GENERATIVE DESIGN BEGINS WITH PHYSICAL EXPERIMENT

Informing architectural design with swarm behaviours in real world

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Abstract. It is understand the physical world is composed of various complex systems which behave and evolve in their own way. Through observing the motion of matters in physical world, we can start to understand various swarm behaviours, and these behaviours becomes a very rich library of references when exploring the potential of generative design. In the last 2 years, a new design procedure has been introduced in the digital architectural design studio of ** University. It does not start from site investigation or document research, but starts from any kind of physical experiment which the students are interested in. The students are asked to simulate the experiments in computer with software or scripts wrote by themselves. In the final stage, the students gather information through on-site investigation, and then use the digital tools they have developed to generate architectural design. Since the physical world is composed of huge amount of individual objects, all experiments explored in this design studio demonstrate certain swarm behaviours. These behaviours could be similar to that of the complex systems in architecture, or could imply new possibilities of organization in architecture.

Keywords. Generative design, complex system, experiment, simulation, parametric design

1. Introduction

Architectural design is considered a design problem that needs to satisfy the objective functional requirements such as usage of space, circulation, struc-
ture, equipment, etc., and at the same time create certain spatial aesthetic experiences for people. There have been a lot of researches that search for optimized design according to functional criteria. But because of the aesthetical value of architecture for human society, function optimization may not result in a good design. Architects are always trying to find intuitive design ideas that could be introduced into their work.

In the past 20 years, the new science of complex system has gradually and continuously changed people’s understanding of architecture and urban planning (Jencks, 1997, Leach, 2009). It is now understood the city and architecture are systems that contains numerous elements such as environment, people, building components, energy, information, and so on. All elements in the system interact with each other and constitute a dynamic and evolving whole. Combines with contemporary digital technologies, new design methods are introduced into architecture. Although different scholars have different preference in terminology, such as parametric design, generative design, algorithmic design, evolutionary design, etc., these new methods overlaps with each other, and referring to certain complex systems which created in computers and connected to the physical world and artificial environment.

Various algorithms used for complex system simulation in science and engineering are borrowed into architecture architectural design, such as cellular automata(CA), multi-agent system (MAS), genetic algorithm (GA), flocking, computational fluid dynamics (CFD), and so on. With these algorithm, people start to employ bottom-up self-organizing mechanism in design and research. Han et al. (2004) employed multi-agent system (MAS) and genetic algorithm (GA) in optimization of layout of parallel multi row housing based on statistics of investigation on residents’ spatial evaluation. Seongki Lee and Ludger Hovestadt (2011) optimized planning of a residential quarter using multi objective optimization based on the design constrains of high-rise apartments. Huang et al. (2011, 2012) try to explore generative designs potentials in architectural design and urban design studios. Tibbits (2014) studies the behaviour of self-assembly system composed of physically fabricated units, which could be considered as a materialized self-organization system. Although these artificial complex system leads to innovative design explorations, their potentials are still limited. Since they are abstracted model of the physical world, they are not comparable to the abundance in real world.

In the physical world, there are massive interesting phenomena happening every day, and behind them are a great variety of evolving complex systems. These systems has the potential to be employed to inform architectural design by their form and organization. Through observing the motion of matters in physical world, we can start to understand various swarm behav-
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iors, and use them as a very rich library of references when exploring the potential of generative design.

2. Design exploration begins with physical experiment

In the last 2 years, a new design procedure has been introduced in the digital architectural design studio of ** University. The idea is to explore the form and organization of phenomena nature, and apply them in architectural design by digital tools that could simulate or imitate the underlying mechanism.

The design process for the 8 weeks studio is as follow.

- Find an interesting phenomenon that consists of multiple elements and complex interactions;
- Experiment on this phenomenon, observe and record the process;
- Analyse the mechanism and controlling parameters;
- Simulate or imitate the phenomenon by digital program or algorithm;
- Investigate optional sites of a gallery design, and chose one as the design site;
- Project the digital logics in step 4 onto the architectural design problem, develop the digital design tools, and generate design prototype;
- Develop the prototype into the final architectural design.

It could be noticed the design process does not start from site investigation or document research as usual, but from physical experiment which the students are interested in. Through experiment, analysis and simulation in the earlier half of the studio, digital tools that could simulate or imitate the observed phenomenon are developed, which has the potential of being applied in generative design. The usual design process are only involved in the latter half of the studio. This 2-phase process makes a clear separation of the tool development, and the problem to be solved. Although the process does not follow the usual problem solving process, it does give more freedom in developing the digital design tools, which is considered easier and more innovative for architectural students. In the latter half of the studio, the students can still chose a site from several options, which allows flexibility in the adaptation of tools and problem.

Another important point of this process is that when developing the digital tools that regenerate the observed phenomenon, it is not required to be as accurate as a scientific simulation. The students can simulate the phenomenon by scripting or by certain software, or even imitate it based on their own understanding of the mechanism. This setting may seems not so professional, but it lowers the requirement of math and science ability for the students in this studio. On the other hand, since the students may be interested in different aspects of the experiments which they considered related to architectural design, it gives them to be more flexible in extracting factors and constructing digital mechanism in their own way.
In each year around 20 undergraduate 3rd year architectural students participated in the studio. The students are organized in pairs of two, and the groups tested a great variety of phenomena in nature, such as boiling congee, screwing paper, fire, smoke, BZ reaction, crystal growth, and so on. Experimental conditions are changed to lead to different results. In simulation stage, students are more design oriented and focus on form and organization that could be implicated in architectural design. Different scripting environment and software are employed, such as Grasshopper, Processing, CFD software, etc. In the final stage, the students gather information through on-site investigation, and then use the digital tools to generate prototypes of architectural design.

3. Example of design process

3 student works are selected in this session to explain the process of experiment, simulation, and design, and the digital methods employed. The potential of this explorative design process is also demonstrated.

3.1. SHRINKING OF COLLOID

Try to press two pieces of glass with drops of glue in between, then split the glass gradually, certain branching pattern of the glue will emerge. Branches and gaps are developed and created beautiful 2D patterns (figure 1). This phenomenon also happens for other colloid when shrinks under surface tension. This spatial branching organization has the potential to be employed in architectural design, and was selected by the students for further exploration.

Grasshopper was selected for programming, and Hoopsnake plugin was used to realize the iteration in evolution simulation. The idea of the program is to simulate the gathering and redistribution of colloid particle, and let the pattern emerge by itself. Figure 2 shows the simulation process. With certain controlling factors, it is possible to create unsymmetrical distributed patterns (shown in the second row), and also patterns with topological void (shown in the third row). Finally, the algorithm can be generalized in 3 dimensional space, and can be easily applied in architectural design (last row).

The final design is a gallery lies in an enclosed space of an art zone, which is an industrial heritage area in ** city. The algorithm created an architecture with open spaces such as alleys and courtyards of convenient scale. A void courtyard space is generated by the algorithm for the big tree that already exist in the site.
Figure 1. Experimental results shows the process of colloid shrinking.

Figure 2. Regenerate the pattern by Grasshopper program.

Figure 3. Architectural design generated by the colloid shrinking algorithm.
3.2. WAVE LIGHT PROJECTION

When swimming in the summer, beautiful pattern of wave light can be seen projected at the bottom of the swimming pool. Experimental results in a water tank are shown in figure 4. The mechanism behind is the law of refraction, and can be easily scripted by Grasshopper or Rhinoscript. In the script, evenly distributed parallel rays are refracted on a curved nurbs surface, and projected onto a flat bottom surface to form a point cloud distribution. The controlling factors are the incident angle, the refraction ratio and the geometry of water surface. In order to be applied in design, certain algorithm are scripted to develop the point cloud distribution into a continuous curve pattern (figure 5).

![Figure 4. Experiment of wave light in a water tank](image)

In order to apply this mechanism in architectural design, it is necessary to develop the generated pattern into 3D space. The method is to add another dimension to the refraction law, which means all the simulation happens in a 4D space, the parallel rays are refracted by a surface in 4D space, and projected onto a 3D space, resulted in a point cloud distribution in 3D space (figure 6). In the 4D algorithm, refraction and projection are still controlled by the same factors, especially the form of the surface where refraction happens. In 4D space, the surface becomes a 3D distribution of vibration amplitude, which is a result of wave sources locations, their frequencies, and phase position.

In the final design, a complex structural framework was generated by the 4D refraction algorithm. 3D functional locations on site were selected as the wave source, and their frequencies were decided by the required space dimension of different functions, such as entrance, lecture hall, cafeteria and
so on. By using these parameters, the generated form becomes the result of design schematics. The 2D patterns generated by script are also used as design of landscape and façade substructure. (Zhang et al. 2013)

Figure 6. 3D pattern generated with refraction algorithm in 4D space

Figure 7. Final design of wave light experiment

Figure 8. 2D pattern controlled by surface wave source locations.

More discussion could be made through the algorithmic tests such as the 2D patterns shown in figure 8. It could be seen that the varying distribution of
wave source result in different patterns of wave light. Such results suggest that in future researches, a lot of spatial potential could be explored through careful arrangement of the wave sources, their amplitudes and frequencies.

3.3. GO CHESS

The Go chess is a traditional game popular in East Asia. Because of the large scale of chessboard and complexity of the game, computer intelligence cannot compete with human yet. The playing of Go game is controlled by two factors, the rules of the game, and the strategy of the players. In Asian culture, the strategy of Go are considered related to people’s understanding of the world, and the process of the game is a reflection of the competition and harmony in nature.

The Go game is an evolutionary complex system. It is similar to CA in that both of them are based on a grid system, and local interactions will result in behaviours of the whole system. But Go is different from cellular automata because it evolves not only base on rules, but also the player’s strategy. Although it is impossible to create intelligent algorithm that can play the game wisely within the 8 weeks design studio, it is still possible to test certain strategies of play and their resulted system behaviour.

There are two strategies commonly employed in play. One is to stable the conquered areas, which is called “qudi”, or take land, and the other is to expend influence in some fresh areas, which is “qushi”, or take potential. In order to simulate the process of Go game and test the strategies, the students developed certain algorithm by scripting. First they realised the logics of playing rules in script, such as the “liberty” and “ko rule”. Then, they developed certain indices that could be used for strategy, such as the field potential, the concentration, and phase of the game.

A series of tests are carried out with different strategy settings, such as shown in figure 9, and the behaviours revealed has the potential to inform architectural design and urban planning.

The final design is based on a Go game simulated by a generalized 3D system. In this game, the white pieces take the strategy of taking potential, and tends to spread in a larger areas, while the black pieces take the strategy of taking land, and forms continues clusters of entities. These strategies are projected in architectural design to depict the relationship of artificial environment, and the nature. In the final design, the black pieces are integrated to form a continuous architectural space, with open spaces transformed from the “liberty” that keeps the clusters alive. The white pieces are developed into the floating elements surrounding the building, which represent the nature. (Kang et al. 2013)
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4. Conclusion

Since the physical world is composed of huge amount of individual objects, all experiments explored in the studio demonstrate certain swarm behaviours. These behaviours are either similar to that of the complex systems in architecture, or could imply new possibilities of organization in architecture. The design process used in this digital design studio allows the students to be more focused on exploring physical phenomena and developing digital tools.
for the simulation, without being restricted by certain design problems. The studio turns out to be very innovative. A great variety of swarm behaviours finally resulted in heuristic form, space and organization of architectural design.

Because of the limited time of the design studio, the student works are just beginning of the exploration of this design methodology. Further researches can be carried to improve the simulation algorithms, or to explore possible application methods of them in design. Meanwhile, great potentials have been demonstrated in the studio. It is believed with the infinite richness of nature, and the fast development of digital technologies, the presented design methodology has the potential to bring new innovations in architecture.

Acknowledgements (sample)

This research is supported by the National Natural Science Foundation of China (No. 51078218 and No. 51278263)

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