INTELLIGENT GENERATION OF ARCHITECTURAL LAYOUT
INHERITING SPATIAL FEATURES OF CHINESE GARDEN BASED
ON PROTOTYPE AND MULTI-AGENT SYSTEM

A Case Study on Lotus Teahouse in Yixing

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Abstract. This study presents an approach for the intelligent generation of architectural layout, in which partial space inherits Chinese garden spatial features. The approach combines spatial prototype analysis and evolutionary optimization process. On one hand, from the perspective of shape grammar, this paper both analyzes and abstracts the spatial prototype that describes the spatial characteristics of Chinese gardens, including the organization system of architecture and landscape, with the spatial sequences along the tourism orientation. On the other hand, taking the design task of Lotus teahouse as an example, a typical spatial prototype is selected to develop the generative intelligent experiment to achieve the architectural layout, in which the spatial prototype is inherited. Through rule-making and parameter adjustment, the spatial prototype will eventually be transformed into a computational model based on the multi-agent system. Hence, the experiment of intelligent generation of architectural layout is carried out under the influence of the function, form and environmental factors; and a three-dimensional conceptual model that inherits the Chinese garden spatial prototype is obtained ultimately.

Keywords. Chinese garden; Architectural layout; Spatial prototype; Multi-agent system; Intelligent generation.

1. Introduction
Architectural intelligence is applied in all stages of a building, including the architectural design stage, the construction stage and the service stage. The intelligent generation of building layout is usually a matter of great concern to architects. In the last decades, researches are mature in intelligent generation of urban and architecture design. However, research on Chinese garden intelligence generation has not been studied fully. Chinese garden has unique charm because of the variety and complexity of the space, which makes it difficult to describe the spatial characteristics through logical description or mathematical formula.
Many Chinese architects tried to create unique experience in part of the space in a building through the Chinese-garden-way. However, there are improper design methods because of the misunderstanding of the traditional space. Therefore, the intelligent generation of Chinese garden layout and its practical application will help to solve the duplication and confusion during the design process.

In 2016, I participated in a project: Yixing Lotus teahouse, which aimed to build a teahouse with Chinese garden experience in the rural environment. The design of the Lotus teahouse is the reflection of modern understanding of Chinese garden. During the project, I found that although the Chinese garden space is complex, there are some basic rules to follow, which can be described with logical shape language, and thus can be translated into a computational geometric language. Therefore, with the mutual aid of shape grammar and programming, the transformation and generation of architectural layout with Chinese garden spatial features, even the intelligent generation of Chinese garden, could be realized.

This paper proposes a spatial prototype to describe the organization of spatial parameters in Chinese garden. Then, the spatial prototype is translated into a computational model based on multi-agent system. The ‘prototype’ theory is the basement of description of the internal organization of Chinese garden space. On the basis of the prototype, the algorithm and rules are formulated to describe the locations, size, facades and functions of rooms. Based on the multi-agent system, the primary scheme of contemporary architectural design is obtained, of which partial space shows characteristics of the Chinese garden.

2. Background

2.1. PROJECT BACKGROUND

Lotus teahouse, located in Lotus farm, was completed in May 2016. The building locates at the end of the road entering the site. There are three tearooms, one management room and one atrium. The atrium retreats away from the water, and the gaps between the volumes are intentionally maintained to connect the view between the lake and the field. There is a topological relationship between the volumes as Chinese garden: the centripetal relationship and the mutual negativity (Zhu G.Y. 1988). There is a similar design method as Chinese garden adopted: varying sceneries with changing view-points(figure 1). Through different combinations of materials, there are three types of facades shown on the teahouse: open, closed and semi-open, which is the miniature of the facades in the Chinese garden.
2.2. LITERATURE REVIEW

Architectural layout planning is an important subject in generative design, also known as the space allocation problem. Based on the evolutionary algorithm, Jagielski R. and Gero J. S. (2005) published the genetic urban planning method with the details and results given. Based on the rule system, a technical strategy of user-defined layout planning on different floors was presented to achieve reasonable results (Lopes R. 2010). Based on mathematical optimization, through solving the multi-objective mixed integer programming model with MIP solver, the optimal layout was figured out (Keatruangkamala K. 2005). The approach binding a multi-agent topology finding system and an evolutionary optimization process for the generation of the multistory architectural layout was proposed (Guo Z.F. and Li B. 2017). There have been considerable results in architectural layout generation with the multi-agent system.

Chinese scholars tend to use humanistic language to describe Chinese garden. There are also a few Scholars analyze Chinese gardens from the perspective of topological geometric (Zhu G.Y. 1988) and space syntax(Lu S.M. 2009). Lu presented a language of Chinese garden which expresses the meaning of the garden with the physical system. It is a desirable approach to describe Chinese garden space. But it is still difficult to convert the language into a computational model. In the architectural spatial research, Robert Kriel put forward the concept of “prototype” in urban typology (Liu X.J 2009). Kriel believed that urban space is formed by deformation of basic geometrics like square, triangular, circular and so on. In addition, the multi-agent system can effectively realize the conversion between the prototype and the computational model. Therefore, the approach of intelligently generating architectural layout inheriting Chinese garden spatial features, even the Chinese garden layout, worth further exploring.

3. Spatial analysis and prototype abstraction in Chinese gardens

Two aspects are considered to analyze Chinese garden space: the relationship between buildings and landscape, and self-organization of outer-space sequences. The former pays attention to the spatial characteristics in a certain area. The latter
is concerned with spatial continuity, including size, direction, etc.

3.1. CONCEPT OF SPATIAL PROTOTYPE

Prototype theory is one of the important concepts in typology theory. It compares architectural space with language, that the elements of spatial composition equal words in a sentence, so that space is formed by the elements through a certain grammar. Zhang Yufeng (2002) established 12 kinds of spatial prototypes in the study of architectural space unit. Then, in the study of spatial structure, he established two structural prototypes. Similarly, there are spatial prototypes in Chinese gardens.

The spatial prototype includes parameters like architecture and landscape. The shape of architecture is abstracted to a rectangle. Landscape refers to the courtyard, patio, water surface, etc. Understanding the Chinese garden from the perspective of the spatial prototype will help to find the essential laws from the complex representation, and grasp the development and change of the Chinese garden space more intuitively.

3.2. ORGANIZATION SYSTEM OF ARCHITECTURES AND LANDSCAPES

Beijing courtyard is a representative of traditional Chinese residence. Because of the limitation of the wooden building, the architectures in the garden is independent from each other, keeping a certain gap space. Buildings usually show a clear enclosure around landscape, separating with gaps. And the layout of multiple-courtyards evolves on the basis of single-courtyard. So, the organization in single-courtyard could represent the basic relationship between architecture and landscape in traditional Chinese architectures. A spatial prototype, in which courtyard is surrounded by four buildings is abstracted.

Compared with the Beijing courtyard, the enclosure of buildings and landscapes is looser in Chinese gardens. In the famous Chinese garden: Humble Administrator’s Garden, there are many beautiful enclosed courtyards, like Southeast courtyard, Xiaocanglang water-yard. It is not difficult to find that the layout of enclosed courtyards could be obtained through the transformation of position and scale from the spatial prototype. Although the layout of Xiaocanglang water-yard is free, with a non-vertical rotation, in fact, its layout has similar characteristics to the spatial prototype too. In Chinese gardens, there are three types of facades: closed facades, like white walls, open facades, like galleries, and semi-open facades, like ornamental perforated windows. Take Southeast courtyard and Xiaocanglang water-yard as examples. The facades are usually open or semi-open on the side facing the courtyard. In the spatial prototype, the above three types of interfaces are represented by solid segments and dashed segments (figure 2).
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Figure 2. Spatial prototype of the enclosure of buildings and landscape.

The normal lines of buildings point to a certain area of the waterscape, which is called the ‘centripetal relationship’. The centripetal relationship appears obvious in the Wangshi garden. When the normal lines of adjacent buildings point vertically or inversely to each other, this relationship is called ‘mutual negativity’. In Humble Administrator’s Garden, architectures around the main waterscape appear the centripetal relationship and the mutual negativity at the same time. In addition, the pavilions in the garden are triangular or fan-shaped in layout, and located in the center or high place of the garden, with normal lines facing buildings in different directions, so as to get important views (figure 3).

Figure 3. Topology between buildings and landscape in Humble Administrator’s Garden and Wangshi Garden.

3.3. ORGANIZATION SYSTEM OF SPATIAL SEQUENCES

People often use phrases such as ‘change from beginning to end’ or ‘closing followed by opening’ to describe the spatial changes in Chinese garden. In this research, spatial features are abstracted into four types: open, close, semi-open, close and semi-open. They are illustrated in the graphic mark (figure 4). The entrance sequences of the Liuyuan garden are considered to be a typical example of the spatial changes of Chinese gardens. The changes along the entrance path
are illustrated with the graphic marks as shown in figure 4. Compared with the Lotus teahouse, it can be found that the tea house is similar to Chinese gardens in spatial experience. Then, key turning points along the tour routine are taken to be illustrated with the depth-width ratio, facade characteristic and so on. As shown in figure 4, for example, point B, in which depth-width ratio is over 1, surrounded by the white walls, is dark here. Compared with Lotus teahouse, it is easy to find that the facade type and features of spatial sequences in the two are similar to each other, although there are great differences between their appearance.

![Figure 4. Organization of spatial sequences in Liuyuan Garden and Lotus teahouse.](image)

Through the above spatial analysis, an abstract spatial prototype can be achieved which can represent the enclosure between architecture and landscape, the three facade types, and the spatial sequences. In the contemporary architectural design, through the transformation and organization of the spatial prototype, the architecture inherits the characteristics and experiences of Chinese garden, even though the materials are totally different. In addition, the spatial prototype is suitable for conversion into computational geometric models because it expresses clear rules of the spatial organization of Chinese garden.

4. Computational generation of architectural layout inheriting spatial prototype

4.1. AGENTS

Based on the spatial prototype and the design task of the Lotus teahouse, the architectural layout is generated by JAVA programming. Three types of agents are defined according to the spatial prototype: room agent, gap agent and courtyard agent. The room and the courtyard agent are separated by the gap agent. The properties of the agent include location, type, the rules of action and the facade. The main program runs as follows. Firstly, the initial position and size of the agents are generated within limits. Then, the agents calculate and move according to the predetermined rules. After balancing and stabilizing, the information of the gap space and the boundary information of the room agent are stored, while the gap space agent is generated. The agents update themselves again. Finally, three-dimensional conceptual models are generated.
The width-height ratio of the room agents is limited accordingly. The total area of the agent is preset according to different functions and adjusted within 10% of the preset area. The rules of agents’ action include attraction, exclusion, and environmental factors. The agent is simultaneously attracted by the target point and repelled by intersecting agent (figure 5). Under the rules, the agent updates by calculating the distance between the central vectors. Through constant adjustment, the agents finally get balance. There are 16 possibilities for the intersection of any agent \( i \) with \( j \) according to the position, the width and height of the intersecting rectangle (figure 6). In order to make the rooms as centralized as possible, all rooms are attracted by the same target point. The mathematical formula is:

\[
V_a = k_1 \left| V_i - V_g \right| 
\]

(1)

\( k_1 \) is a constant, which controls the speed of the agent, \( V_g \) represents the target point vector, \( V_i \) represents the center vector of the agent \( i \).

The movement value of the agent is correlated with the width and height of the intersecting part. For example, the agent \( i \) intersects with the agent \( j \), taking the agent \( i \) as the active object. When the height of the intersecting part is greater than the width, the agent \( i \) moves in the opposite direction to the agent \( j \) in the \( x \) coordinate. The displacement value of the agent is related to the rectangular size of the intersecting area. The formula for the displacement vector \( \vec{V} \) is as follows:

\[
\vec{V} = k_2 a_j \vec{I}_w + k_2 a_j \vec{I}_h
\]

(2)

\( \vec{I}_w \) represents vector of intersecting part in \( x \) coordinate. \( \vec{I}_h \) represents vector of intersecting part in \( y \) coordinate. \( a_j \) indicates the location of the agent \( i \) and agent \( j \). \( a_j \) equals 1 if the agents intersect, and \( a_j \) equals 0 if the agents separate. Once the agent intersects, it will not be completely separated, and there must be a certain thickness of intersecting, which provides the basis for generating the gap space.

In fact, the repulsion force on any agent \( i \) is the combined force of all other intersecting agents. The force from target points has different weights \( k \) for the
three kinds of agents. As a result, tearooms will be more likely to appear around
the courtyard and more likely to get more landscape view.

\[ V_i = \sum_{j=1}^{n} \left( k_2 a_j \vec{I}_w + k_2 a_j \vec{I}_h \right) \]  (3)

4.2. COMPUTATIONAL GENERATION EXPERIMENTS

The generation experiment includes layout generation and 3D model generation.
The layout is generated with agent groups, in which the numbers of tearooms,
yards, and office agents are assigned correspondingly. The tearoom, courtyard and
office are surrounded by each other. That is, the initial positions of the courtyards
are randomly obtained in the middle area, tearooms are in the loop-shaped area
around the courtyard area, and offices are in the outermost area. The generating
process is shown in figure 7. The process from getting the initial position to the
stable state of the agents is described as follows:

Set all agents to ROOM

WHILE TRUE

Agent \( i \) initial displacement \( d_v \leftarrow 0 \)

FOR \( r : \) ROOM

Calculate the displacement of agent \( i \) \( d_v \)

\( d_v \leftarrow d_v + d_v^r \)

END

RETURN \( d_v \)

Figure 7. Process of layout generation.

After the stabilization of room and courtyard agents, gap agents appear. The
gap agents are generated according to every intersecting area between agents
(figure 8-A). The width of gap agent is constant. Then gap agents participate in
the optimization and adjustment until next stabilization. When the gap agent is
generated, the facades of the room agents are determined, taking three types of
facades as examples: wall, glass and grates. Once the boundary type is recorded,
it will not change again. The facade type is mainly decided on the relationship
between room and environment. The model is built by HE_Mesh, which is a Java
library for creating and manipulating meshes. A wall can be established on the
basis of a line (figure 8-B). The conditions for determining boundaries can be set
by the designer as needed.
4.3. RESULTS
The typical results are shown as below, with different group or room numbers (figure 10). As a whole, the results reflect the diverse relationship between the buildings and the courtyards. With the increasement in the number of functions, random results that meet the constraints can still be generated quickly. The facades of rooms are diverse that rooms have visions to courtyard accordingly. There are also various spatial experiences along the tour path. On this basis, designers can select appropriate results according to site conditions and functional requirements.

5. Discussion
This paper explores the rational design approach of integrating the spatial characteristics of Chinese gardens into architectural intelligent generative design. The rules of spatial organization in Chinese gardens could be expressed by the combination of geometric relations, which is clear and concise. In this study, the
relationship between architectures and landscapes, and the composition of spatial
sequences in Chinese gardens are analyzed from synchronic and chronological
aspects, to abstract the spatial prototypes. The spatial prototype is abstracted from
the perspective of shape grammar to obtain the rational rules which describe the
spatial characteristics of Chinese garden, and to become the basis of establishing
the computational model by JAVA programming. The results show the feasibility
of intelligent generation design inheriting Chinese garden spatial features.

There are still some shortcomings in the research. Due to the limited time
of program learning, the experimental results are still in the initial stage. More
general applications need to be explored. In the intelligent generation experiment,
more rules and constraints need to be added, and the algorithm needs to be further
optimized. In the future, generation of pedestrian path and spatial changes on the
path need to be further explored to complete the intelligent generation of Chinese
garden layout. Sometimes, it is difficult to define the organization rules of Chinese
garden accurately, so data-based method and neural network will be the method to
be tried in the future research. From this point of view, the intelligent generation of
architectural layout inheriting the Chinese garden features, and even the Chinese
garden layout are difficult tasks but worth looking forward to.

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