Generative Tool for Courtyard Pattern

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Abstract

The generative tool presented in the paper explores the possibilities for developing potential approach of Chinese traditional spirit of vernacular dwellings yard. Chinese spatial qualities are rhythmic and crisscrossed. The ethic orders play a crucial role in the layout principles, and the rational topological relations facilitate the habitants’ activities. Patterns of traditional Quadrangle Dwellings are investigated as a self-organisational system, from which constitutes the mathematical model of the generative tool.

Multi-agent system (MAS) is efficient to employ the self-organisational rules extracted from the courtyards. Each agent in the MAS presents a courtyard in the whole layout. The architectural constraints and the extracted rules set up the behaviour standards for the agents. The interactions between them make the system self-adaptive. Based on the system, a design tool was built and applied in the practical projects.

The complex patterns emerged from the system lead to new understandings of the traditional spirits. Innovative methodology and perspective is provided for architects to deal with Chinese courtyard.

1. Introduction

With the development of architecture globalization, inevitably, courtyard space as a Chinese traditional architecture characteristic has lost in the past several decades. Two main reasons should be responsible for this consequence: First, the scale of traditional courtyard can not meet the request of modern architecture for large-scale public space with the rigorous site limitation. In addition, the existing courtyard design method is incapable of dealing with the complexity of architecture, together with the cultural context. Therefore, how to design courtyard space in public architecture integrated with traditional pattern becomes an emergent task for Chinese architects.
On the other aspect, MAS (Multi-agent System) has been proved to have the ability to deal with complex organization problems in past several years. Compared to traditional design method, MAS is a top-down self-organized system defined by abstract regulations. This paper explores the potential of courtyard layout designed with this evolution tool.

The second part of this paper is to explain the characteristics of Chinese courtyard space. The study takes Chinese Quadrangle Dwellings as investigated objects, and analyzes traditional architectures from two dimensions, through which derives program organized regulation:

- Relation among courtyards. The function, ranking, and social character decide the location and scale of each unit.
- Shape of courtyard. Courtyard with different ranking corresponds to various space organization and topological pattern, interrelated with the active mode of space-user.

The third chapter focuses on the program process through mathematical algorithm, and the result of the program is also described in this part. In the program system, each agent represents a courtyard unit, and ranks, adjacent relations, courtyard area and building area are programmed through the regulation derived from former analysis. Based on MAS system, a generative design tool was built and applied in the practical projects.

At last, the limitation and disadvantages of this tool will be proposed for future exploring and developing.

2. Background

Chinese tradition in its most ancient roots conceives of the elementary units of reality as changes from yin to yang or vice versa. More particularly, an identifiable unit of reality is a harmony of yin-yang transformations. (Robert C.Neville) Some dialectic references in China, such as inside and outside, being and non-being, solid and void, may be comprehended and articulated through the terms yin and yang. Courtyard is
also a system integrated with yang/solid and yin/void, which consists the internal organization logic. The organization of courtyard system, hence, may be comprehended as structured by two categories: the structure combining each unit with its social function, and the organization of yin and yang, being and non-being.

2.1 Courtyard organization order

The founder of Tao philosophy, Laozi, stated in his Daode jing that "Out of Tao, One is born; Out of One, Two; Out of Two, Three; Out of Three, the created universe", in which Laozi put forward the concept of one as the foundation of the spatial schema, starting from one to two, and moving from two to three. Based on this philosophy, the process of courtyard organization, generating its own motion by the interaction of forces, is fundamentally transformational. There is no final beginning or end in this process; rather, there is the identifiable rhythm, order, and cadence of transformation. (Roger T. Arnes) There are three main measures of traditional design method: repeat in north-south direction, move parallelly in both widths and depths orientations, and scale-up or scale-down based on corresponded hierarchy.

So many theories and diagrams in ancient China are contributing to the centrality thought. Bagua, is an Eight Trigrams, founded on the categorization of the eight directions of the world with the void in the centre. The strong correlation in numerology, structure and ethics, between man and Heaven marks man’s esteemed status in the cosmos, and hence formed the centrality. Eight elements around the central void space correspond to rigorous hierarchy and the complementarities and restrictions among each unit build a harmony and consistent system. And according to the diagram, Nine Realms of Zhou, the degree of barbarism increases or the degree of culture deceases with the square of the distance from the centre. To this regard, the reality of traditional architecture emerges from the transformation of space to reflect social meanings.
The active mode of ancient Chinese also decides the orientation and arrangement order of courtyard. From the records, based on the east-west orientation, in Chinese courtyard, the west architecture is usually reserved for sleeping and the east is for daily activities. However, in the ordering of external space, the north-south orientation occupied the principal place in Chinese culture. Thus, the spatial arrangement as well as settlements came to incline towards this orientation. The north is revered and esteemed on Earth, for example, the emperor faces the south and his subjects profess allegiance to the north. Therefore, architecture is sited with its back to the north, facing the south. Such layout idea may of course have had a rationale of Chinese temperate condition, which naturally favours the warm sunlight that comes through into the south-facing interior and has its back turned away from the harsh cold wind form the north.

Meanwhile, the Chinese concept of space was founded upon a spatial imagination that emerged and evolved over time. Indeed, Chinese enclosure space is appreciated as it relates to impending departures or arrivals, that is, in terms of movement from one space to another; it is dynamic. Take Prince Gong’s Mansion (Gong Wang Fu) as an example. Prince Gong’s Mansion is Beijing’s largest and the best preserved Qing Dynasty (1644-1911) princely mansion. The mansion was constructed around the year 1777, and covers a total area of 60,000 square meters. The residential portion stands within three sets of courtyards occupying a central, eastern and western situation. The movement through the main, central section comprising the front door, the second door, the anterior hall, the major hall and an extended pavilion, composes the sacrifice routine. Each of the western and eastern sections contains three smaller courtyards for residential function, and based on the east-west orientation rules, the eastern section has higher hierarchy than the western section. In Figure 5, the most important courtyard is located in the centre of the mansion, surrounding by eight lower ranking courtyards. The orientation and the distance from the central courtyard decide the social function and hierarchy class of these eight units, and vice versa. The service courtyards and entrance courtyards are arranged at the outside of the complex, because of their assistant functions.
2.2 Pattern of courtyard

Laozi claimed that the universe created carried the yin at its back and yang in front, and through the union of the pervading principles it reaches harmony (Daode jing), from which he expanding the planar schema into a three dimensional schema with the concept of yin and yang. That forms the elemental entity in Chinese traditional conception of space. In cases of Chinese space, the spatial imaginations are manifested as two rudimentary characteristics: enclosure and enclosing qi, being and non-being. Architecture space is defined by its enclosure/being and enclosing qi/non-being.

Differences between transformations consist in different patterns of yin and yang being exhibited. Thus there are patterns that can be ingredient in a harmony, and over time those patterns can be repeated or exchanged for other patterns.

3. Program description

The mathematical model of the experimental program takes the rank as the crucial trait of every courtyard. The ranks reflect the status of the inhabitants in traditional courtyards. The ranks could be derived from the different functions of the parts in modern architectures, such as museum and hotel with traditional space pattern. The
model assumes that the units with higher rank would be located nearer the centroid than the others with lower ranks.

The topology is the basic trait of the courtyards in both traditional dwellings and today’s architectures. Each courtyard has particular “neighbours” for the convenience of various activities or the ethic principles in the Chinese traditional architectures. The adjacent relations between the units are essential parameters for the architectural organization in practical designs. In the mathematical model, each pair of the courtyards is assigned to “make neighbours” based on the initial specification. Though the bubble diagram has been well developed in conventional design process, this program just take the simplest mode for descriptions of adjacency relationships.

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<th>ID</th>
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<th>CAR</th>
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<th>Adjacency</th>
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</table>

Figure 7: program structure

The Courtyard Area Reference (CAR) is a reference value of courtyard area. The true value in final articulation after execution is always smaller than the value calculated by CAR, for this system is still under test with some inevitable disadvantages. The value of building area controls the building area of each courtyard precisely. The building area could be equal to the CAR when the building covers the whole courtyard. In this condition, this model is not only for courtyards organization, but also ordinary organizations of unit spaces. A unit with higher rank usually has a higher value of CAR and building area, however, there are exceptions. For example, a unit presenting garden may have low rank, large CAR and very low building area.

The ranks, adjacent relations, courtyard area and building area are basic configurations of the mathematical model. The multi-agent system based on this model could test any space problems which can be described by these parameters, while the self-organization of the system will bring out interesting hints.

Figure 8: the ranking of courtyard
3.1 Employing rules by MAS

The configuration based on parameters could not lead to any forms or patterns without other composition rules. Architects are good at applying their rules to the existing configurations even though they may not notice this key process. The generative tool needs its own rules to produces forms. Multi-agent system (MAS) is efficient to employ the local-organization rules based on the configuration information. The initial state of the MAS is set up by random function and the self-organizations of the units generate population of forms during the whole life period of the system. One initialization leads to a unique but unpredictable process of running and a particular final form articulation. From a traditional viewpoint this situation turns counter to the notion of design by its indeterminacy and ambiguity, while it is a feasible way towards true analogy of nature evolution and it brings out abundance resources of forms for designers.

Every agent in this system presents a courtyard with the parameters of rank, neighbourhoods, CAR, building area and location. The locations of all agents are randomly initialized. The behaviours of the agents are put into five categories: pushing, making neighbours, exchanging locations, assembling and keeping in site. All behaviours are induced by virtual forces. The system’s main character is that all the forces are “soft”. This character creates new possibilities in the process of layout generation and brings some inherent disadvantages.

![Figure 9: early layout of individualistic agents](Image)

The behaviour of pushing aims to avoid the overlapping of the courtyards. Because the force of pushing is soft (the magnitude is proportioned to the overlapping area), the agents are still likely to overlap under the pressure of other forces. That is why the CAR could not precisely control the courtyard area of the courtyard. Fortunately, it is not a vital problem for the deviation does not obstacle the generation process and does not reduce the building area. When two agents are overlapped during
running time, they will exchange their locations if the one with higher rank is on the outer side. This mechanism keeps the high rank agents around the centre of the whole group. And it is capable of improving the robust of the system for this mechanism provides uncontinuous changes to the smooth evolutionary process, just as the role of the mutation in genetic algorithms.

Any pair of agents which are defined as neighbours move towards each other until they touch each other. The magnitude is proportioned to their distance. This type of behaviours could fulfil most adjacent requirements together with the special mechanism (exchanging locations) in the pushing behaviour. While some complicated topological configuration will induce premature convergence and result in ill layouts.

If any agent is not completely covered by the area of the site, there is a force push the agent into the site. In early period, the system is tested without any site boundary. The performance is better than the situation with boundaries, for there is more space for the agents to modulate their locations. Compared with the forces for pushing and making neighbours, this kind of force is very small so the restricts of site boundary will not be too strong to interrupt the running of the system. The additional force of assembling for each agent is constant and much smaller than other forces. In fact, there is not necessary for the assembling forces coming into play until the main topology structure is shaped.

As soon as the system reaches equilibrium, the framework of the courtyards layout is generated. The equilibrium does not always imply an optimal organization. There are many “neighbours” which are far away from each other in ill equilibriums. An easy way to solve this problem is to develop a user interface for the designers to change any courtyard’s location. In spite of that, this strategy could not improve the capability of the multi-agent system.
In the other hand, the system is difficult to become stable in some situations. Usually, the behaviours of the system become periodic: it may reach some state near equilibrium, then rush into chaos and move towards another semi-stable state. The generative tool allowed the designers to freeze the semi-stable state and start building generation.

3.2 Building generation process

Several layout patterns in single courtyard have been extracted from traditional precedents. In the building generation process, every courtyard chooses a layout pattern for building generation, based on the true area of the courtyard and the predefined building area. This operation is an absolutely parametric, different from the self-organization scheme of the previous process. It's a direct way connecting the traditional patterns to the practical design tasks.

![Figure 11: employ shape of courtyard in the program](image)

4. Conclusion

Through the research of Chinese philosophy, the interrelated organized rules and layout pattern of courtyard has been derived. The centrality and yin-yang theory take the most crucial place in Chinese traditional architecture planning system, although some orders have changed over time. An evolutionary mathematical tool has been advanced to deal with the complexity of modern architecture, integrated with the traditional courtyard pattern. This method offers architects a flexible, dynamic and feasible measure to explore the possibility of Chinese courtyard pattern in practice.

However, as a primary experiment of a long-term research, there are some limitations and disadvantages of this program. Several architectural factors are not taken into account in the generative process. Feng Shui (traditional knowledge about
geomantic omen) plays an important role in the layout of traditional buildings. But most part of this knowledge is far from scientific analysis and cannot be applied in the computation. The accessibility is essential to every courtyard. For example, the main access must be placed on the southeast side in most traditional courtyards. This program does not consider this factor for its complexity.

5. Reference