety. Most Qi-lou follow the same order of height, width and building structure. Order means balance, symmetry, and repetition. Excessive emphasis on order will lead to monotony, giving people a sense of stiffness and boredom. Based on the original design rules of Qi-lou, the decoration details, materials and colors of the buildings can be adjusted appropriately to make each building have its own characteristics (*Fig. 3-20*). The characteristics of the store are displayed through architectural features, not limited to the use of doors, windows and billboards, and the efficiency of external publicity is improved by enlarging the visual display area.

Fig. 3-19. Wall update reference (Source: https://www.gooood.cn/yongqing-fang-lab-dh.htm)

Fig. 3-20. Order and diversity in Qi-lou (Source: designed and drawn by author)

Fig. 3-21. Building facade material (Source: designed and drawn by author)

Third, this project demonstrates the vitality of the street by realizing visual communication. The aesthetic reconstruction of historical Buildings should not simply pursue the appearance of buildings, but should try to express the activities of people living in them. Modern highways and buildings have cut the connection between people, and people in modern society are more accustomed to hiding their lives. These behaviors weaken the vitality of the city. In the renovation project, a pedestrian street of moderate scale is used to create a space that encourages communication. The design considers how to realize the interaction between the internal space of the building and the external environment, so that the corridor originally used for sheltering from wind and rain will not become a barrier to people's communication in modern society. The perforated steel and polycarbonate materials can be used to renovate the damaged exterior wall of the building. The color of new material can be close to the original color of Qi-lou, and it also has the characteristics of light weight and transparency. On the one hand, the texture of the new material is compared with the texture of the original material to produce unexpected artistic effects. On the other hand, pedestrians outside the building can feel the atmosphere of the interior space through the materials, but they cannot see the interior clearly, which ensures the privacy of the interior space; and the people inside can also see the passing by. This design allows people inside and outside the building to feel the connection between themselves and others, thereby showing the vitality of the street.

Fig. 3-22. Structural materials update reference (Source: https://www.gooood.cn/yongqing-fang-lab-dh.htm)

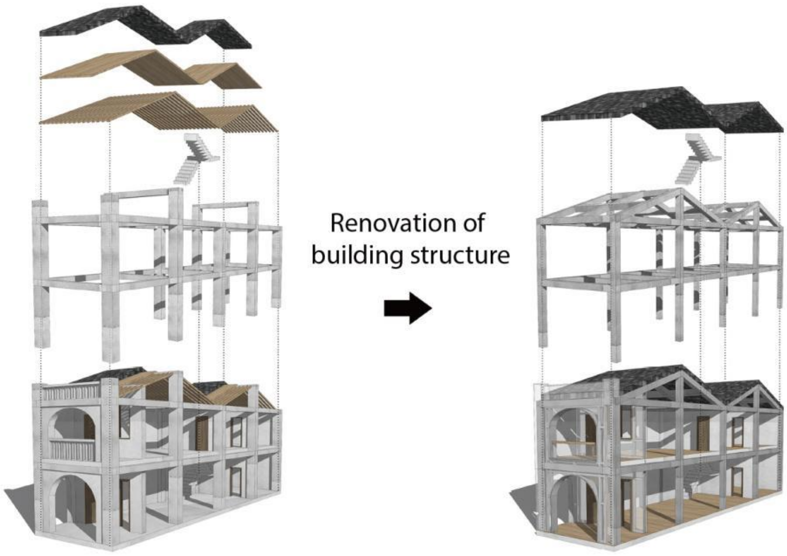


Fig. 3-23. Renovation of building structure (Source: designed and drawn by author)

3.6 Discussion

Experiments prove that the MAS has practical value in the field of design evaluation of historic blocks and buildings. Traditional pedestrian behavior simulation ignores the external environment's impact on pedestrians' vision and psychology, making the accuracy of prediction not enough. Thus, an algorithm focusing on people's perception is built in this paper, and the internal state of pedestrians is dynamically reflected by collecting visual information. The EVR can clearly and accurately reflect the visibility of each store. In other words, the commercial value of each area can be evaluated through the EVR value, and different types of stores can be arranged according to the EVR value of different areas to realize the effective allocation of resources. Although this model is more innovative and practical than the traditional model, it does not mean that the model is perfect. The model is built on the Grasshopper platform, and the visual evaluation needs to be performed in three-dimensional space, which also leads to the following problems. First of all, because the simulation environment is three-dimensional, the plane stage in the early stage of design is directly skipped, so this technology cannot be used in the early stage of design, and can only be used in the evaluation process at the end of the design process. Second, the complexity of 3D simulation leads to insufficient applicability of algorithmic models. Therefore, this research need to explore a plane-based, flexible, and widely applicable visual assessment method.

Fig. 3-24. Rendering of Minzhu Road historic district (Source: designed and drawn by author)

Chapter 4: Master design 2 - application of 2D VGA in Zhanjiang Steel Factory renewal

4.1 Site analysis

The author participated in the factory landscape renovation project of Baosteel Zhanjiang Steel Co. Ltd. during his internship at the Architectural Design and Research Institute of Guangdong Province (GDAD). Zhanjiang Steel Factory is located on Donghai Island (*Fig. 4-1*). Environmental rectification has become a serious problem for many big industrial units at now, owing to China's carbon neutrality legislation. In order to improve the overall landscape quality of the industrial park and highlight the characteristics of corporate culture, Zhanjiang Steel Factory proposed the need for landscape renovation.

Fig. 4-1. Project location (Source: designed and drawn by author)

Fig. 4-2. Aerial photography of Zhanjiang Steel Factory (Source: photo by GDAD)

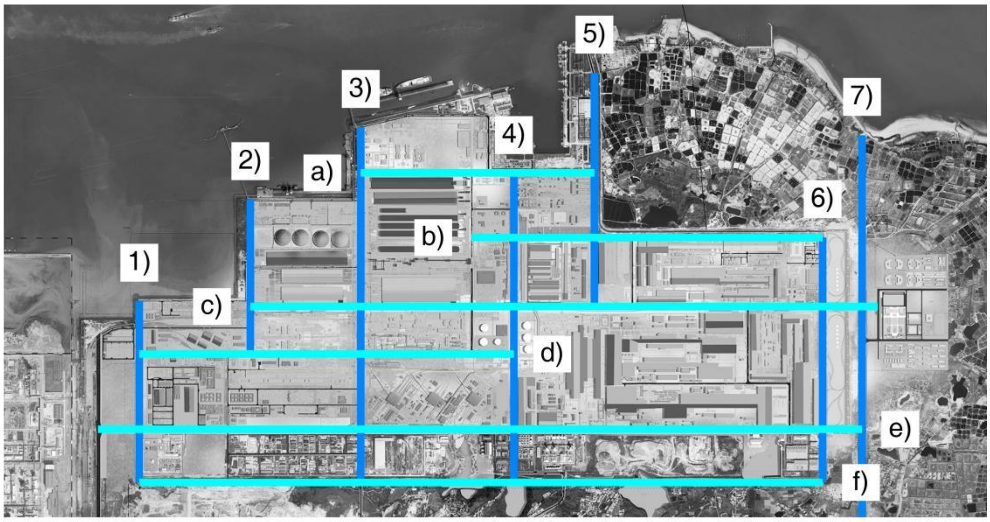
There are 5 manufacturing divisions in this factory: iron, steel, hot rolling, cold rolling, and heavy plate, as well as 6 supporting regions (*Fig. 4-3*). The factory area has 7 main roads running north-south and 6 main roads running east-west. Warp Road runs north-south, from west to east, it is Warp 1 to 6 Road, and the easternmost Island East Road separates the manufacturing and residential areas. From north to south, the east-west route is known as Weft Road, and it runs from Weft 1 to 6 Road. There are many branch roads within functional divisions (*Fig. 4-5*).

1) Iron Plant
2) Steel Plant
3) Hot Rolling
4) Cold Rolling
5) Thick Plate
6) Command Center
7) Water Control
8) Wharf
9) Supporting Area
10) Dongshan Lake
11) Living Area

Fig. 4-3. Functional divisions of steel factory (Source: designed and drawn by author)

1) 2) 3) 4) 5) 6)

Fig. 4-4. 1) Iron plant, 2) steel plant, 3) hot rolling plant, 4) cold rolling plant, thick plate plant, 5) water control center (Source: drawn by author)



1) - 6) Warp 1 Road to Warp 6 Road, 7) Island East Road
a) - f) Weft 1 Road to Weft 6 Road

Fig. 4-5. Main road of steel plant (Source: designed and drawn by author)

4.2 Research methods

Due to the impact of the epidemic and the consideration of safe production, the designer needs to complete the huge research and analysis of the entire factory area in a short period of time. In addition, due to financial constraints, the designer must clearly identify the key renovation areas and concentrate the cost investment on the key renovation areas. Therefore, designers need to explore a method that can accurately evaluate the renovation value of each space in the factory area in a short time.

The study applies the default linear mathematical analysis method of DepthmapX software, generates an axis map by calculating a series of parameters, and then to select the main variables in the space syntax model by analyzing variables, including the integration value and choice value [60]. In order to perform quantitative research on spatial organization and examine the interaction between factory space and users, the map from 2021 is chosen as a study sample, converted into a space syntax model, and loaded into DepthMapX software for analysis. Based on the analysis results, the author preliminarily identified the important transportation nodes within the factory at a macro level, and these factory areas with high utilization rates may become important areas for the factory's update. As shown in *Fig. 4-6*, darker areas have higher usage rates. The spatial syntax axis analysis method has positive significance for large-scale urban space study, but the accuracy of the analysis results for micro-space is low. Therefore, based on the axis analysis, the author used VGA to conduct micro-level visual quantitative analysis on the areas that may need key transformation, in order to evaluate their transformation value. In addition, by comparing the different visual effects before and after the transformation, the author developed corresponding design schemes for the area.

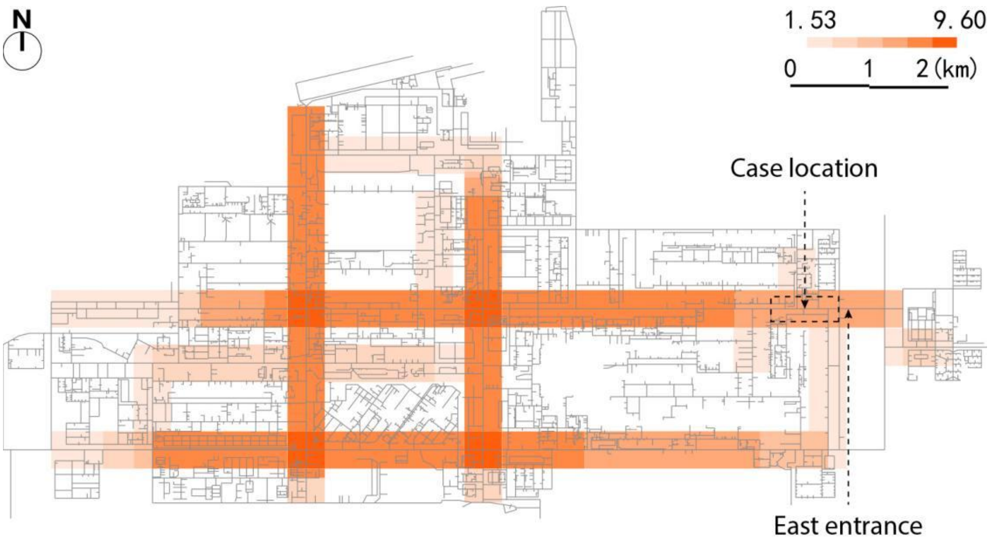


Fig. 4-6. Axis analysis results (Source: designed and drawn by author)

4.3 Before and after comparison of landscape update

This study mainly uses the grid-based connectivity of VGA to conduct quantitative analysis on the factory renewal space and provide data support for the renovation design. The main method used in this study to analyze the factory's major renovation areas is grid-based connectivity. Connectivity measures how many other elements can be seen from one element, and the result is fed back to the element, where it is recorded. The element has better visibility the higher its numerical value. The east entrance of Weft 3 Road serves as a vital link between the production and residential areas, making it a significant facade of the factory and thus possessing high renovation value. Therefore, this entrance is used as an illustrative case in the following discussion.

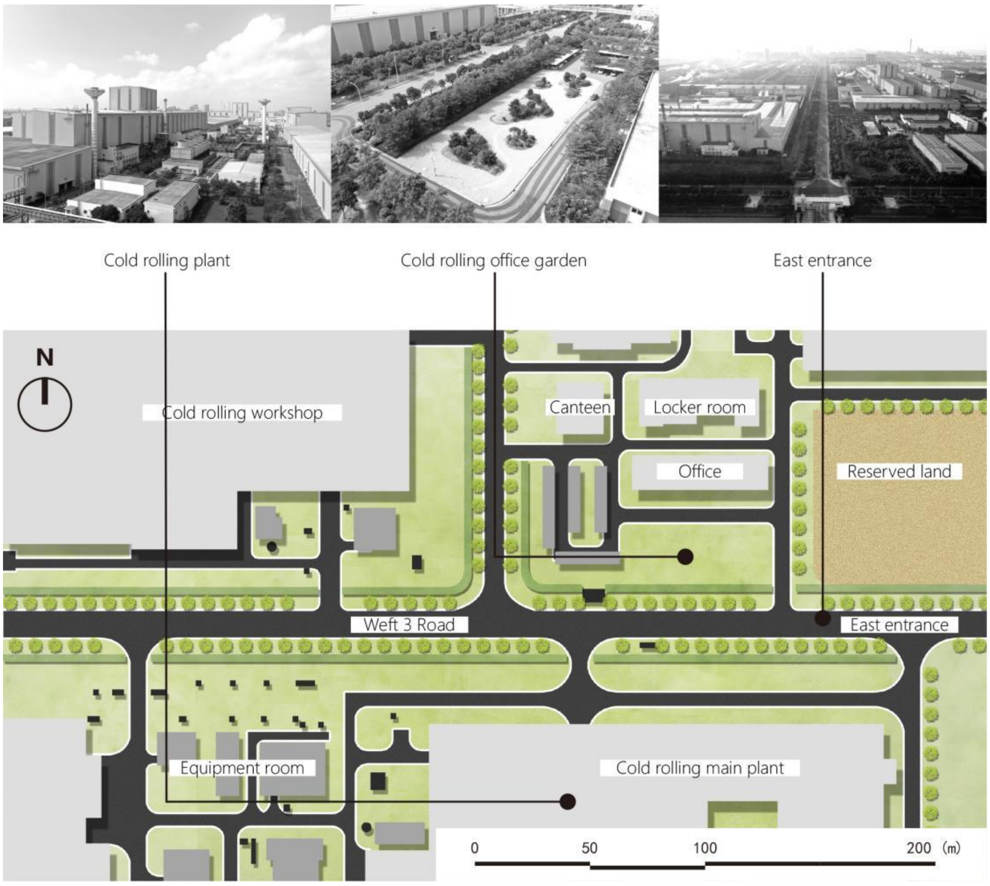


Fig. 4-7. Site conditions before renovation (Source: designed and drawn by author)

Before the renovation design, point A was the area with the highest visual connectivity in the entrance area, and there were areas with high visibility at both ends of point B. From a holistic perspective, the areas with good visibility were relatively scattered and had weak connectivity, which was not conducive to the construction of the overall landscape system. Point B is located in the green space with good visibility between the north of the hot rolling area and Weft 3 Road. This area's usage efficiency is low since the bushes' shadowing prevents connection between the factory area and the main axis. At point C, there are a lot of pipelines and frame buildings, which reduces the area's visibility. Point D is located next to the office building, canteen, changing building, and parking lot on the south side of the cold rolling area. Point E is the reserved land for the factory in an abandoned state. The large and exposed loess greatly reduces the environmental quality of the main entrance (*Fig. 4-7*).

Fig. 4-8. Landscape renovation strategies (Source: designed and drawn by author)

The VGA after renovation is shown in *Fig. 4-9*. The tangled shrubs that lined Weft 3 Road on either side is moved to Point E. On the one hand, it is better to improve the link between the main road, green area, and hot rolling area, and it is also possible to fully exploit the B area's outstanding view characteristics. On the other hand, by hiding point E with shrubs, the entrance's visual attention is focused to the locations of points A and B. The independence and privacy of this location will not be significantly compromised if the shrubs at point D are removed.

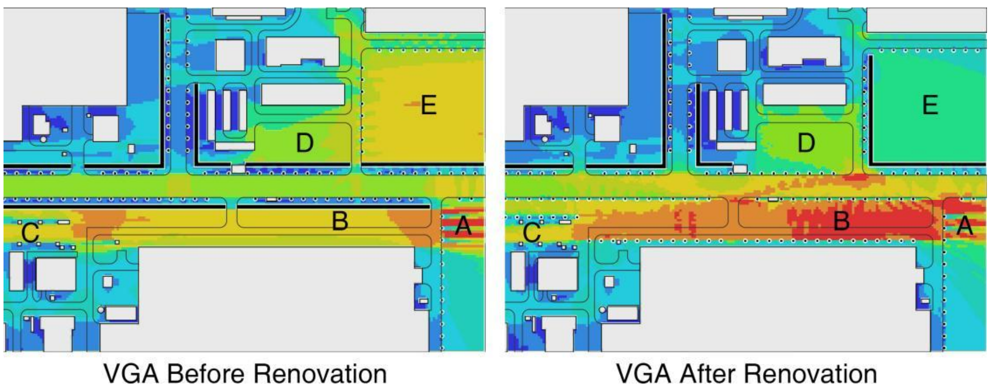


Fig. 4-9. VGA of east entrance area (Source: designed and drawn by author)

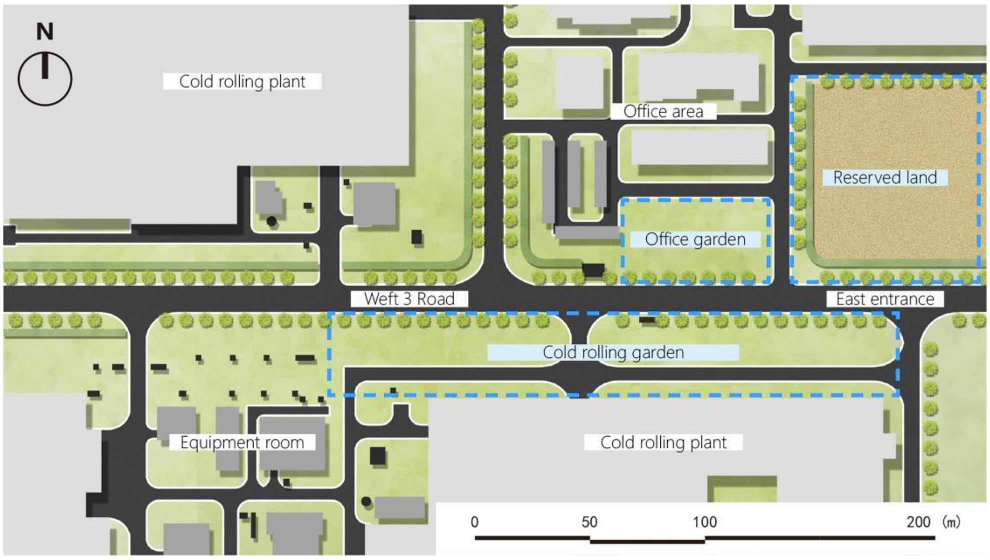


Fig. 4-10. Key renovation areas (Source: designed and drawn by author)

4.4 Landscape renewal design

The east entrance area of Weft 3 Road has convenient transportation and a wide view, and the surrounding area is mainly a cold rolling plant area, with a clean environment. The project focuses on updating the cold rolling garden on the south side of Weft 3 Road, and builds a rest and activity area for employees based on the surrounding environment. It can display the characteristics of corporate culture and green production to meet the standards of the carbon neutral policy [63].

Fig. 4-11. Design elements (Source: designed and drawn by author)

The author extracted the important design elements of Zhanjiang Steel Factory, took industry and environmental protection as the design theme, and upgraded the landscape of the enterprise display area at the entrance. In terms of design details, the pavement is mostly comprised of square stone slices, pebbles, and steel in the details. Steel gabions are utilized as seats, with some landscape structures added to the site to demonstrate the company's development process. Landscape structures are mainly divided into landscape walls and landscape sculptures. They are mainly made of rust plates and weathering steel plates, which are low-cost materials. While controlling construction costs, these relatively special materials are used to show corporate characteristics.

Fig. 4-12. Industrial landscape wall reference (Source: drawn by author)

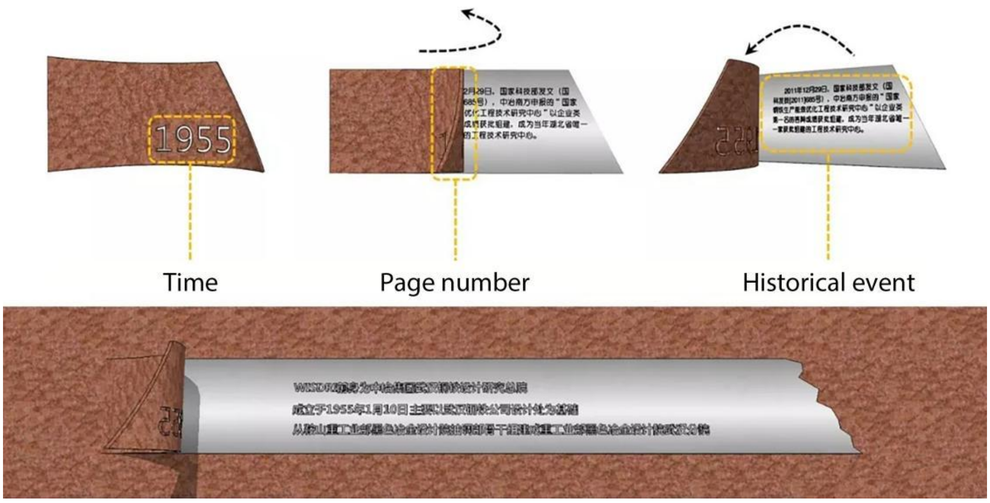


Fig. 4-13. Corporate culture wall design (Source: designed and drawn by author)

Fig. 4-14. Corporate culture wall rendering (Source: designed and drawn by author)

The author used rust plates and weathering steel plates to design multiple feature walls in the garden, resembling books and scrolls, with important events and content related to the enterprise's development engraved on them. By contrasting the rough texture of the rust plates with the smooth texture of the weathering steel plates, it suggests that the enterprise will continue to move forward, and is about to embark on a new chapter (*Fig. 4-14*).

Fig. 4-15. Selected arbor (Source: drawn by author)

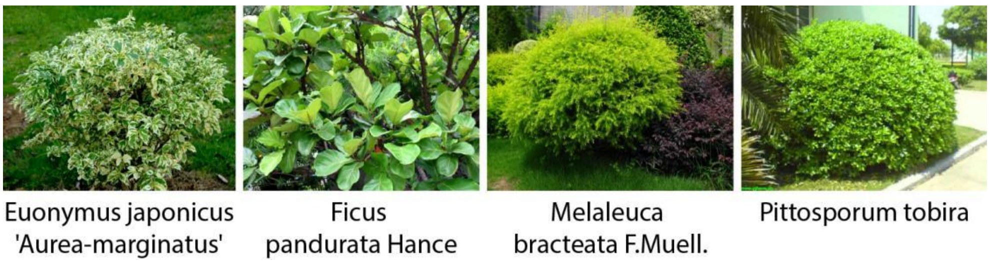


Fig. 4-16. Selected shrub (Source: drawn by author)

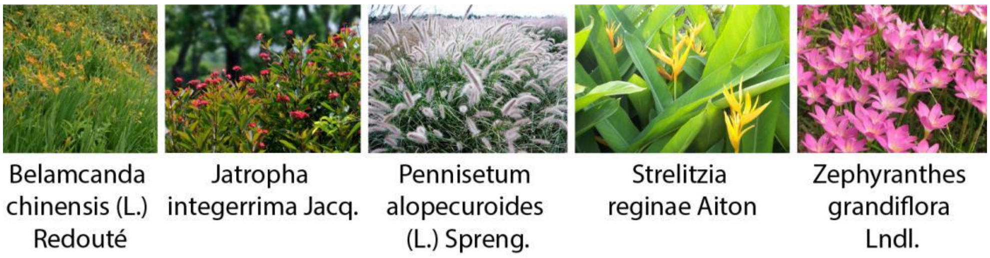


Fig. 4-17. Selected herb (Source: drawn by author)

Based on the local climate in Zhanjiang and the characteristics of the steel plant, the author selected various types of heat-resistant, corrosion-resistant, and low-maintenance deciduous arbors (*Fig. 4-15*), shrubs (*Fig. 4-16*), and herbs (*Fig. 4-17*) in the cold rolling plant garden area. In *Fig. 4-18*, the landscape redesign incorporates various material textures to highlight the industrial theme, and combines these artificial landscape structures with a diverse range of natural plants to showcase the harmonious coexistence between modern factory and the environment [64].

Fig. 4-18. Cold rolling garden seating area (Source: designed and drawn by author)

Additionally, the renovation removed the shrubs between Weft 3 Road and the cold rolling office garden, and added some low-growing herbaceous plants that do not interfere with users' visual experience. Inspired by molten steel, the author designed a sculpture with corporate characteristics, which serves as the visual focus of the area and highlights the theme of the cultural park (*Fig. 4-21*).

Fig. 4-19. Industrial sculpture reference (Source: drawn by author)

Fig. 4-20. Corporate culture sculpture design (Source: designed and drawn by author)

Fig. 4-21. Cold rolling garden corporate cultural display area (Source: designed and drawn by author)

Fig. 4-22. Cold rolling garden corporate cultural display area (Source: designed and drawn by author)

At the same time, the author created a corridor with a lattice wall and a low-water feature at the edge of the garden, which, together with the existing street trees, defined the spatial boundaries of the cold rolling office garden and Weft 3 Road. This design preserves the open view of the garden at both ends of Weft 3 Road while also ensuring the privacy of the office garden (*Fig. 4-23*).

Fig. 4-23. Cold rolling office garden redesign (Source: designed and drawn by author)

4.5 Discussion

VGA, a flexible and widely applicable visual evaluation method, has high practicability in urban landscape design. Taking Zhanjiang Steel Plant as the research object, because the plant has grown to the size of a small town, its spatial elements are relatively simple, which reduces the interference factors of quantitative spatial organization analysis. The author used VGA to quantitatively analyze the spatial structure of the factory's key transformation areas, and compared the simulation results with the real situation to demonstrate the feasibility of VGA, and found that it has the following advantages:

- The use of VGA can reduce the interference of on-site research;
- Space syntax analysis can increase site analysis work efficiency;
- Using VGA to identify hotspots and formulate design strategies can avoid resource waste.

Fig. 4-24. Overall renovation effect of the east entrance of Weft 3 Road

(Source: designed and drawn by author)

Fig. 4-25. Aerial photography of Zhanjiang Steel Factory (Source: designed and drawn by author)

However, the use of VGA in urban renewal has limitations. Although the VGA model can play a role in the analysis and evaluation of quantitative visibility in the micro-scale space, it is still a static model and cannot be intelligently designed and generated as an independent algorithm model. Therefore, the next research will focus on how to make full use of the bottom-up dynamic characteristics of the MAS and the theory of visual quantitative analysis to construct a digital model that can predict pedestrian activities in microscopic urban spaces, and test the accuracy of the model in practical applications.

Chapter 5: Master design 3 - application of MAS in historic district renewal

In recent years, historical districts have received more attention and have become a key factor for assessing urban quality. The renovation should give the space new functions while still protecting historical elements, reviving the area's energy, and realizing the history-present symbiosis. Furthermore, as a public area with shared functions, the historic district's reconstruction should be directed by the public's current and future demands. The essence of public activities is traffic behavior, and movement, as a dynamic link in the behavior system, is critical to comprehending the activity space of historic districts [63]. When designing urban open spaces, pedestrian simulation is always considered a MAS that can be effectively used to lead the initial design of the project [65]. Pedestrian simulation in the macro direction is primarily utilized in urban planning, whereas pedestrian flow simulation, evacuation simulation, and building evaluation are primarily used in the micro direction. Penn and Turner proposed that pausing and congestion can influence the dynamic simulation of agents based on the VGA space syntax theory. Turner also introduced a dynamic agent model that evaluates the aggregation ability of spaces from the visibility of the built environment [66]. The MAS model developed by Moulin in 2003 was used to study pedestrian behavior in urban [67]. However, most evacuation models use the shortest path algorithm as the core representation of activities, ignoring the influence of internal state and vision on activities, and their accuracy is seriously insufficient in daily pedestrian activity simulation. Aiming at the problems of insufficient simulation accuracy of the evacuation model and low efficiency of 3D visual quantification, this study proposes a dynamic pedestrian activity model based on a multi-agent system combined with visual features.

1) 2)

Fig. 5-1. 1) West entrance of Datong Road, 2) Heping Road (Source: photo by author)

1) 2)

Fig. 5-2. 1) Collection Hall, 2) Broken Qi-lou (Source: photo by author)

5.1 Research method

The aim of this study is to use MAS to assist designers in updating outdated urban areas. To achieve this goal, a series of experimental methods such as field research, comparative studies, and data quantification were adopted to establish a reasonable algorithm model and integrate simulated and on-site results into actual design projects. The study first explores the use of MAS to simulate pedestrian activity. Zhanjiang Minzhu Road was used as a case study example in this current research. Due to the limited width and dominant straight roads of historical streets, even minor changes in the environment can have a significant impact on simulation results. These simulation conditions provide a favorable environment for training MAS models with accurate predictive capabilities. In the initial investigation, the team conducted field research on the historical block. The research focused on investigating the site environment and recording the status of pedestrians in the environment. This information formed the basis for building the basic MAS model. Subsequently, researchers used the data collected on site to compare and study the simulation results, focusing on the correlation between simulated and real paths and the different proportions of destinations in agent simulations. This method was used to evaluate the accuracy of the simulation results. Based on the shortcomings found in comparative experiments, the researchers proposed an optimization method to refine environmental factors for better simulation results. However, the limited space in historical street reconstruction projects makes it difficult to construct an automated model that can reflect the actual functionality of the model itself. Therefore, the square space of the important urban renewal project, the Huizhou Jiangbei Sports Center, was selected as the research object for developing an automatically generated model. Based on the optimized pedestrian model, the author constructed an MAS model that can automatically generate design results, exploring the potential applications of the model in design practice (*Fig. 5-3*).

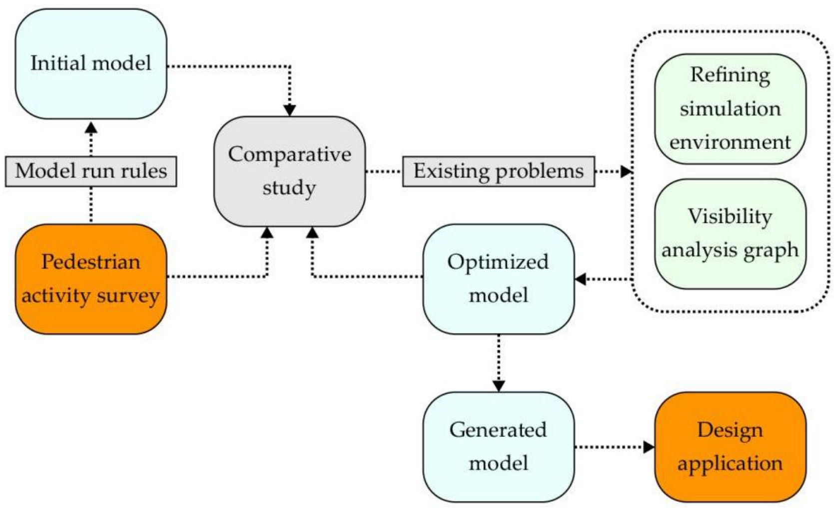


Fig. 5-3. Research framework (Source: designed and drawn by author)

5.2 Pedestrian activity survey

At the outset of the study, the author utilized video recording and personal tracking methods to collect data on pedestrian activity in the Minzhu Road pedestrian district. 48 pedestrians were selected as subjects from eight block entrances to record their movement paths, including passing pedestrians and tourists (*Table 3 and Table 4*). Each subject was equipped with a miniature action camera to capture their visual history, and the author would follow the person and record their movements using a mobile phone video (*Fig. 5-4*). The study primarily examined how the environment interferes with pedestrians' internal states through visual factors, thus affecting their movement. The collected behavioral data served as the basis for building a simulation model, and the trajectory was compared with the simulation results to evaluate the accuracy of the pedestrian simulation [33].

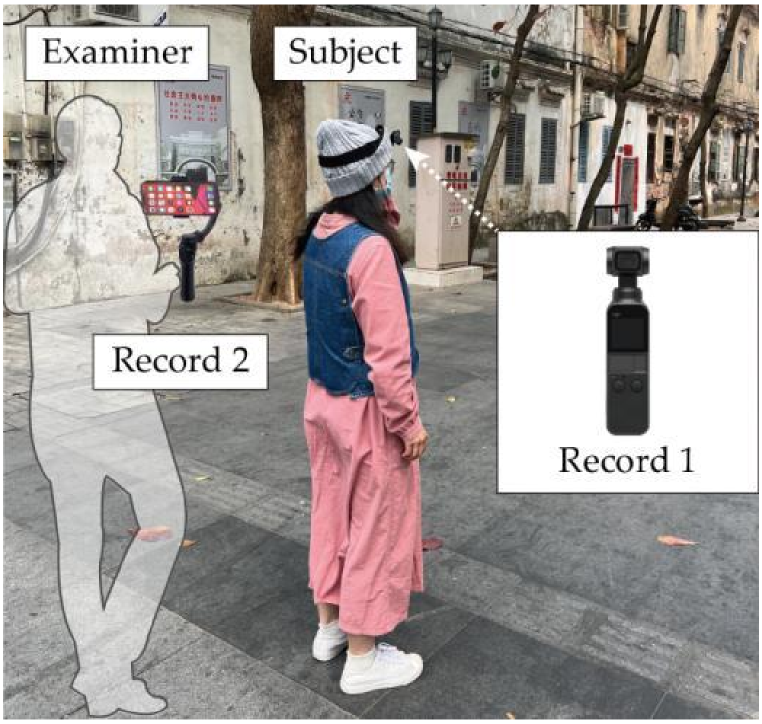


Fig. 5-4. Pedestrian activity path record (Source: designed and drawn by author)

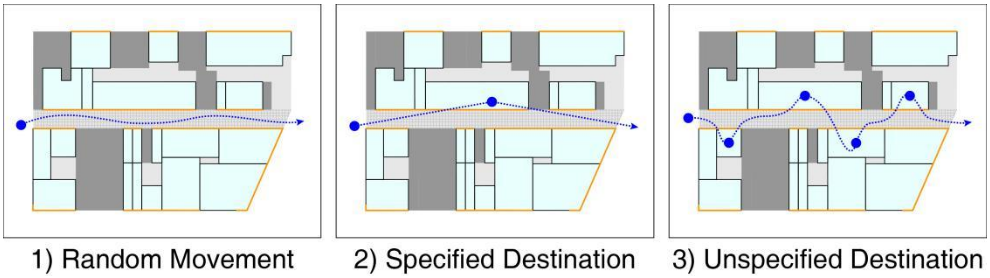


Fig. 5-5. Different types of pedestrian activity in the historic district (Source: designed and drawn by author)

The recording experiments were conducted according to the following rules:

- To reduce the interference of other activities on pedestrian routes, the study chose to be conducted within a closed pedestrian street area;
- The study chose to be conducted on cloudy days or in the afternoon to avoid pedestrians moving to shaded areas and to reduce the impact of weather on pedestrian activities;
- The area was divided into a square grid with a resolution of 1.2 m per square to record the movement paths;
- Turning directions were simplified into eight directions (east, south, west, north, north-east, south-east, south-west, north-west);
- The recorder followed the research subject for video recording, and maintained at least a two-meter distance between the recorder and the research subject to reduce the interference of the experiment on pedestrian activity and decision-making;
- Subjects were required to inform the author about the factors that led to changes in their movement;
- The experiment ended when the recorded subject entered a store or reached the area exit.

Table 3. Basic information of pedestrians in activity path research (Source: designed and drawn by author)

Datong Road						
Number	Age	Gender	Role	Purpose	Start	End
1	28	Male	Visitor	Travel	West entrance	Heping Rd. south exit
2	24	Male	Visitor	Travel	West entrance	Minquan Rd. north exit
3	23	Female	Visitor	Travel	West entrance	Minquan Rd. north exit
4	48	Male	Resident	Transportation	West entrance	East exit
5	29	Female	Resident	Consumption	West entrance	Bakery on Heping Rd.
6	52	Male	Resident	Consumption	West entrance	Antique shop on Minzu Rd.
7	23	Female	Visitor	Travel	East entrance	Heping Rd. south exit
8	32	Male	Visitor	Consumption	East entrance	Antique shop on Minzu Rd.
9	38	Male	Visitor	Travel	East entrance	Minquan Rd. south exit
10	35	Female	Visitor	Travel	East entrance	Minquan Rd. south exit
11	44	Male	Resident	Transportation	East entrance	West exit
12	35	Female	Resident	Transportation	East entrance	Minzu Rd. north exit
Heping Road						
Number	Age	Gender	Role	Purpose	Start	End
1	16	Female	Visitor	Travel	North entrance	South exit
2	52	Female	Visitor	Travel	North entrance	Datong Rd. east exit
3	23	Female	Visitor	Travel	North entrance	South exit
4	25	Male	Visitor	Consumption	North entrance	Coffee shop on Heping Rd.
5	54	Male	Resident	Transportation	North entrance	Datong Rd. west exit
6	56	Male	Resident	Transportation	North entrance	Datong Rd. west exit
7	36	Male	Visitor	Travel	South entrance	North exit
8	31	Female	Visitor	Travel	South entrance	North exit
9	24	Male	Visitor	Consumption	South entrance	Shop on Heping Rd.
10	41	Male	Resident	Transportation	South entrance	Datong Rd. west exit
11	45	Male	Resident	Transportation	South entrance	North exit
12	38	Female	Resident	Transportation	South entrance	Minzu Rd. north exit

Table 4. Basic information of pedestrians in activity path research (Source: designed and drawn by author)

Minzu Road						
Number	Age	Gender	Role	Purpose	Start	End
1	26	Female	Visitor	Travel	North entrance	Heping Rd. south exit
2	26	Female	Visitor	Travel	North entrance	Heping Rd. south exit
3	45	Male	Visitor	Travel	North entrance	Minquan Rd. south exit
4	39	Male	Visitor	Consumption	North entrance	Restaurant on Heping Rd.
5	51	Female	Resident	Transportation	North entrance	Datong Rd. west exit
6	35	Female	Resident	Transportation	North entrance	Dormitory on Minzu Rd.
7	42	Male	Visitor	Consumption	South entrance	Antique shop on Minzu Rd.
8	25	Male	Visitor	Travel	South entrance	Heping Rd. north exit
9	48	Female	Resident	Transportation	South entrance	North exit
10	53	Female	Resident	Transportation	South entrance	North exit
11	50	Male	Resident	Transportation	South entrance	Datong Rd. east exit
12	48	Female	Resident	Transportation	South entrance	Datong Rd. east exit
Minquan Road						
Number	Age	Gender	Role	Purpose	Start	End
1	25	Male	Visitor	Consumption	North entrance	Coffee shop on Minzu Rd.
2	43	Female	Visitor	Consumption	North entrance	Shop on Heping Rd.
3	45	Male	Visitor	Travel	North entrance	South exit
4	31	Male	Visitor	Travel	North entrance	Heping Rd. north exit
5	55	Male	Resident	Transportation	North entrance	Datong Rd. west exit
6	39	Male	Resident	Transportation	North entrance	Datong Rd. east exit
7	23	Female	Visitor	Travel	South entrance	Heping Rd. south exit
8	34	Male	Visitor	Travel	South entrance	Datong Rd. west exit
9	26	Female	Visitor	Consumption	South entrance	Bakery on Heping Rd.
10	55	Male	Resident	Transportation	South entrance	Datong Rd. east exit
11	31	Male	Resident	Consumption	South entrance	Coffee shop on Minquan Rd.
12	57	Female	Resident	Transportation	South entrance	North exit

After analyzing the pedestrian trajectories collected, the following findings were made (*Fig. 5-6*): First, a large number of turns occur at the intersection of Heping Road and Minquan Road. Pedestrians here are more likely to turn than to continue moving in the original direction, possibly due to the narrow width of the intersection. In contrast, the intersection of Minzu Road is wider, allowing pedestrians to obtain more environmental information and maintain their previous activity mode. At smaller intersections, pedestrians, especially unfamiliar tourists, tend to turn to obtain more environmental information. Second, pedestrian activity paths on Minquan Road and

Datong Road are concentrated mainly in the middle due to their narrowness. This is especially true for surrounding residents who use these roads frequently. However, tourists tend to swing forward because of the irregular distribution of historic buildings and high-rise residential buildings on these two roads, with tourists more likely to be attracted to historic buildings. Third, the above observation is evident in the pedestrian activity paths on Heping Road. The western side of Heping Road is lined with historic buildings, while the eastern side comprises high-rise buildings. Pedestrian activity paths tend to be influenced towards the side with the historical buildings. The author hypothesizes that this could be due to subconscious behavioral habits. However, in some road sections, it can be observed that some pedestrians concentrate on one side even when they are walking on the left side of the road, which cannot be explained by behavioral habits (*Fig. 5-7*).

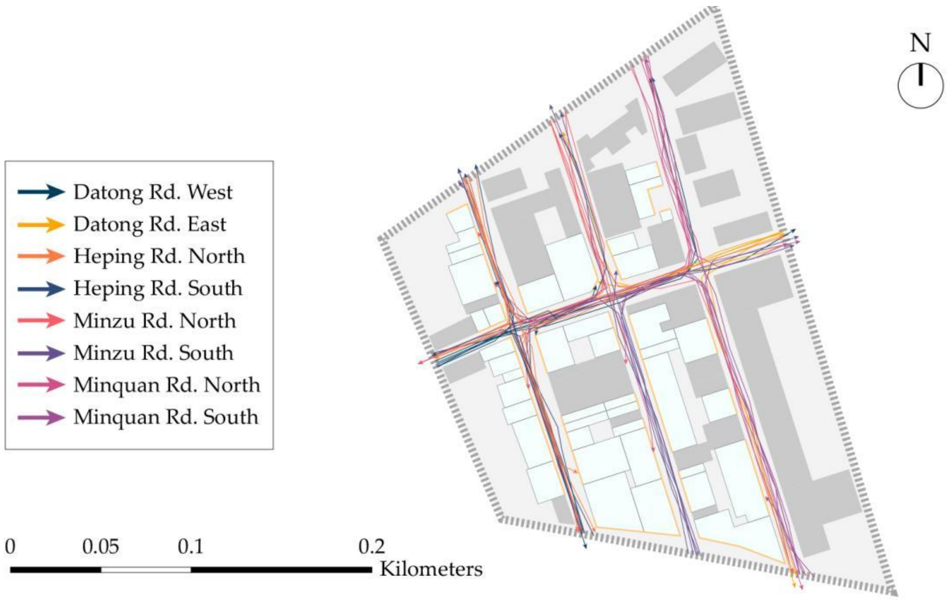
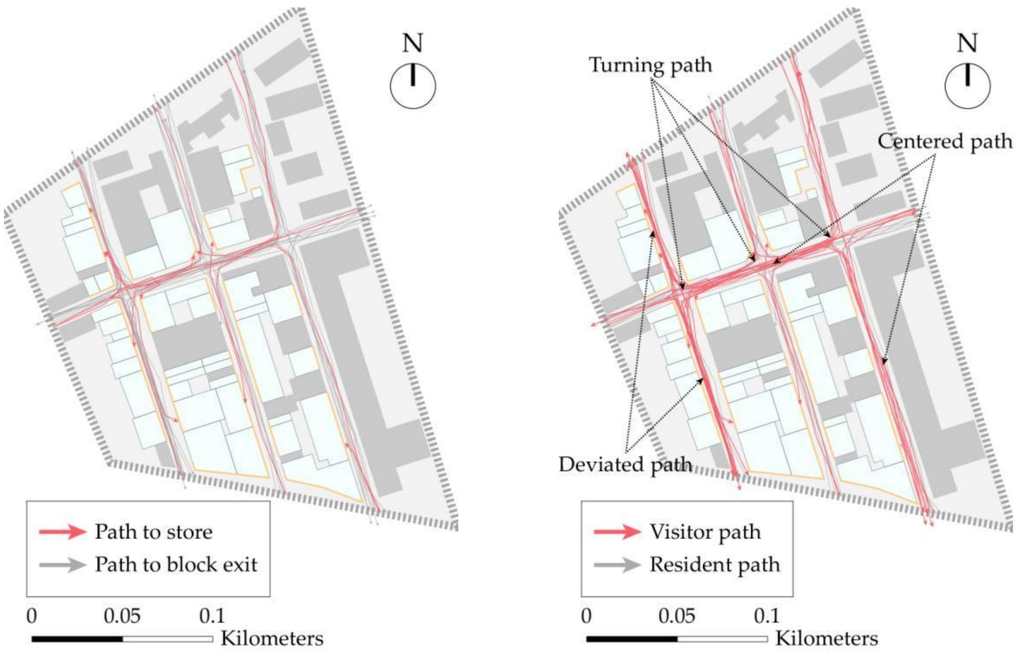


Fig. 5-6. Pedestrian activity path (Source: designed and drawn by author)



a)　　　　　　　　**b**)

Fig. 5-7. a) Paths for different activity purposes, b) Path characteristics of different roles

(Source: designed and drawn by author)

To explore the visual changes in pedestrian activities in traditional Korean place, Hwang developed a computational algorithm that can quantify the foreground and privacy of pedestrians' vision [34]. Based on this, Karoji developed a pedestrian simulation model that can be used for commercial environment simulation, and integrated the dynamic internal state of pedestrians into the simulation model, emphasizing the important influence of visual intervention on pedestrian activities [33]. He believes that the areas where stores disseminate information (store windows and billboards) are often more attractive to passersby. In addition, the distance between the information and the pedestrians is also an important influencing factor. Kent and Schiavon developed a computational method to quantify the distance between window views and residents, called Observer Landscape Distance (OLD). The study also emphasized the importance of visual factors and found that residents prefer to view urban features from a distance, but the same recommendation does not apply to natural environments [68]. After analysis and research, the author identified three main reasons for this phenomenon. First, pedestrians' attention may be drawn to the interior environment and advertising signs of the shops, but the external corridors and environmental interferences (such as trees and utility poles) of Qi-lou architecture hinder their observation, forcing them to approach one side of the shops to obtain effective and continuous visual information. Second, for tourists, the exquisite architectural structures and decorations of historical buildings convey rich visual information and are more attractive. Third, the large volume of high-rise residential buildings requires pedestrians to maintain distance in order to obtain more effective visual information.

5.3 Predictive model construction

The author developed a pedestrian activity MAS based on the NetLogo platform (*Table 5*). NetLogo is a multi-agent programming language and modeling platform used to simulate natural and social phenomena. It has the capacity to control thousands of agents at the same time, effectively simulating the behavior of micro-individuals and macro-patterns, as well as their relationships. The MAS consists of three main modules: turtles, patches, and observers. In the software, dynamic agents are called turtles, which represent pedestrians in the simulation. Patches are small squares that form a 2D plane when divided by an orthogonal grid, providing the background for the agent activity. The observer is the manipulator that controls the turtles and patches, and has the ability to temporarily change the parameters during the simulation process, which is beneficial for the correction of model operation [69].

Table 5. Initial model construction (Source: designed and drawn by author)

Components	Process	Model work order
Patches	Import	Import the site plan to NetLogo.
	Scale	Each patch has a width of 400mm, similar to a human's.
	Area division	Each patch is colored to identify different areas.
	Obstacles	Use patch color to identify obstacles and adjust pheromone to reduce agent movement in those areas.
	Target	High pheromones should be assigned to patches for block exits and store entrances.
	Pheromone	Pheromone is critical for the model optimization as it connects agents to their environment and to each other.
Turtles	Generation	The agent reproduces at the entrance with a limited rate threshold.
	Activity	The turtle checks for obstacles or area boundaries before each step and adjusts movement accordingly, with all operations performed simultaneously and interrelated.
	Direction selection	The agent rotates with small angle random turns during regular movement and to avoid obstacles.
	Vision	Agent vision is set to move towards visible target points and reduce invalid rotation frequency.
	Disappear	The agent dies at the destination.
	Path	Record the trajectory of agent from generation to final disappearance.
Observer	Wandering angle	A 0° angle results in unrealistic straight lines.
		A 10° angle produces a more natural slight wiggle. It is more plausible.
		The agent appears to wander near the block's entry at 30° and 60°.
	Horizontal viewing angle	A 60° angle limits the agents' field of view, causing illogical twists and gathering at the block entrance.
		A 90° angle produces clearer paths with fewer irrational twists and less concentration at the entry.
		A 120° angle is the most probable option, based on human vision rules.
		A 180° angle results in too much information and leads to aggregation at the entry.
	Visual distance	Agent aggregation occurred at 6 and 20 meters.
		10 and 16 meters produced the best route simulation results.
	Turning angle after finding the target	A 30° angle results in a dispersed path inconsistent with real pedestrian activity.
		A 60° angle roughly depicts pedestrian preferences in specific road segments, showing a preference for turning over proceeding straight.
		A 90° and 120° angle result in many unreasonable twists and inflexible broken-line.

First, the study locates different areas within the site by changing the patches color, such as entrances, points of interest, and obstacles. Corresponding pheromone levels are assigned based on the characteristics of each area, such as higher pheromone levels in points of interest and negative pheromone levels in obstacles. These static pheromones are not affected by agent activities and are currently only used for basic agent navigation. Secondly, adding commands to the agents' activities is crucial, such as controlling their basic movements and target search. During the field investigation, the author found that pedestrians do not move in a straight line when walking on the street, but rather exhibit small random sways. To simulate this characteristic, random commands are used to control agents to perform low-frequency, small sways. The randomness in agent activity increases the uncertainty of simulation results, which can inspire different simulation outcomes. The agents' search for targets and avoidance of obstacles are mainly achieved through virtual sensors and the difference in pheromones between patches. Virtual sensors are set in a triangular area in front of the agent, simulating the pedestrian's visual field. During agent activity, if there is a difference in pheromones in the sensor area, the agent is more likely to move towards areas with higher pheromones, thereby achieving the effect of searching for targets and avoiding obstacles. Thirdly, both stochastic parameters such as the number of agents, wandering angle (*Fig. 5-8*), and turning angle (*Fig. 5-9*), and fixed parameters such as the angle and depth of virtual sensors (*Fig. 5-10*), can be adjusted in the observer.

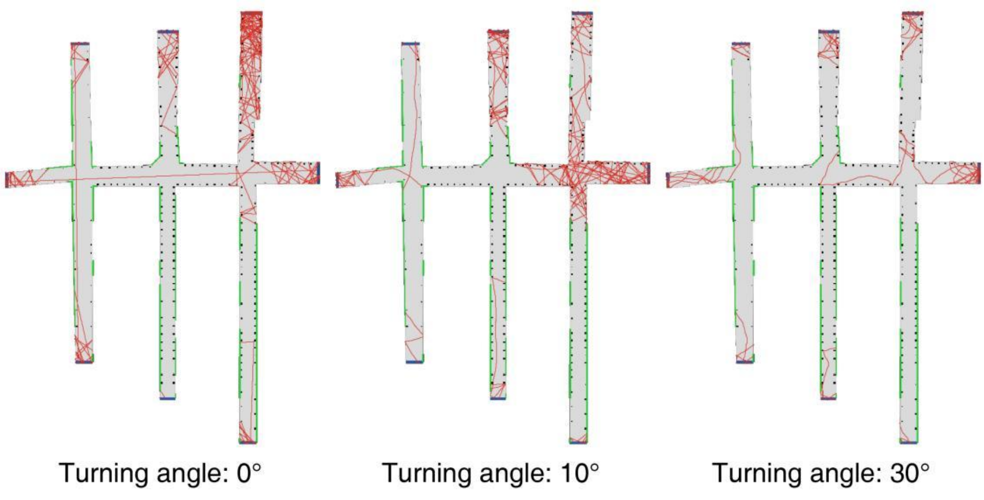


Fig. 5-8. Wandering angle (Source: designed and drawn by author)

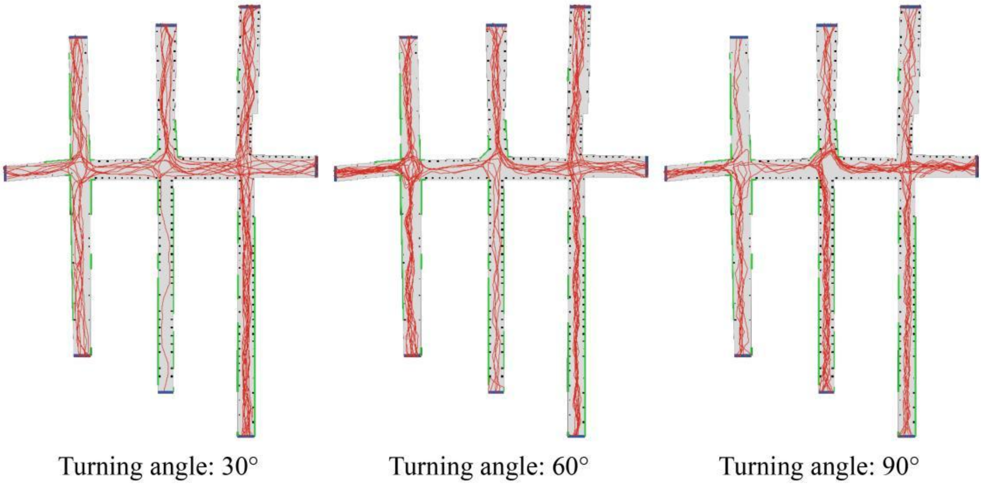


Fig. 5-9. Turning angle after finding the target (Source: designed and drawn by author)

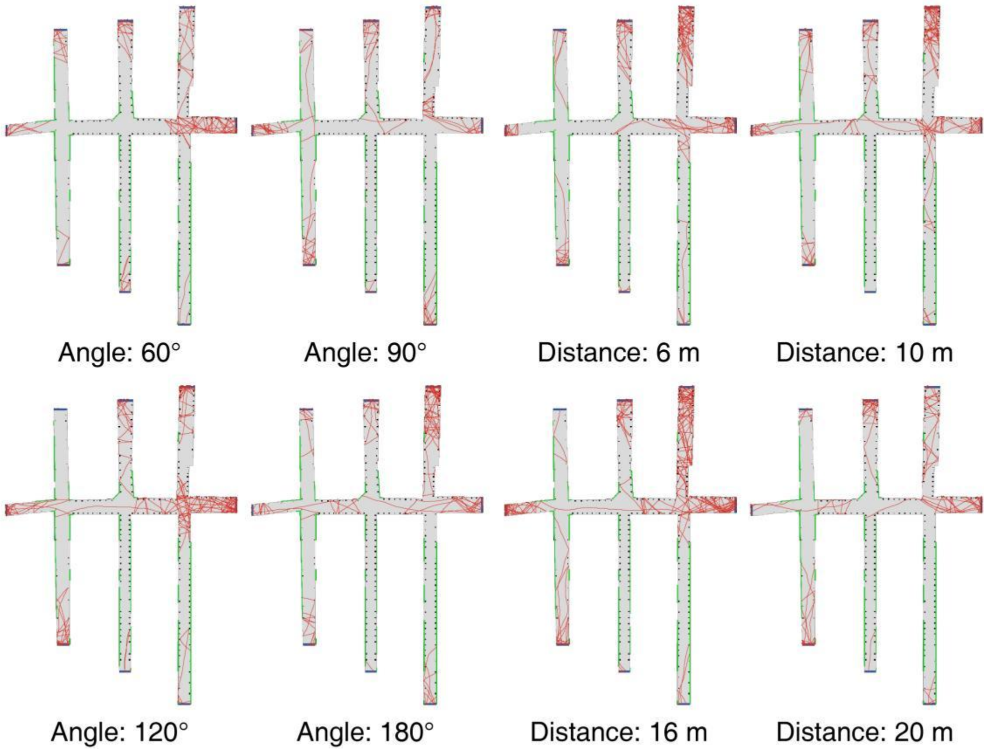


Fig. 5-10. Visual angle and distance (Source: designed and drawn by author)

The author compared the simulation results obtained under different parameters with the field investigation results to find a parameter combination that reflects reality and conforms to human observation and activity patterns. In the setting of virtual sensors, horizontal viewing angle and visual distance are two important parameters. The simulation results are closest to the field investigation results when the angle is 120° and the distance is between 10 and 16 meters. A viewing angle of 60° is generally comfortable, and the effective viewing angle is 120°. Additionally, people can recognize the accurate 3D information within 11 meters, but only the basic 3D information can be recognized up to 20 meters [65] (*Fig. 5-11*). Thus, the optimal parameters for the virtual sensor's angle and depth conform to the observation rules of pedestrians.

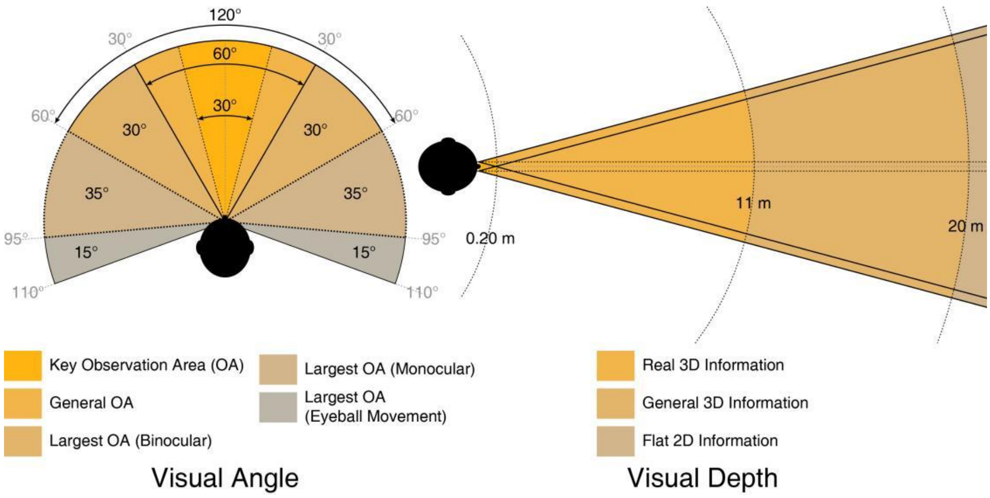


Fig. 5-11. Viewshed (Source: designed by Nurul Chowdhury and drawn by author)

5.4 Comparative analysis

By comparing the simulation results of the initial model with the recorded pedestrian activity paths on site, it can be observed that the model captures certain patterns that reflect the physical environment and human behavior. Specifically, the simulation paths on both sides of Heping Road show a westward shift, indicating the attraction of historic buildings to pedestrian activity. This finding aligns with the recorded pedestrian activity paths. Moreover, the simulation paths on the north side of Minzu Road exhibit a dispersed pattern, while the south side of Minquan Road shows a concentrated and slightly oscillating pattern, both of which match the recorded results perfectly. Similarly, the simulation paths of Minquan Road display similar characteristics to those of Minzu Road, consistent with the recorded results. However, the simulation paths on Datong Road present a different pattern than what was recorded on site. While the recorded activity paths showed a dispersed pattern on both ends and a concentrated pattern in the middle, the simulation results showed a gradual eastward divergence, which suggests that the model may not fully capture the complexity of human behavior in this area. At the intersections of Heping Road, Minzu Road, and Datong Road, the simulation paths exhibit frequent turning, which is consistent with the survey results. However, the simulation paths at the junction of Minquan Road and Datong Road did not show frequent turning (*Fig. 5-12*). Additionally, the on-site survey also counted the number of pedestrians entering shops and reaching the exits of the block, which can reflect the proportion of different groups of people with consumption behavior and passing behavior in the environment. Among them, the number of people entering the shops was 11, accounting for 23% of the total number of people. However, in the simulation results, the proportion of pedestrians consuming only accounted for 16% of the total number of pedestrians, which does not match the actual situation. Further optimization is needed to improve the simulation's accuracy in reflecting the different types of pedestrian behaviors in the environment (*Fig. 5-13*).

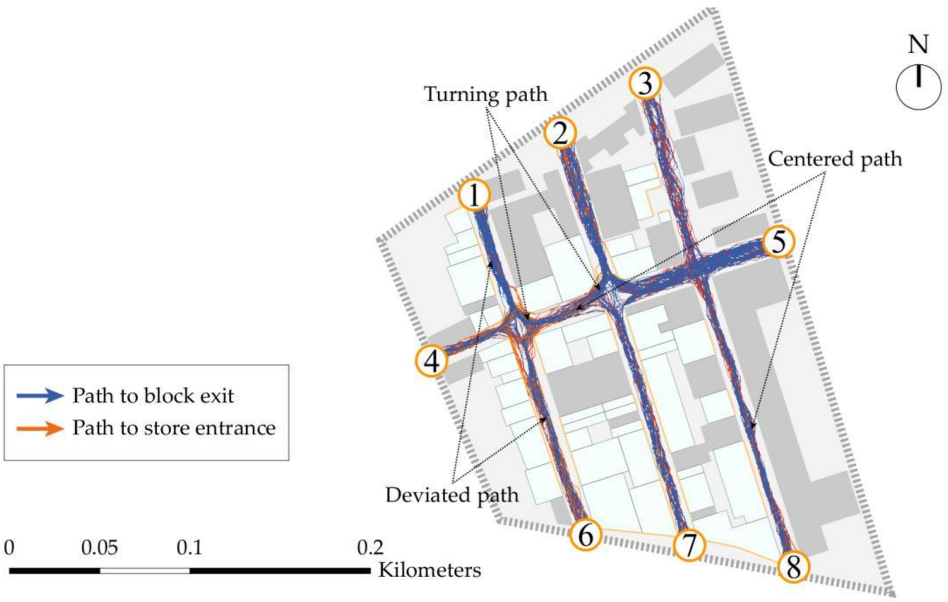


Fig. 5-12. Path results from the initial model simulation (Source: designed and drawn by author)

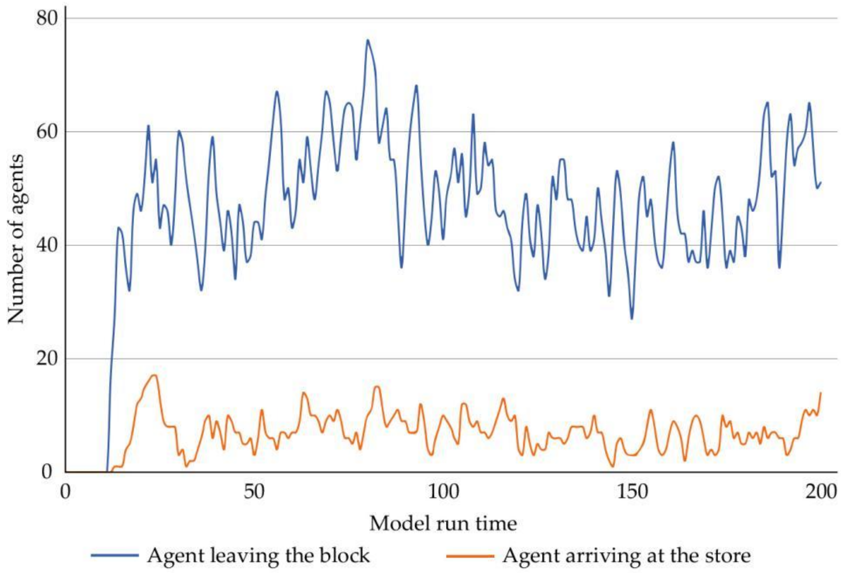


Fig. 5-13. Number of agents with different activity types in the initial model
(Source: designed and drawn by author)

5.5 Model optimization

The author not only refined the simulation environment but also aimed to find a quick method for evaluating the visibility of shops. In a commercial street, if a store has good visibility, it is more likely to attract pedestrians to enter [34]. However, this evaluation method needs to be linked with the MAS to produce an optimized effect. In 2017, Hu proposed a method using a combination of VGA and multi-agent model to improve the accuracy of pedestrian models [65]. However, this study lacks comparative research between simulated results and actual pedestrian paths, and the feasibility of the model needs further verification. The VGA algorithm model, which is used to evaluate spatial visibility, has the advantages of flexibility and convenience [14]. Additionally, VGA and the MAS in this study are both two-dimensional models that can be associated through planar analysis diagrams. To start with, the author determined the valid area for agents to move in AutoCAD, including the block entrance, block space, and store interior. The author imported the modified plan into the DepthMap software to build the VGA. The obtained visibility evaluation map through the model calculation only needs to retain the street space part and then convert it into a grayscale image to reduce the complex colors' interference to MAS. Finally, the VGA grayscale image is combined with the MAS map shape and imported again into NetLogo for simulation operation (*Fig. 5-14*).

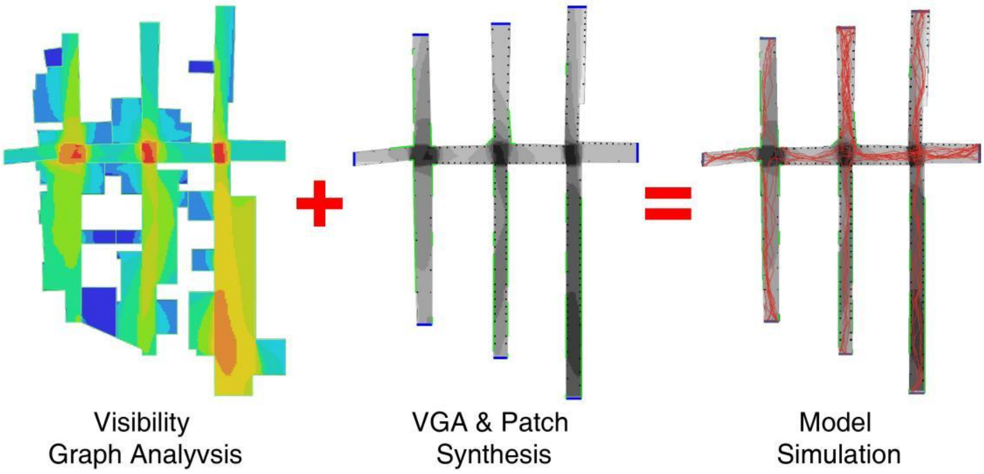


Fig. 5-14. Optimization process (Source: designed and drawn by author)

After comparing the optimized simulation results with the recorded paths, it can be found that the simulation results retain the original correct predictions and further improve the deficient parts. The simulated path in the middle section of Datong Road further converges towards the center, and there are signs of turning at the junction of Datong Road and Minquan Road, correcting the problem in the initial model where the agents would continue to walk straight ahead (*Fig. 5-15*). In terms of data, the initial simulation results showed that the proportion of agents entering the shops was 14% of the total number of agents, while after optimization, the proportion of agents entering the shops increased to 22%, which is close to the field survey result of 23% (*Fig. 5-16*).

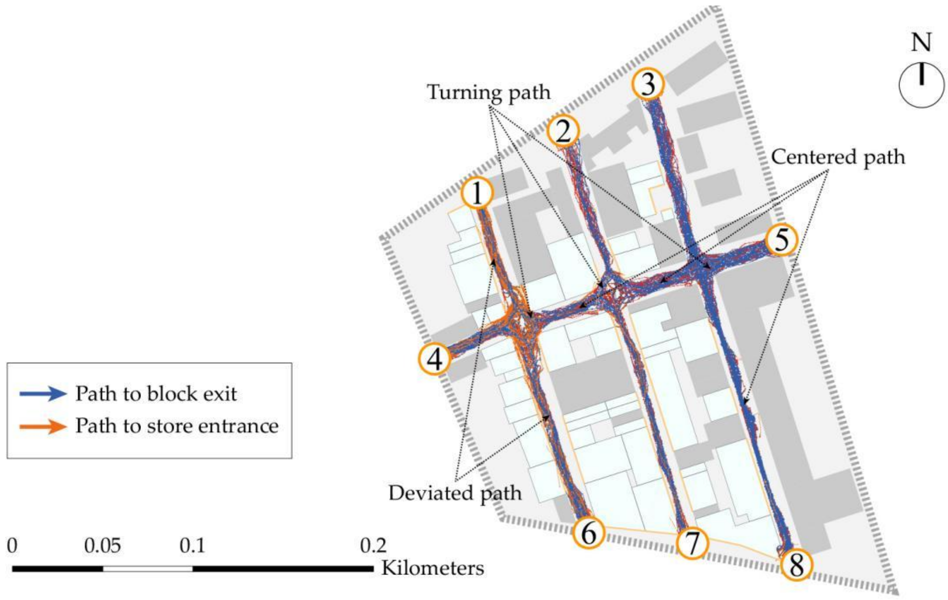


Fig. 5-15. Path results from the optimized model simulation (Source: designed and drawn by author)

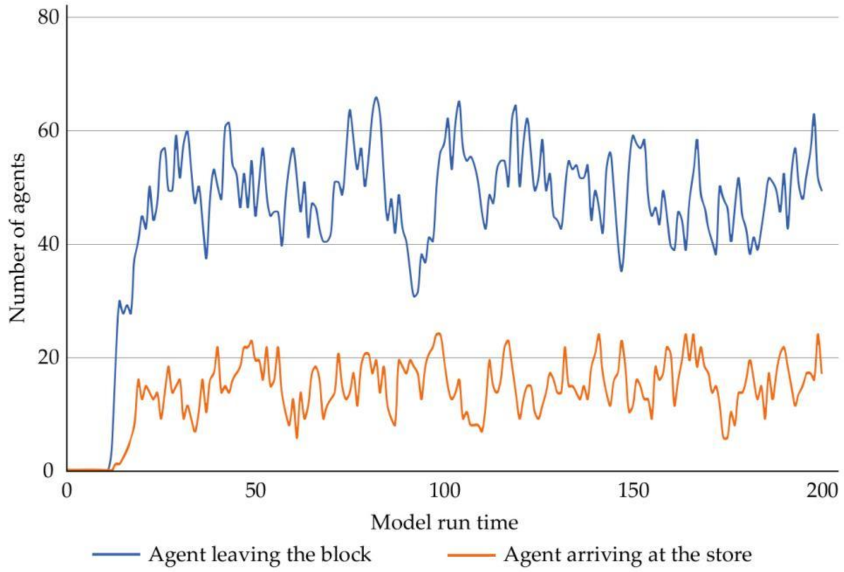


Fig. 5-16. Number of agents with different activity types in the optimized model (Source: designed and drawn by author)

5.6 Discussion

Through research, the author investigated the pedestrian activity in the Minzhu Road historical district. The features of pedestrian activity in the area were identified after the data was analyzed, and the hypothesis that environmental pheromones may have an impact on pedestrian activity was put forth. The goal of the subsequent study was to build an effective and realistic MAS model of pedestrian routes that reflected reality while also having influence parameters (number of agents, moving speed, turning angle when wandering, field of view, turning angle for finding targets) that were consistent with the basic rules of actual pedestrian observation and activity. The author developed the fundamental model algorithm by the several comparison tests and generally identified the basic set of relevant influencing parameters. The author utilizes the depth map to further improve the gravity in the patches using the pheromone gradient and realizes more precise route guidance because the simulation results at this stage are still unable to predict the behavior of people. This research shows that it is possible to use space syntax to enhance the MAS of urban space, and the improved MAS has the advantages of convenience, rationality, and accuracy. In addition, the current development model, which established the definition of pheromone, will be extremely beneficial for future research since it will assist with the transition from design analysis to design generation.

Fig. 5-17. Rendering of Heping Road historic district (Source: designed and drawn by author)

Chapter 6: Master design 4 - application of automatic generation in urban renewal design

6.1 Research object

The author received a commission during the internship and had the opportunity to participate in the preliminary work of the Huizhou Sports Center renovation. This project is located on the north side of the Dongjiang River in Huicheng District, Huizhou City, Guangdong Province (*Fig. 6-1*). It has a design area of about 30,884 square meters, is situated in the center of Huizhou City, and benefits from excellent geographic location and greater accessibility to transit. It is surrounded by three main roads, Citizen Park West Road, Yunshan West Road and Wenchang 1st Road, and is close to a series of important urban public buildings and areas: Huizhou Museum, Science and Technology Museum, Citizen Park, Convention and Exhibition Center, and Beihu Park (*Fig. 6-2*). Designers should strengthen the unique functions of the sports center and differentiate it from other public areas, mobilize the enthusiasm of users through transformation, and build a vital, unique, functionally complementary public space that integrates sports, leisure, entertainment, and sharing.

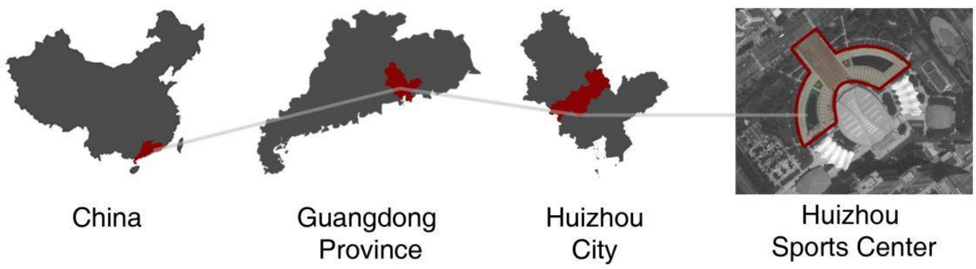


Fig. 6-1. Project location (Source: designed and drawn by author)

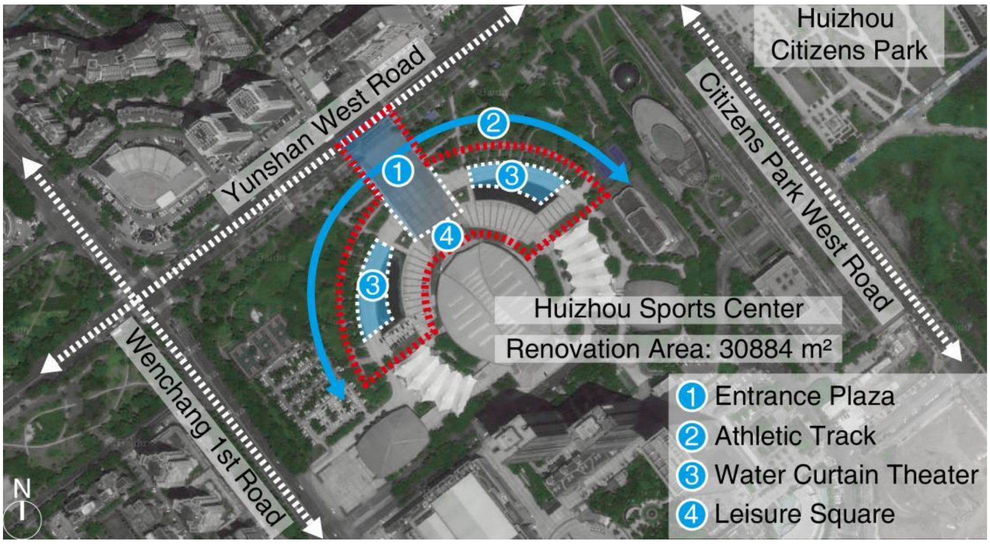


Fig. 6-2. Original floor plan of Huizhou Jiangbei Sports Center (Source: designed and drawn by author)

Fig. 6-3. Huizhou Jiangbei Sports Center (Source: https://www.vcg.com/creative/1287597841)

After the inspection, it was found that the original landscape mainly had the following problems: pavement was old and partially damaged; facilities were aging; some spaces had single functions and low utilization rate; the theme of the park was insufficient. It can be seen from *Fig. 6-4* that the water curtain theaters on both sides of the square have been damaged. The huge abandoned area not only hinders pedestrian activities on the square, but also reduces the overall landscape quality of the sports center. Due to the subtropical monsoon climate, there is abundant rainfall, and the abandoned area will cause water accumulation during the spring and summer rainy seasons, breeding mosquitoes. Secondly, because the sports center was built earlier (2001), its vague and backward theme no longer meets the requirements of modern society, and there is also a lack of interaction between the square landscape and the gymnasium. In addition, the original ground pavement of the square paid too much attention to the design style, while ignoring the integrity, theme, functionality and ecology of the design.

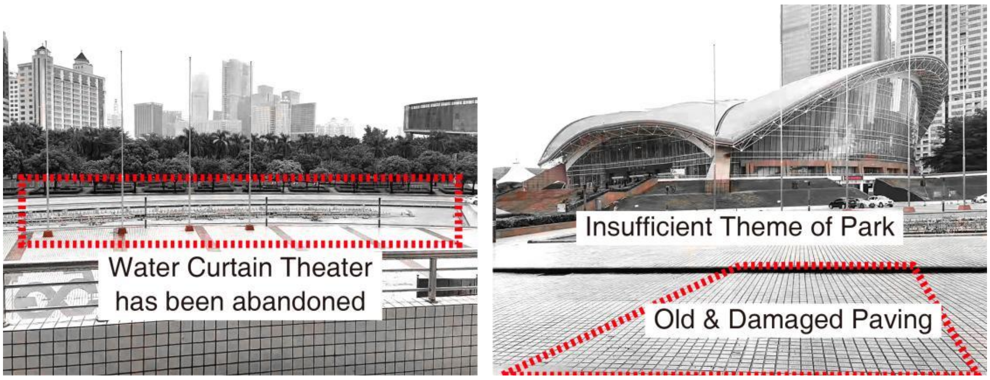


Fig. 6-4. Site status (Source: drawn by author)

Based on the current situation analysis and the owner's requirements, the project will focus on upgrading the entrance square and landscape. In order to attract more people and expand the service area of the park, strengthen the overall space concept and add functional sections with higher frequency of usage. In the details of the renovation, the designer improved the ground pavement according to the overall theme of the park. The design starts from the user's point of view, combined with the corresponding art design methods, to create a square public space that is both practical and artistic. In terms of new functions, the designer will create a modular temporary structure, which echoes with the gymnasium and the square, forming a transitional space from the square to the gymnasium, weakening the strangeness brought by the empty square to users. While the structure guides the activities of pedestrians, it is also easier to form crowds and promote interaction and communication among strangers (*Fig. 6-5*).

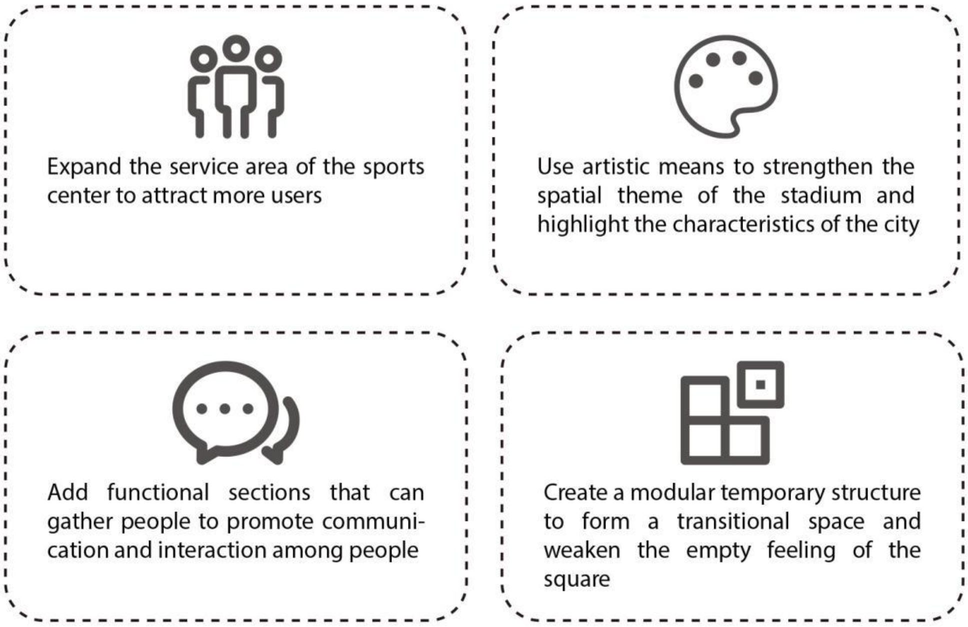


Fig. 6-5. Sports center renovation strategies (Source: designed and drawn by author)

6.2 Model construction

The pedestrian path model constructed earlier can accurately predict pedestrian activity, but it cannot generate design results. The model achieves one-way interaction between agents and the environment, but it fails to achieve interaction between agents, the environment, and other agents. In other words, individual agents can change their behavior based on certain characteristics of the environment, but their activities cannot affect the environment or other agents. The automatic generation model is inspired by the Ant Colony Optimization (ACO), which is widely used for optimizing models related to path generation (*Fig. 6-6*). For example, Srivastava's research found that using ACO can optimize path models, and the optimized models have the ability to automatically generate optimal paths [70]. Sayyari proposed a pathfinding model based on ACO and model-based testing, which has faster running speed and greater coverage [71]. Qu proposed a hybrid solution using mutual learning and ACO (MuL-ACO) to simulate agent motion in uneven environments with various obstacles, and demonstrated that MuL-ACO can generate high-quality collision-free trajectories [72]. Agents can change certain characteristics of the environment through their activities, and the changes in the environment, in turn, affect the agents. Therefore, agents can use the environment as a medium to achieve communication, competition, stimulation, and optimization with other agents, generating infinite possibilities [73]. While the environment serves as a communication medium, it also serves as a carrier for recording agent activity paths, which is more conducive to the construction and use of infinite loop models. For these reasons, the author added dynamic properties to the pheromones of the model's patches based on the pedestrian activity model. After extensive comparative experiments, it was found that the effect was optimal when the 3 control variables, pheromone-per-step (PPS), minimum-route-pheromone (MinRP), and maximum-route-pheromone (MaxRP), were all set to 60 (*Fig. 6-7*). The model distinguishes the pheromones of different states through different patch colors: gray, yellow, red.

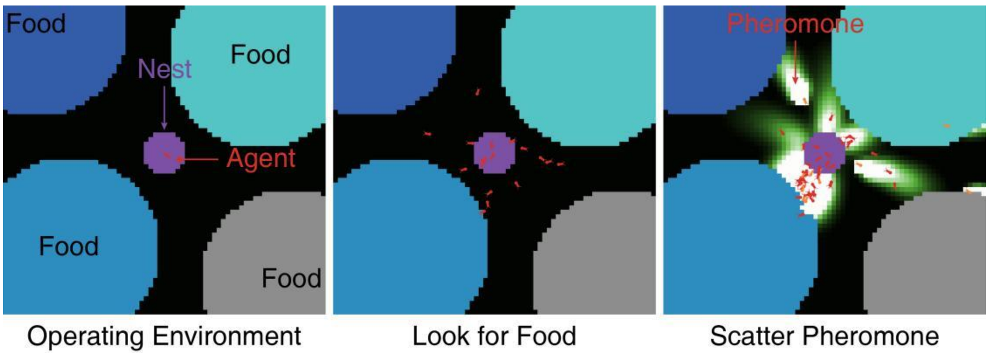


Fig. 6-6. Ant Colony Optimization (Source: designed and drawn by author)

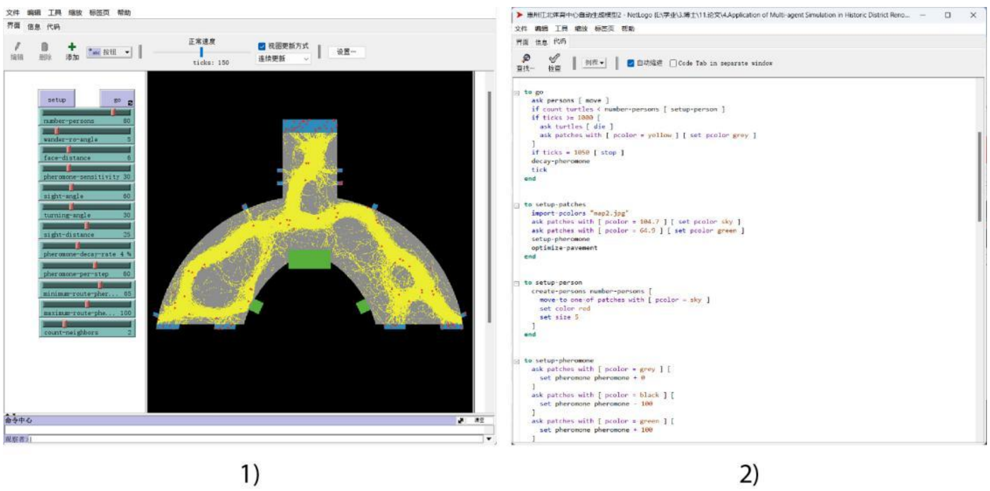


Fig. 6-7. 1) Model running interface, 2) Part of the model code (Source: designed and drawn by author)

Table 6. Generative model construction (Source: designed and drawn by author)

Components	Model work order
Gray patches	Gray patches indicate the agent's movable area and have a pheromone of 0 at the simulation's start.
	Before each movement, the agent must check if the next patch is gray (non-entrance, target point, or obstacle), and if it is, pheromone is added based on the PPS slider.
	Pheromones on patches impact the agent's activity, increasing the likelihood of the agent moving towards patches with higher pheromone.
	Gray patches' pheromone are set to 0 when they drop below 1.
Yellow patches	Patches' pheromone exceed MinRP only when continuously traversed by the agent, influenced by both PPS and MinRP.
	Yellow patches result when pheromone exceed MinRP.
	Pheromone decay occurs on gray and yellow patches not visited by the agent.
	Pheromone on yellow patches drop below 1, changing them back to gray and setting the pheromone to 1 until the agent revisits, exceeding MinRP and turning the patch yellow again.
Red patches	Red patches' pheromone levels decrease over time but remain red and do not disappear.
	Patches change from yellow to red when their pheromone levels exceed MaxRP.
	When PPS, MinRP, and MaxRP are the same, the patches that the agent traverses no longer change from yellow to red, which is not reasonable. An optimization command inspired by the Game of Life needs to be added to the model.
	Before each simulation run, the adjacent red patches need to determine the number of neighboring red patches. When the number is greater than or equal to 2, the patch remains red; when the number is less than 2, it changes to yellow.
	Initially, each patch is typically traversed once by the agent, and few red patches are formed due to the above criteria. Over time, the area of these patches expands.
	The model produces many scattered red patches and gaps that do not meet design requirements. The model requires commands to remove patch fragments and fill gaps.

6.3 Model experiment and analysis

In the 1950s, Walter Gropius proposed a method called "Disney's road design" which aimed to provide visitors with a safe and peaceful environment by separating pedestrians and vehicles. This design maximizes the efficiency and enjoyment of visitors' tours by utilizing a combination of circular and branching roads, thereby improving their mobility and sense of direction. In addition, he scattered grass seeds in the park, allowing visitors to freely walk on the grass when it grew, and based on the resulting worn paths, he designed the park's roads [74]. Now, the MAS model can accomplish the same tasks more efficiently and environmentally friendly, eliminating the need for designers to wait for grass to grow. The simulation environment's concentration of pheromones also replaces the worn paths, while countless agents offer designers numerous design options.

The model continuously refines and optimizes the agent's activity path and patch structure during its operation. After loose red patches are eliminated and holes in the patches are repaired, the patch structure eventually stabilizes (*Table 7*). The study found that the patch structure becomes stable after 300 model runs. Therefore, when ticks are greater than 300, all agents and yellow patches in the environment are eliminated, and the model stops running at tick 320. The view only retains the red patch structure, which requires focused design (*Fig. 6-8*).

Table 7. Simulation process of generative model (Source: designed and drawn by author)

Number of model runs	Simulation results
50 ticks	Agent enters from blue and searches for green target with random moves. Model and agent in chaotic stage with no reference value. Many broken red patches at entrance form basis for overall patch group structure.
100 ticks	Main agent channel seen from yellow patches, broken red patch area expanding.
150 ticks	Yellow channel is clearer, red patch group structure more apparent.
200 ticks	Yellow channel optimized, agent activity inertia formed. Red patch group distributed along channel as pheromone area fixed.
300 ticks	Yellow patches absorbed by red patches, creating relatively stable structure. Many fractured patches and holes in red structure.
320 ticks	Agents and yellow patches eliminated, leaving only optimized red patches.

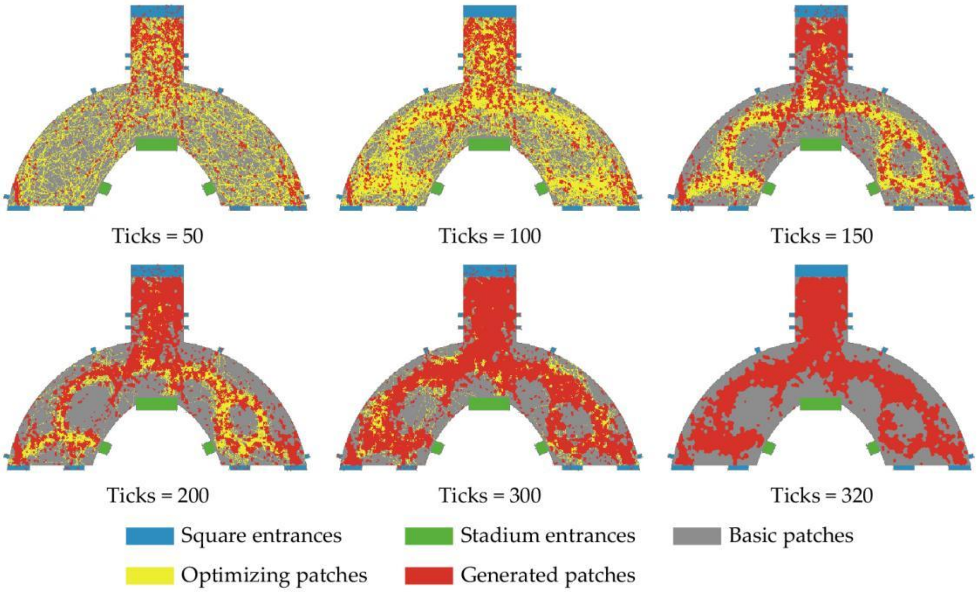


Fig. 6-8. Simulation process of generative model (Source: designed and drawn by author)

The author compared and analyzed 10 simulation results and found that in a symmetrical simulation environment, due to the large randomness of the agent's entry location and their activities, the resulting patches group structure is usually not symmetrical. In addition, through comparative research, it can be found that the patches group structure has two characteristics. First, most of the simulation results show that the larger patches group is usually biased towards one side of the square, while the other side is the thinner channel. Secondly, it can be seen from *1-4) in Fig. 6-9* that a large elliptical cavity will appear inside the patches group with a large area, making the path in this area present a circuit network structure. On the other side, the slender passage connects the rectangular plaza, the gymnasium entrance and the plaza entrance in a tree form (*Fig. 6-10*).

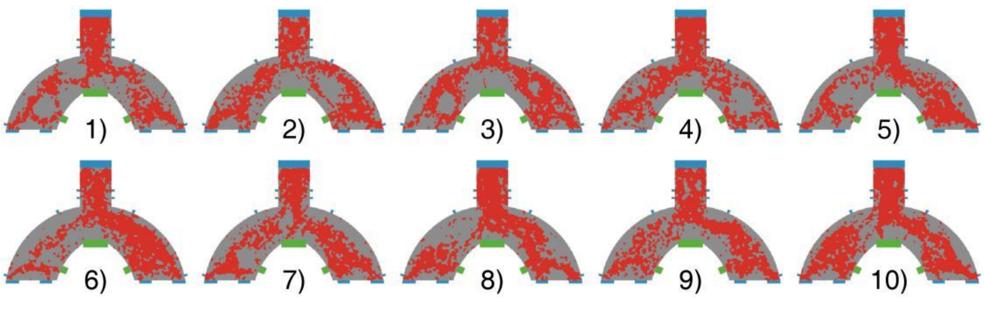


Fig. 6-9. Comparison of simulation results (Source: designed and drawn by author)

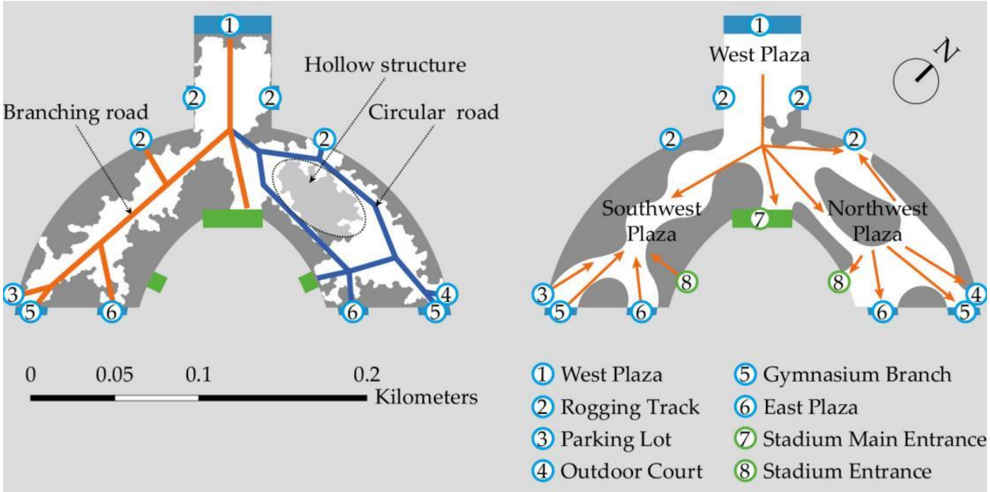


Fig. 6-10. Application of simulation results in design (Source: designed and drawn by author)

6.4 Design practices

Huizhou is also known as Goose City. The shape of the main gymnasium mainly highlights the image of Goose City. The building looks like a white and elegant flying swan, which symbolizes the new image of the rapid development of Huizhou's cultural construction, reflects the pioneering and innovative spirit of Huizhou people, and also embodies the distinctive characteristics of health and vitality of sports [75]. In addition, the city flower of Huizhou City is Bougainvillea. There are many varieties of Bougainvillea, with bright flowers and fragrance. The author combines the two elements of goose city and city flower, which is associated with the famous Chinese Song poem "Butterfly Love Flower". The poem describes the season of Grain Rain, which is rainy and cold in the south. The river is rising, the grass on the river bank is green, and the geese are playing on the water. The most pleasant thing in this season is to take a small boat on the winding river. According to the picture described in the poem, the author centered on the theme of "Joyful Huizhou, vibrant and colorful", combined the spring water, goose, flowers and other energetic elements with the above research results, designed the square ground pavement and artistic structures, and created the public space landscape showing the urban heritage (*Fig. 6-11*).

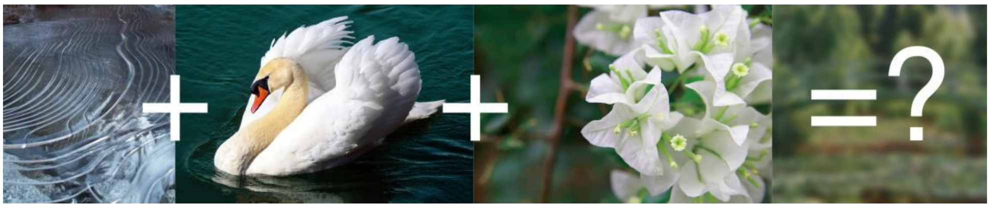


Fig. 6-11. Design theme (Source: designed and drawn by author)

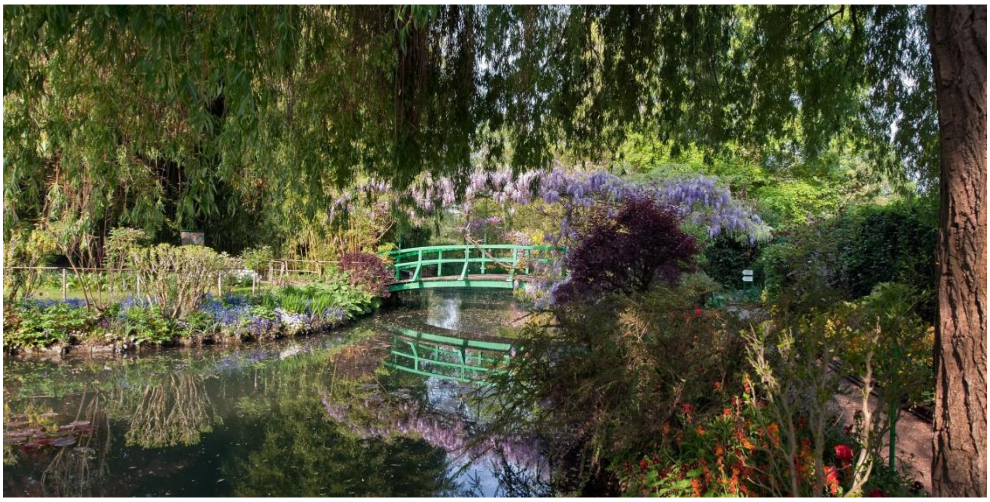


Fig. 6-12. Spring river reference (Source: https://www.thepaper.cn/newsDetail_forward_18117196)

Fig. 6-13. Design elements (Source: designed and drawn by author)

It can be seen from *Fig. 6-10* that the square on the northeast side of the sports center is easier to form a circulation channel with a circuit network structure. The structure has better trafficability, and the crowd activities in the area will be more dispersed, so this area is more conducive to the construction of traffic landscape. In contrast, the square on the southwest side is more likely to form a concentrated and stable crowd structure. According to the analysis, the author sets the northeast square as the area mainly serving traffic, and the red patches group is mainly used for road paving. The southwest square is set as a public space combining multiple functions, and the red patch area is mainly used to build a modular temporary art gallery for special time periods such as festivals and events.

Afterwards, the author obtained the different characteristics of the northeast and southwest squares based on the simulation, endowing the area with new functionality, and the new functionality and artistic design should be unified and coordinated. Entrances in the Southwest Plaza respectively connect the parking lot, Gymnasium Branch, and East Plaza. Residents around the sports center can enter the stadium through the West Plaza, while citizens further away will enter from the Southwest parking lot. As the space that can accommodate the most users, the Southwest Plaza is also the space that links multiple critical nodes, and a branching road structure can efficiently transport pedestrians to their respective destinations. On the other hand, the Northeast Plaza, although connecting the East and West Plazas, mainly connects the running track, tennis court, and Gymnasium Branch, where the crowd gathering capacity is weaker, and pedestrian activity is more dispersed. Therefore, a circular road can be constructed in the Northeast Plaza to delay pedestrian activity routes, and new functions can be added inside the road's inner circle to enhance space functionality, interest, and artistry. Based on the sports center plaza's spatial characteristics, the author selected a patches cluster with a circular road in the Northeast and a branching road in the Southwest for detailed design. Based on positive and negative patch structure images from simulation results, the sports center plaza can be upgraded through pavement, green landscapes, device installation, and lighting. Using circuit and tree-like patch structures, combined with the different characteristics of the Northeast and Southwest plazas, targeted designs for different plaza areas can enhance their functionality and achieve a harmonious and coordinated art and functional design for the sports center's space (*Fig. 6-14*).

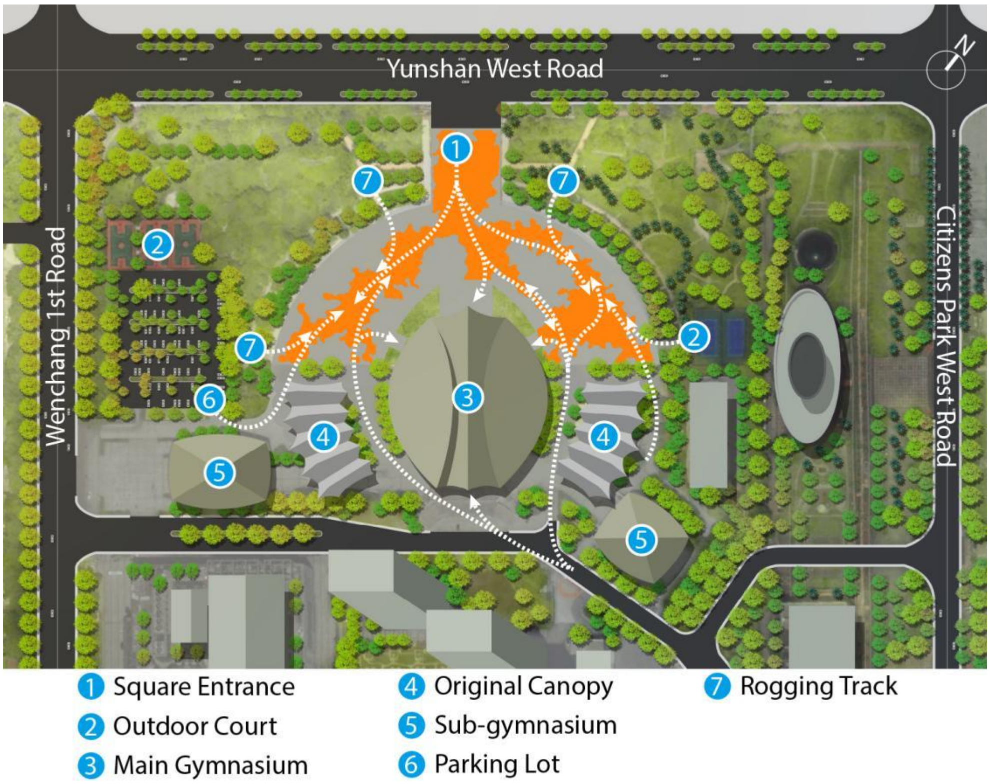


Fig. 6-14. User and entry relationship (Source: designed and drawn by author)

Fig. 6-15. Design concept (Source: drawn by author)

6.4.1 Ground pavement

The author uses MAS to automatically generate positive and negative images of pedestrian active areas, and adjusted the image contour curve according to the design theme to make it smoother. In addition, because the crowd activities in southwest square are concentrated, they will be relatively concentrated in the white positive area. Therefore, the author designed more centripetal and guiding decorative curves on the ground of the positive area. On the other hand, northeast square has the characteristics of scattered users. The author sets centrifugal and guiding decorative curves in the positive area of this area to guide the citizens to various target points.

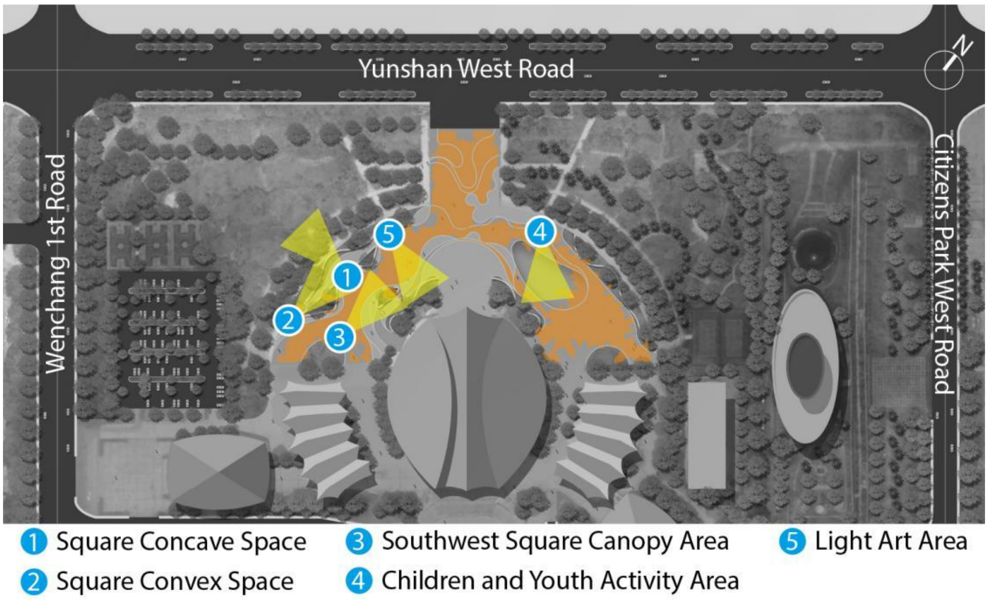


Fig. 6-16. Important functional areas (Source: designed and drawn by author)

The ground renovation of the square uses a lot of curves to simulate the appearance of water flow, and uses two different ground colors to simulate the reflection effect of the water surface (*Fig. 6-17*). The curve of the ground weakens the sharp corners in the square and the building structure, which serves as a transition and connection between the main stadium and the front square. The curved design can bring users a friendly and comfortable experience, while the asymmetrical square pavement design will strengthen the psychological hints of the environment to users, and create a relaxed and lively atmosphere while guiding citizens' activities (*Fig. 6-18*).

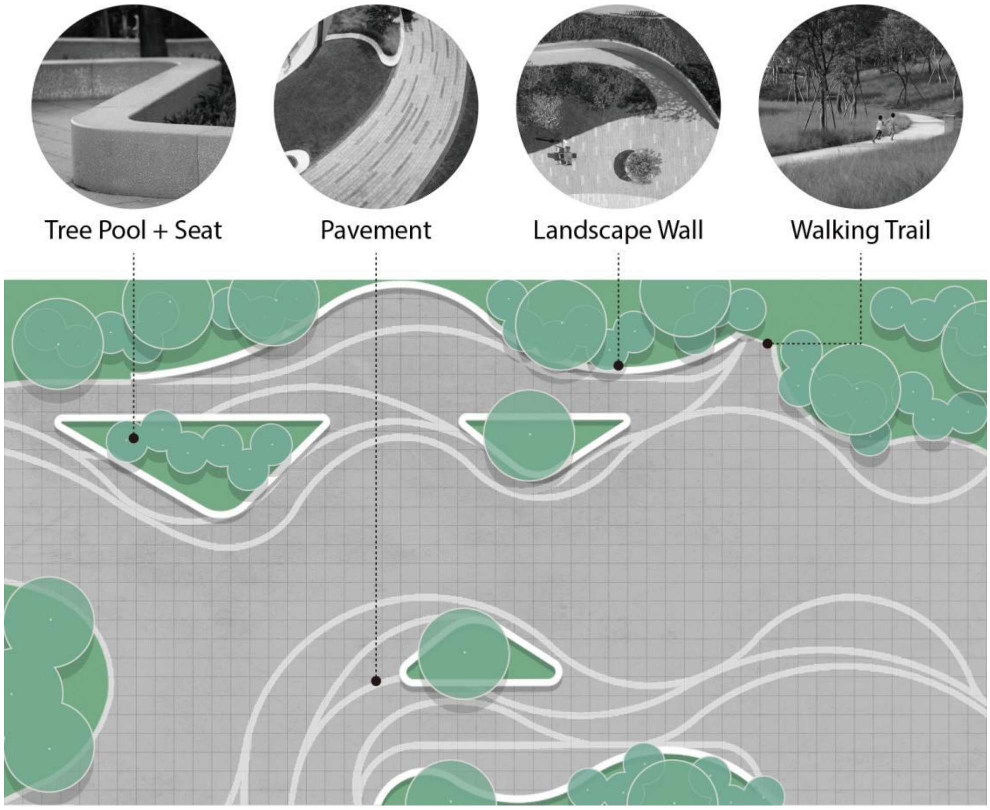


Fig. 6-17. Southwest square detail design (Source: designed and drawn by author)

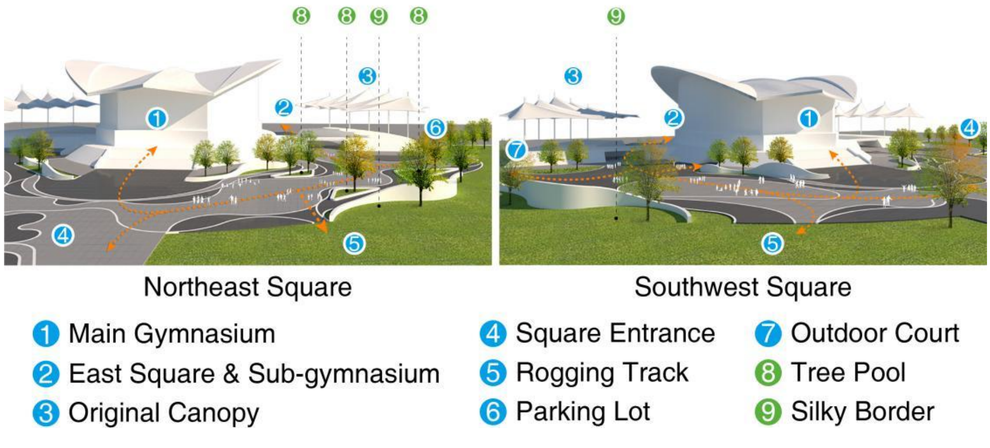


Fig. 6-18. Comparison of northeast and southwest squares (Source: designed and drawn by author)

6.4.2 Green landscape

The greening transformation of the northeast and southwest squares is mainly concentrated on the negative space with low utilization rate on the inner and outer sides of the square. The author uses the curved green area for decoration to reduce the division of the square and the surrounding green space by the original circular boundary. Streamlined structures are set in the green area, and the sports center gradually transitions from the plant area, to the plant and structure combination area, and then to the ground pavement area from the outside to the inside. The new green space imitates the curved appearance of the river bank, making the landscape of the park more in line with the design theme. Curved landscape walls protruding inward form a convex space, while those protruding outward form a concave space. The convex space will guide the activities of pedestrians, while the concave space encourages the gathering of pedestrians, which is more conducive to stimulating interaction and communication among strangers, and is also conducive to the organization of small-scale activities and performances (*Fig. 6-21*). In the negative space of southwest square, a small number of tree pools above the ground are added, which are also used as seats to provide resting places for citizens while planting. The lower height of the tree pool will not interfere with the observation of pedestrians, nor will it cause too much impact on pedestrian activities (*Fig. 6-24*).

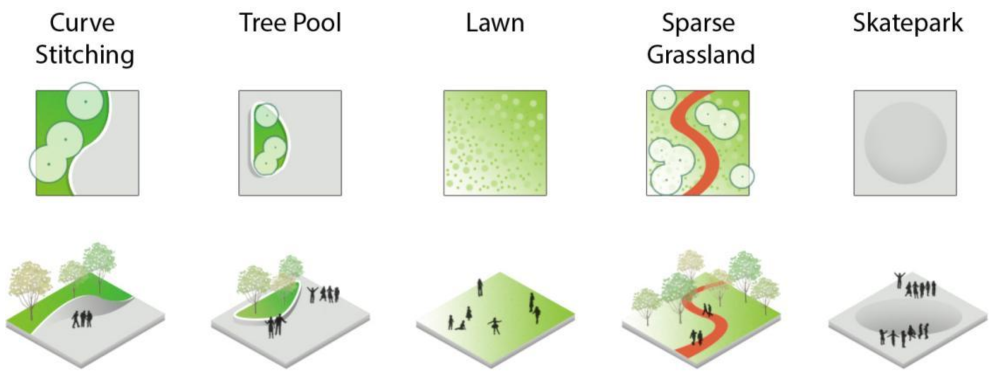


Fig. 6-19. Relationship between vegetation and pavement (Source: drawn by author)

Fig. 6-20. Activity area reference (Source: drawn by author)

Fig. 6-21. Square concave space rendering (Source: designed and drawn by author)

Fig. 6-22. Green landscape reference (Source: drawn by author)

Fig. 6-23. Jogging track reference (Source: drawn by author)

Fig. 6-24. Square convex space rendering (Source: designed and drawn by author)

6.4.3 Temporary canopy construction

In terms of installation and equipment, it is necessary to repair or replace the old infrastructure in the area, such as street lamps, rest seats, trash cans, signage systems, etc., and also add a temporary canopy to the site. As shown in *Fig. 6-25*, the canopy is constructed on both sides of the square in the form of tensioned membranes based on the simulated patches group structure.

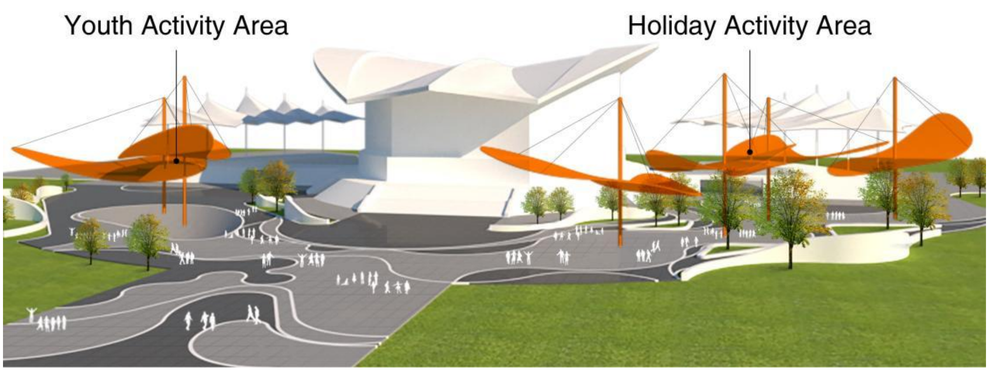


Fig. 6-25. Canopy placement (Source: designed and drawn by author)

In terms of functionality, the canopy can provide citizens with a sheltered area to cope with the hot and rainy summer in Guangdong. During festivals, the semi-temporary canopy on the northeast square can provide citizens with a place to organize events and gather. The canopy of southwest square mainly serves the outdoor children and youth activity area, providing them with a place to play roller skating, skateboard and bicycle. Minors usually play in the area with their parents or friends, which can bring more people to the square, stimulate the vitality of the space, and make it serve a wider group (*Fig. 6-26*).

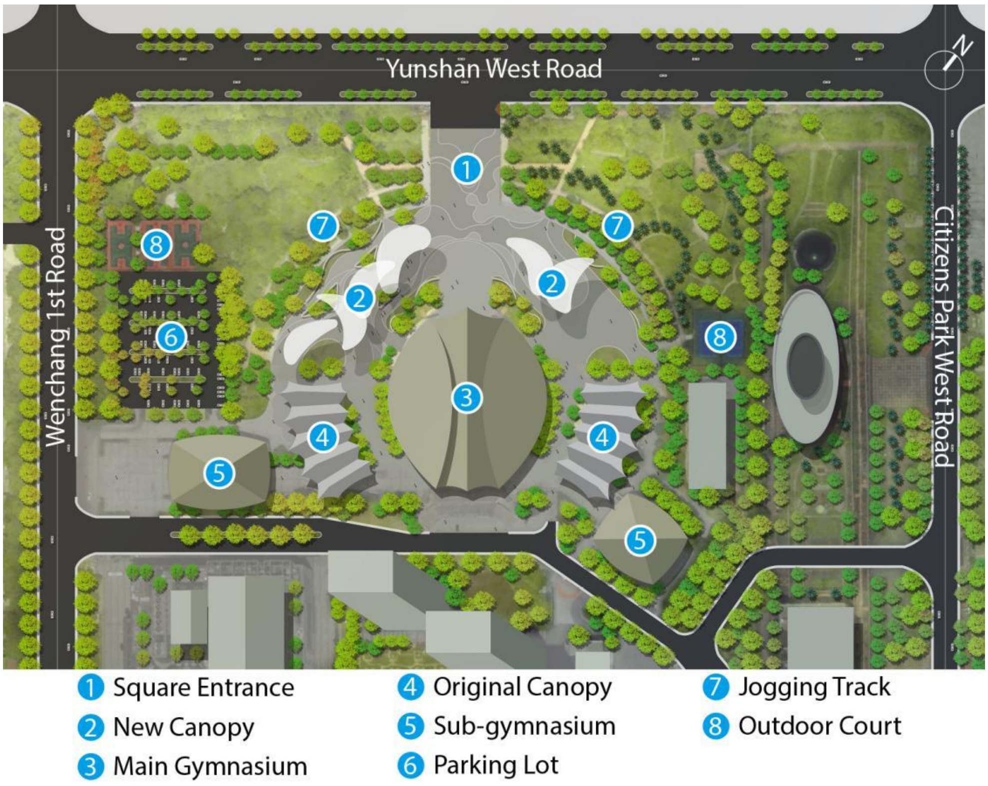


Fig. 6-26. Floor plan of Canopy (Source: designed and drawn by author)

In terms of artistic design, the canopy system is composed of multiple drop-shaped small canopies of different heights. An overly large and closed canopy structure will give people a dark and oppressive feeling, while a combination of thin and flexible canopy modules can give people a light and relaxed feeling. The sleek canopy shape and the streamlined pavement of the ground echo each other, and the canopy is like duckweed floating on the water, adding vitality and a sense of flow to the site. In order to coordinate with the original building, the canopy is mainly off-white (*Fig. 6-27 and Fig. 6-28*).

Fig. 6-27. Southwest square canopy (Source: designed and drawn by author)

Fig. 6-28. Children and youth activity area (Source: designed and drawn by author)

6.4.4 Lighting art

The canopy will be used emphatically during special festivals or events. The author combines the lighting art with the canopy to form an interactive design of light environment that is artistic, ecological and scientific in the square space. The scenes produced by sunlight and artificial lighting are collectively called light environment, and the design in this field is the need of normal production and life. A comfortable and healthy light environment allows us to perceive and experience the environment and obtain the external information we need in life. Now, space design innovation increasingly requires the participation of light environment design. The author seeks a new design element and method to enhance people's emotional sense of belonging and aesthetic principles. On the basis of ensuring standard physical lighting and ecology, modern science and technology are effectively used to express different spiritual aspects of people through light. In this way, an artistic light environment atmosphere is created, and a unique cultural connotation is given to the space environment (*Fig. 6-26*).

Fig. 6-29. Light art for festive events (Source: designed and drawn by author)

6.5 Discussion

MAS can provide new intelligent models for solving complex design problems. Moreover, as a bottom-up, decentralized, self-organizing, and dynamic modeling approach, it fits perfectly with the characteristics of crowd activities and is applicable to urban renewal design. Although the pedestrian activity model can predict the activity status of pedestrians in a place with reasonable accuracy, it cannot complete the task of automatic generation. Therefore, the study proposes a model that can generate design results automatically based on the pedestrian activity model and a dynamically changing pheromone gradient. Agents can influence and change the environment through pheromones, and the environment's changes in turn affect new agents. This interactive communication process is more conducive to stimulating competition, stimulation, and optimization of the model. Through a large number of iterations, the generative model eventually forms a relatively stable simulation result, which goes beyond the scope of design analysis and evaluation and moves towards a higher level of automatic generation.

Subsequently, the author demonstrated the feasibility of using the model's automatically generated design results in actual projects through design practice. The simulation results of the model are not fixed and can produce multiple different possibilities through multiple simulations. Users can choose the most reasonable simulation results for further design according to their needs. This can reduce the designer's workload while inspiring their thinking and creativity through different design proposals. Additionally, the self-generating model developed in this study also demonstrates good applicability when facing different environments, and researchers do not need to readjust the parameters to obtain relatively reasonable and practical simulation results. At present, this model can be used to complete the work of positioning pavement, canopy, and greenery in urban public space design. Compared with traditional design methods dominated by empiricism, MAS has higher efficiency, lower investment costs, and a wider range of applications. This technology can effectively promote the development of urban renewal and the protection of historic districts, and assist in achieving sustainable urban development at the technical level.

Chapter 7: Discussion and conclusions

7.1 Research findings

Finding 1: MAS is beneficial to the simulation of human activities, and the construction of dynamic models with automatic generation capabilities still has great potential. (charter 1)

MAS may find unique intelligent models for resolving difficult design issues. Furthermore, the system functions as a decentralized, bottom-up, self-organizing dynamic modeling approach, which is well-suited to modeling the complex, decentralized, and dynamic nature of human activity. Currently, most dynamic multi-agent models are used to predict macro-level changes in urban development, but overlook the potential application of this technology in micro-level urban construction. In addition, many models on the micro scale use the shortest path algorithm as the core representation of activities, ignoring the impact of internal states and vision on activities. Thus, developing a pedestrian activity model with visual features has great research potential.

Finding 2: Visual quantification is of great significance for building a refined pedestrian activity simulation model. (charter 2)

The evacuation model uses the shortest path algorithm as the core representation of activities, ignoring the influence of internal state and vision on activities. Related studies have proved that incorporating internal state and visual features into the pedestrian model can further improve the simulation accuracy. Therefore, the study of visual quantification in the environment has great research significance for the construction of pedestrian activity simulation models.

Finding 3: Use the EVR value to quantify the visibility of different areas to evaluate their commercial value and realize the effective allocation of resources. (charter 3)

The multi-agent evaluation system developed based on the Grasshopper platform has considerable practical value in the evaluation field of historic blocks and historical buildings. Research has proven that EVR can clearly and accurately reflect the visibility of each store. Designers can use the EVR value to quantify the visibility of different areas, evaluate their commercial value, and realize the effective allocation of resources. However, the model needs to run in 3D environment, so it cannot be used in the early stage of design, and can only be used in the evaluation process at the end of the design process. And, the complexity of 3D simulation leads to insufficient applicability of algorithmic models.

Finding 4: The VGA model has higher efficiency in the quantitative analysis of the visibility of the micro-environment. (charter 4)

To address the issues of low efficiency in 3D modeling, this study proposes to use VGA to carry out visual quantitative analysis on the spatial structure of the factory's key renovation area, and compare the simulation results with the real situation, demonstrating that VGA, a two-dimensional, flexible and widely applicable visual evaluation method, has higher application value in urban landscape design. Although the VGA model can more quickly complete the quantitative analysis of visibility in the micro-scale space environment, it is still in the category of static models, and cannot be used as an independent algorithm model to automatically generate design results, nor does it have predictive capabilities.

Finding 5: VGA has a significant optimization effect on the MAS of pedestrian activity. (charter 5)

The author conducted field research and recorded pedestrian activity information and patterns, and used this as a basis to construct a pedestrian activity model. Comparing the simulation results of the model with the recorded pedestrian activity paths, it was found that some sections and nodes did not achieve the expected results. To optimize the model and obtain simulation results that are closer to reality, the author combined the basic model with VGA and further refined the gravity in the patches through static pheromone gradient, achieving more accurate path guidance and demonstrating the feasibility of VGA in improving the simulation accuracy of the pedestrian activity model. But the essence of the model remains an analytical tool with predictive properties. Automatic model generation often requires a large number of iterative operations to finally form a relatively stable simulation result. Although the model realizes the interaction between the agent and the environment, it does not realize the linkage between the agent, the environment and other agents. A model that lacks communication cannot form competition, stimulation and optimization, which are the core of automatically generated models.

Finding 6: Using pheromones to stimulate the competition, stimulation and optimization of models can effectively construct automatic generation models for urban space design. (charter 6)

Based on the pedestrian activity model, the author independently developed a self-generating model that can be used for urban renewal design by combining dynamic pheromone theory. The dynamic distribution of pheromone is advantageous in constructing a simulation environment where multiple agents can interact with each other. Agents influence and change the environment by releasing pheromone during the activity process, and the changes in the environment in turn affect new agents. This interactive communication process is more conducive to stimulating the competition, stimulation, and optimization of the model. The new model finally forms a relatively stable simulation result through a large number of iterative operations, achieving the goal of self-generation. This study also tested the feasibility and rationality of the self-generating model through design practice and demonstrated its application value in real urban renewal design work. Compared with the traditional empirical design approach, MAS has higher efficiency, lower investment cost, and a broader range of applications. This technology can effectively promote urban renewal and the protection of historical districts, and provide technical support for achieving sustainable urban development.

7.2 Self-criticism and discussion

In this study, to minimize interference with pedestrian activity and decision-making during the process of recording pedestrian paths, the recorder should maintain a distance of at least two meters from the experimental subject. However, the experimental process may still have an impact on the internal state of pedestrians, as the Hawthorne effect cannot be completely avoided. Additionally, the Minzhu Road historical block was used as the basis for developing an accurate pedestrian activity model. However, due to the limited space available in the area, there are some issues when using an automatically generated model to simulate the environment. When the parameters are set slightly higher, almost all the roads in the environment become the focus of reconstruction, while setting the parameters slightly lower results in the inability to create a continuous pedestrian activity space. From a practical standpoint, the roads in historical blocks are typically around 10 meters wide and it is difficult to allocate more space for purposes other than pedestrian activities. In this sense, the simulation results generated by the automatically generated model are reasonable. However, if both the front and back models could be completed in the same space, the research process would be more intuitive, and the results would be more convincing.

The agent activities in the pedestrian activity model are mainly influenced by the pheromones received by the sensors in the environment. When simulating pedestrian activities in the environment, environmental factors affect individual sensory perceptions through vision, which then interferes with human behavior. However, the automatically generated model is constructed based on the pedestrian activity model and is relatively simple in terms of influencing factors. To build a higher-level automatically generated model that covers the entire design and construction process, a large number of functional modules need to be set up, including site conditions, user behavior, climate conditions, economic indicators, regional policies, etc. Among them, site conditions can be further subdivided into soil, altitude, terrain, etc. Each sub-item can be further subdivided. It can be predicted that as related research and experimentation continue to deepen, the model size will exhibit exponential growth. In comparison, this study is only a small glimpse into the possibilities of this research field, and further exploration of the potential of related models is still needed. However, if designers still have to continuously develop intelligent programs based on their own needs or for specific issues manually, instead of fundamentally liberating design productivity, they are simply jumping from the quagmire of design work to the quagmire of software development.

7.3 Research conclusion

As urbanization continues to develop, the function of urban renewal is becoming increasingly prominent. It is considered an effective method for increasing land value, improving environmental quality, and strengthening social connections. In recent years, the drawbacks of extensive renovation methods have become increasingly apparent in urban renewal. China's urban development is gradually shifting from a focus on quantity to quality, which has led to an increased emphasis on urban renewal and preservation as important factors for evaluating urban quality. However, traditional design methods limit design efficiency. With increasing work pressure, designers have no extra energy to improve the design quality of projects, leading to a dilemma between protection and reconstruction in urban renewal. The fourth industrial revolution has brought about significant changes to people's lifestyles and work patterns. This study aims to combine urban renewal with emerging technologies to address the dilemma between efficiency and quality in urban renewal. However, most research needs to be completed on existing analysis software platforms. These static models based on graph theory and topology can only output fixed results, lacking creativity. Building a dynamic model with automatic generation capabilities is of great significance for improving the efficiency of designers.

Currently, most dynamic multi-agent models are used to predict macro-level changes in urban development, but overlook the potential application of this technology in micro-level urban construction. This study explores a practical application method that combines MAS technology with urban renewal design. MAS is a bottom-up, decentralized, self-organizing, and dynamic modeling method that is well-suited for use in urban renewal design due to its compatibility with crowd behavior. Evacuation models are most commonly studied at the micro-scale, with the shortest path algorithm as the core representation of activities, ignoring the influence of internal states and vision on activities.

In order to better quantify the visual changes of pedestrians in daily activities, the multi-agent evaluation system developed by the author based on the Grasshopper platform has shown considerable practical value in the visual evaluation of historic blocks and historic buildings. Research has proved that EVR can clearly and accurately reflect the visibility of each store, and using EVR to evaluate the commercial value of each area can promote the effective allocation of resources. However, building the required 3D environment for simulation and slow analysis speed increases the workload of designers. Additionally, in order to improve the efficiency and usable range of the model, the author changed the research direction from the three-dimensional model to the two-dimensional model. The study demonstrates that VGA, a plane-based, flexible and widely applicable visual evaluation method, has the possibility of being used in urban landscape design. Compared with the 3D visibility evaluation, VGA has higher efficiency and better convenience. However, the above models still belong to the category of evaluation and analysis and cannot automatically generate corresponding design results.

To address the issues of inadequate accuracy in evacuation model simulations and low efficiency in 3D modeling, this study proposes a dynamic pedestrian activity model based on a multi-agent system that incorporates visual features. The research first conducts a survey of pedestrian activity paths in historical blocks to identify the significant influence of visual factors on pedestrian behavior. The survey results serve as the foundation for model development and also as a critical reference for verifying simulation accuracy. By comparing simulation results under different parameters with actual pedestrian activity paths and using VGA to refine static information in the simulation environment, the study obtains simulation results that closely match reality paths.

Based on the pedestrian activity model, the author independently developed a self-generating model that can be used for urban renewal design by combining dynamic pheromone theory. The dynamic distribution of pheromone is advantageous in constructing a simulation environment where multiple agents can interact with each other. Agents influence and change the environment by releasing pheromone during the activity process, and the changes in the environment in turn affect new agents. This interactive communication process is more conducive to stimulating the competition, stimulation, and optimization of the model. The new model finally forms a relatively stable simulation result through a large number of iterative operations, achieving the goal of self-generation. This study also tested the feasibility and rationality of the self-generating model through design practice and demonstrated its application value in real urban renewal design work. Compared with the traditional empirical design approach, MAS has higher efficiency, lower investment cost, and a broader range of applications. This technology can effectively promote urban renewal and the protection of historical districts, and provide technical support for achieving sustainable urban development.

References

[1] Undesa P. World urbanization prospects: the 2018 revision[J]. Retrieved August, 2018, 26: 2018.
[2] Zheng H W, Shen G Q, Wang H. A review of recent studies on sustainable urban renewal[J]. Habitat International, 2014, 41: 272-279.
[3] Zhong X, Chen X. Demolition, rehabilitation, and conservation: Heritage in Shanghai's urban regeneration, 1990–2015[J]. Journal of Architecture and Urbanism, 2017, 41(2): 82-91.
[4] Boussaa D. Urban regeneration and the search for identity in historic cities[J]. Sustainability, 2017, 10(1): 48.
[5] Xiao Q, Zhao L, Ji L, et al. Ecological characteristics of distributed energy planning in ecological urban renewal design[J]. Energy Reports, 2022, 8: 13037-13046.
[6] Zhang L, Chen J, Tochen R M. Shifts in governance modes in urban redevelopment: A case study of Beijing's Jiuxianqiao Area[J]. Cities, 2016, 53: 61-69.
[7] Cui J, Broere W, Lin D. Underground space utilisation for urban renewal[J]. Tunnelling and Underground Space Technology, 2021, 108: 103726.
[8] Zou Y, Chen Z, Zhong N, et al. Urban planning as a way to pursue quality-oriented urbanization: Anatomy of the urban planning of Xiong'an New Area, China[J]. Journal of Urban Affairs, 2021: 1-16.
[9] Wei Z, Jiejing W, Bo Q. Quantity or quality? Exploring the association between public open space and mental health in urban China[J]. Landscape and Urban Planning, 2021, 213: 104128.
[10] Pannell C W. China's urban geography[J]. Progress in human geography, 1990, 14(2): 214-236.
[11] Delafons J. Sustainable conservation[J]. Built Environment (1978-), 1997: 111-120.
[12] Schwab K. The fourth industrial revolution[M]. Currency, 2017.
[13] Huang X, Lu Z, Zhuang Z. Analysis of the wind environment to improve the thermal comfort in the colonnade space of a qilou street based on the relative warmth index[J]. Sustainability, 2019, 11(16): 4402.
[14] Bazazzadeh H, Nadolny A, Attarian K, et al. Promoting sustainable development of cultural assets by improving users' perception through space configuration; case study: The industrial heritage site[J]. Sustainability, 2020, 12(12): 5109.
[15] Rao X, Zhou J, Ding K, et al. Research on the cultural tracing of the patriarchal clan system of traditional buildings in the Eastern Zhejiang Province, China, based on space syntax: The case study of Huzhai in Shaoxing[J]. Sustainability, 2022, 14(12): 7247.
[16] Monachesi P, Witteborn S. Building the sustainable city through Twitter: Creative skilled migrants and innovative technology use[J]. Telematics and Informatics, 2021, 58: 101531.
[17] Minsky M. Society of mind[M]. Simon and Schuster, 1988.
[18] Shen W. Multi-agent systems for concurrent intelligent design and manufacturing[M]. CRC press, 2019.
[19] Huang Z, Kim J, Sadri A, et al. Industry 4.0: Development of a multi-agent system for dynamic value stream mapping in SMEs[J]. Journal of Manufacturing Systems, 2019, 52: 1-12.
[20] Penn A, Turner A: Space syntax based agent simulation: Springer-Verlag, 2002.

[21] Turner A, Penn A. Encoding natural movement as an agent-based system: an investigation into human pedestrian behaviour in the built environment[J]. Environment and planning B: Planning and Design, 2002, 29(4): 473-490.
[22] Kitazawa K, Batty M. Pedestrian behaviour modelling[J]. An Application to Retail Movements using a Genetic Algorithm. Centre for Advanced Spatial Analysis, University College London, 2004.
[23] Kalay Y E. Integrating an agent-based model and a statistical model into a user model[J]. Design Computing and Cognition'06, 2007: 61.
[24] Cenani S, Çagdas G. Agent-based system for modeling user behavior in shopping malls[C]. Proceedings of the 26th eCAADe Conference, 2008: 635-642.
[25] Koutamanis A, Van Leusen M, Mitossi V. Route analysis in complex buildings[C]. Computer Aided Architectural Design Futures 2001: Proceedings of the Ninth International Conference held at the Eindhoven University of Technology, Eindhoven, The Netherlands, on July 8–11, 2001, 2001: 711-724.
[26] Helbing D, Farkas I J, Molnar P, et al. Simulation of pedestrian crowds in normal and evacuation situations[J]. Pedestrian and evacuation dynamics, 2002, 21(2): 21-58.
[27] Xu P, Zhang R, Deng Y. A novel visibility graph transformation of time series into weighted networks[J]. Chaos, Solitons & Fractals, 2018, 117: 201-208.
[28] Zolfagharkhani M, Ostwald M J. The spatial structure of yazd courtyard houses: A space syntax analysis of the topological characteristics of the courtyard[J]. Buildings, 2021, 11(6): 262.
[29] Puusepp R. Generating circulation diagrams for architecture and urban design using multi-agent systems[D]. University of East London, 2011.
[30] Feng Y, Tong X. Incorporation of spatial heterogeneity-weighted neighborhood into cellular automata for dynamic urban growth simulation[J]. GIScience & Remote Sensing, 2019, 56(7): 1024-1045.
[31] Liu J, Xiao B, Li Y, et al. Simulation of dynamic urban expansion under ecological constraints using a long short term memory network model and cellular automata[J]. Remote Sensing, 2021, 13(8): 1499.
[32] Shatu F, Yigitcanlar T, Bunker J. Shortest path distance vs. least directional change: Empirical testing of space syntax and geographic theories concerning pedestrian route choice behaviour[J]. Journal of Transport Geography, 2019, 74: 37-52.
[33] Karoji G, Hotta K, Hotta A, et al. Pedestrian dynamic behaviour modeling[C]. 24th International Conference on Computer-Aided Architectural Design Research in Asia: Intelligent and Informed, CAADRIA 2019, 2019: 281-290.
[34] Hwang J H, Lee H. 3D visual simulation and numerical measurement of privacy in traditional Korean palace[C]. 22nd International Conference on Computer-Aided Architectural Design Research in Asia: Protocols, Flows and Glitches, CAADRIA 2017, 2017: 355-363.
[35] Lynch K. Good city form[M]. MIT press, 1984.
[36] Scholl H J. Agent-based and system dynamics modeling: a call for cross study and joint research[C]. Proceedings of the 34th annual Hawaii international conference on system sciences, 2001: 8 pp.
[37] Gilbert N, Terna P. How to build and use agent-based models in social science[J]. Mind & Society, 2000, 1: 57-72.
[38] Skyttner L. General systems theory: An introduction[M]. Springer, 1996.

[39] 袁烽, 柴华. 数字孪生 关于 2017 年上海“数字未来”活动“可视化”与“物质化”主题的讨论[J]. 时代建筑, 2018(01): 17-23.
[40] Leach N. (In) formational Cities[J]. Architectural Design, 2015, 85(6): 64-69.
[41] Holland J H. Emergence: From chaos to order[M]. OUP Oxford, 2000.
[42] Resnick M. Decentralized modeling and decentralized thinking[J]. Modeling and simulation in science and mathematics education, 1999: 114-137.
[43] Haggett P, Chorley R J. Network Analysis in Geography[M]. Edward Arnold, 1969.
[44] Resnick M. Turtles, termites, and traffic jams: Explorations in massively parallel microworlds[M]. Mit Press, 1997.
[45] Castle C J, Crooks A T. Principles and concepts of agent-based modelling for developing geospatial simulations[J], 2006.
[46] Hurley J S. Real Virtuality: Slavoj Zizek and'Post-Ideological'Ideology[J]. Postmodern Culture, 1998, 9(1).
[47] Javier R-T V. Modeling and Simulating the City: Deciphering the Code of a Game of Strategy[J]. International Journal of Architectural Computing, 2007, 5(3): 571-586.
[48] Batty M, Torrens P M. Modelling and prediction in a complex world[J]. Futures, 2005, 37(7): 745-766.
[49] Williams C J. Computers and the Design and Construction Process[J]. Visions for the Future, 2005.
[50] Delorme M. An introduction to cellular automata: some basic definitions and concepts[J]. Cellular automata: a parallel model, 1999: 5-49.
[51] Adamatzky A. Computing in nonlinear media and automata collectives[M]. CRC Press, 2001.
[52] Rodrigues A, Raper J: Defining spatial agents, Spatial multimedia and virtual reality: CRC Press, 2021: 111-129.
[53] Russell S J. Artificial intelligence a modern approach[M]. Pearson Education, Inc., 2010.
[54] Wooldridge M. Intelligent agents[J]. Multiagent systems: A modern approach to distributed artificial intelligence, 1999, 1: 27-73.
[55] Miorandi D, Sicari S, De Pellegrini F, et al. Internet of things: Vision, applications and research challenges[J]. Ad hoc networks, 2012, 10(7): 1497-1516.
[56] Bonabeau E, Guérin S, Snyers D, et al. Three-dimensional architectures grown by simple ‘stigmergic’agents[J]. BioSystems, 2000, 56(1): 13-32.
[57] Feng Y, Liu Y, Tong X, et al. Modeling dynamic urban growth using cellular automata and particle swarm optimization rules[J]. Landscape and Urban Planning, 2011, 102(3): 188-196.
[58] Raisbeck P. PROVOCATIVE AGENTS: AGENT BASE MODELLING SYSTEMS AND THE GLOBAL PRODUCTION OF ARCHITECTURE[J], 2007.
[59] Yamu C, Van Nes A, Garau C. Bill Hillier’s legacy: Space syntax—A synopsis of basic concepts, measures, and empirical application[J]. Sustainability, 2021, 13(6): 3394.
[60] Zixin L, Várady G, Zagorácz M B. Application of visual simulation in the activation of historical district[J]. Pollack Periodica, 2022, 17(2): 168-174.
[61] Zhao D, Bachmann B, Wang T. ‘Beautiful China’project: A development proposal for non-heritage rural areas in North China[J]. Pollack Periodica, 2019, 14(1): 235-246.
[62] Chen C, Lin H, Chiu M. A scenario-based agent system for digital city interaction[C]. Proceedings of CAADRIA, 2004: 693-705.

[63] Wu M, He H, Bachmann B. The activation of industrial heritage: Transformation in the Petite Ceinture[J]. Pollack Periodica, 2021, 16(2): 150-155.
[64] He H, Wu M, Gyergyak J. Intervention and renewal– Interpretation of installation art in urban public space[J]. Pollack Periodica, 2021, 16(3): 139-145.
[65] Hu H, Luo Z, Chen Y, et al. Integration of space syntax into agent-based pedestrian simulation in urban open space[C]. CAADRIA 2017–22nd International Conference on Computer-Aided Architectural Design Research in Asia: Protocols, 2017: 325-334.
[66] Hillier W, Yang T, Turner A. Normalising least angle choice in Depthmap-and how it opens up new perspectives on the global and local analysis of city space[J]. Journal of Space syntax, 2012, 3(2): 155-193.
[67] Moulin B, Chaker W, Perron J, et al. MAGS Project: Multi-agent geosimulation and crowd simulation[C]. Spatial Information Theory. Foundations of Geographic Information Science: International Conference, COSIT 2003, Kartause Ittingen, Switzerland, September 24-28, 2003. Proceedings 6, 2003: 151-168.
[68] Kent M, Schiavon S. Evaluation of the effect of landscape distance seen in window views on visual satisfaction[J]. Building and Environment, 2020, 183: 107160.
[69] Kumeno F. Multi-agent Simulation for Risk Prediction in Student Projects with Real Clients[C]. Knowledge-Based Software Engineering: 2022: Proceedings of the 14th International Joint Conference on Knowledge-Based Software Engineering (JCKBSE 2022), Larnaca, Cyprus, August 22-24, 2022, 2023: 113-125.
[70] Srivastava P R, Baby K, Raghurama G. An approach of optimal path generation using ant colony optimization[C]. TENCON 2009-2009 IEEE Region 10 Conference, 2009: 1-6.
[71] Sayyari F, Emadi S. Automated generation of software testing path based on ant colony[C]. 2015 International Congress on Technology, Communication and Knowledge (ICTCK), 2015: 435-440.
[72] Qu F, Yu W, Xiao K, et al. Trajectory generation and optimization using the mutual learning and adaptive ant colony algorithm in uneven environments[J]. Applied Sciences, 2022, 12(9): 4629.
[73] Zhai L, Feng S. A pedestrian evacuation model based on ant colony algorithm considering dynamic panic spread[J]. Journal of Industrial and Management Optimization, 2023, 19(4): 2799-2823.
[74] Qiu S Z P S. Digital Morphogenesis Research and Design Implementation (Parametric Design in the Field of Industrial Design)[J]. Heritage & Vision: 36.
[75] 姜兴贵，罗杰：惠州焕发国家历史文化名城新活力[N], 2022-11-25.