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Influence on Architectural Geometry by Emergent Design

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***Abstract*—This paper centers on the influence on architectural geometry by emergent design under the principle of emergence theory and the help of computer software, and how this will generate positive effects and what should also be concerned during such procedure.**

Keywords-component; architectural geometry; emergent design; influence

I. INTRODUCTION

There has been an increasing interest in the influence brought to architecture by new theories and technologies, among which the emergence theory is a newly risen and developed one. Emergence theory is well known for its influences on many fields, which also brings new thinking patterns and strategies to architectural, as a common finding in much literature such as Francis Heylighen's article "Self-Organization, emergence and the architecture of complexity" [1].

However, architecture cannot only be regarded as a whole subject when discussion about how it will be influenced by certain theories, as architecture itself is a complex system of the combination of space, skin, structure, geometry, material, etc. Among these, Geometry lies at the core of the architectural design process. Geometric forms of architecture in different periods own different characteristics and design methods. Therefore, a key problem is how the emergence theory will influence architectural geometry in different aspects.

The aim of this article is to give an analysis and summary of what influence emergence theory has brought to architectural geometry and to give a conclusion of what is the proper method to utilize this theory into the design of architectural geometry.

II. BACKGROUND

A. Significance of Architectural Geometry

Geometry lies at the core of the architectural design process. It is omnipresent, from initial form-finding stages to actual construction. It also underlies the main communication medium. Namely, graphical representations are obtained by precise geometric rules. The generation of Geometry often comes from two aspects: the internal, such as the use and limitations of design tools and design methodologies, paradigm and precepts provided by history and theories; the outside, such as the task and conditions faced with, users and owners' involvement and intervention, technical and material's limitations and support [2].

B. Development of Architectural Geometry before Emergent Design

Traditional architectural geometry mostly relies on graphics established on the basis of Euclidean geometry and the Cartesian coordinate system, which is mainly in perpendicular and parallel forms. Such graphic system not only determines the main output form of architecture, but also gradually develops a custom thinking pattern of design. Despite that the curve is sometimes used in architectural design (both in the classical period and after- modernism period, the use of the curve can be found in many construction cases) straight lines and right angles still occupy a major position in architecture design. In addition, Euclidean geometry is the graphics (as a rigid body) that stay same in movement—its study focuses on the positional relationship between points, lines, surfaces, volumes, and their metric nature. The movement that can only be allowed in the Euclidean geometry is the rigid motion (translation, rotation, reflection). In such types of movement, the distance between any two points on the graphics remains the same. Therefore, the nature of Euclidean geometry is to maintain the same nature in the rigid motion.

The basic orientation of modern architecture is now a geometric abstraction, without tedious decoration in traditional architecture, abandoning the rigid dogma, abandoning the walls, columns, windows, etc. as the meaning of the architectural elements, which are completely replaced by the concept of constitution [3]. In essence architecture is the combination of geometric elements such as point, line, face and block. Simple geometry is often taken as the prototype, through deformation of the prototype, segmentation and reorganization of the prototype, or a combination of multi-geometry to form new architectural geometries. Therefore, although modern architecture is to be more diversified, and there are more irregular geometries in architecture, such geometries can still be expressed by the Euclidean geometry, with the essence not being changed. (Figure 1)

Whereas the variety of shapes that could be treated by traditional geometric methods has been rather limited, modern computing technologies have led some geometry revolutions. The emergence and development of parametric design provide architectural geometry with more

liberalization, more complexity and more varieties, especially more possibilities of generating more curves and curve surfaces in geometry. (Figure 2)

However, the design methods still remain in the traditional way that starts from plane design, section design to facade design. As before, Euclidean geometry can be used to express the architectural geometry, with its nature stayed same. In addition, many types of geometries in nature cannot be expressed in the Euclidean geometry. Fractal, for example, is widely found in many natural structures and format, which does not exist in the Euclidean geometry system. Until the arising of the theory of emergence, the generation and expression of architectural geometry is more naturalized.

Figure 1. The villa savoye

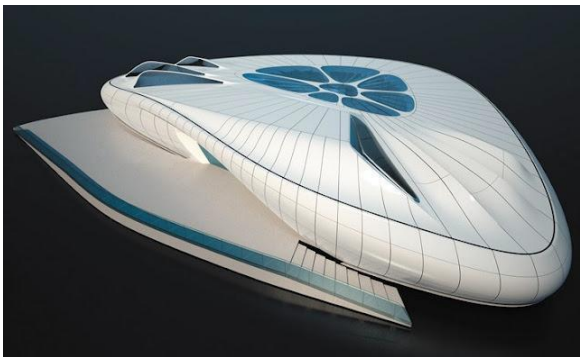

Figure 2. Channel exhibition pavilion in Hong Kong designed by Zaha Hadid

III. Basic Theory and Main Contents of Emergence

A. Definition of Emergence Theory

In the 1950s and 1960s, with the development of social information technology and complex thinking, complexity theory was gradually formed and developed. The emergence theory gradually began to take shape. In the 1990s, on the basis of the "complex adaptive system" (CAS research), John Holland completed the book "Emergence from Chaos to Order ", in which "emerging" was described as a cross-disciplines, with the scientific theory of the universal expositions of the initial system.

As Francis Heylighen pointed out, “emergence is a classical concept in systems theory, where it denotes the principle that the global properties defining higher order systems or ‘wholes’ can in general not be reduced to the properties of the lower order subsystems or ‘parts’. Such irreducible properties are called emergent”.

B. Main Contents of Emergence Theory

The arguments put forward by Holland build a general framework of the theoretical studies of contemporary emergence, which mainly include the following contents:

1) Universal: the “emergence” is a common phenomenon occurring in many seemingly unrelated areas. Biological phenomena such as the growth of seeds, the fertilized egg, ant activity, neural network activity is one type of emergence; Non-biological phenomena such as chess battle, electromagnetism, running of the Internet, running of the global economic system, shares similar characteristics of emergence.

2) Cluster Effect: the emergence of all kinds of different things or systems share the similar characteristics that “the behavior of the whole is much more complex than the behavior of the parts” and “simplicity can generate complexity”. Through the “cluster” fabrication and following a few rules, the basic unit or individual phase can generate very complex results.

3) Restricted Generation: the emergence is a “restricted generating process”, and put forward elements and the dynamic level of restricted generation. “Restricted generation" includes three elements: 1. A basic unit or individual; 2. Rules for activities; 3. Complex inter-effect between the basic units or individuals in the system. In the emergence process, under the domination of certain simple rules, the basic units or individuals in the system, as “subjects”, constitute complex non-linear interactions, and through a complex interaction, generate “the whole is greater than the sum of its parts” or “simplicity generates complexity” phenomena. The interactions between units or individuals in the system share “acentric” or “self-organized” spontaneous characteristics. “Restricted generation” in emergence is a dynamic process with system levels. Some complex systems from “restricted generation” become the basic unit or subsystem which will consist of greater and more complex systems.

4) Internal and External Factors Interaction: emergence of things is limited by not only internal rules and interactions between basic units or individuals, but also the external environment. It is the complex interactions based on internal and external factors.

5) Adaptability: the adaptability of the system proposed by Holland is in a broad sense, including an instant reaction, a certain time of learning and improving, long-term evolution and other forms.

6) Modeling: model construction is the research subject of the emergence. Through computer simulation of a variety of emergence phenomena, understanding, prediction and regulation grasp of emergence can be achieved. With digital abstract and figurative characteristics, computer models can be more specific to simulate the emergence of different things or system status, and can control a variety of conditions and changes.

IV. Influence on Architectural Geometry by Emergent Design

Peter Testa and three other authors describe emergent design as an approach to architectural design that is characterized by several fundamental principles:

- In order to comprehend the complexity of a contemporary design scenario numerous situational factors of a scenario must be identified and their inter-relationships must be well understood even though they may not be well defined.
- An effective solution to a complex design scenario is achieved through a non-linear process of bottom-up experimentation involving independent, related or progressive investigations into architectural form and complex organizations. This interactive process increasingly builds a complex solution which considers the numerous complicated, interdependent relationships of the scenario.
- A complex solution derived in such a bottom-up, investigative style is advantageous because it retains explicability and has the flexibility to be revised in any respect appropriate to a change or new understanding of the design scenario.
- Computer software is an excellent means of performing bottom-up architectural experimentation because, despite a simple specification, a decentralized, emergent software simulation can yield complex behavior, exploit graphics capability to model organization and pattern, can be written flexibly so that alternatives can be quickly examined.

One of the most significance influences by emergence theory on architecture is that it requires a qualitative change to design methods, namely the emergent design strategy. This transformation of thinking produces changes to the emerging of architectural form, with influence on generation and characteristics of architectural geometry.

A. Influences on Generation Methods of Architectural Geometry

1) From Top-down Design to Bottom-up Design: Before the emergent design, “top-down” design is the dominant design method, in which the overall form is designed at first, and then gradually more in-depth detailed parts are design. With the development of computer technology and in support of the emergence theory, architects can test operation conditions and rationality of the micro-units after gathering through computer simulation, generating dynamic results that respect the individual needs and meet the complexity association in self-organization methods. Such approach not only allows bottom-up design approach to be expanded, but also enables the design and generation of architectural geometry to be achieved from parts to the whole, from units to groups.

2) Design of Process Becomes a Core Issue: emergent design requires a transition of the thinking pattern of design, which concerns more about the process of design. Such transition brings the same influence on the design of architectural geometry as well. It is the description of the boundary conditions and rules of a process, rather than the simply geometric description, which forms the core issue of architectural representation. Emergence converts architecture from “results” to “processing”. Alejandro Zaera Polo once said: "We introduce a continuous development process in the design, which is not just a form or an image. We allowed the growth, to wait for the emergence of the project, rather than stick to the reproduction of the traditional mode of or invention from the sketch.” [4] Design becomes an endless process of evolution once started, which do not need to rely on external control. Architect can design in an environment of morphogenetic simulation, summarized from the law of form and stimulation of variation for natural selection to optimize the best solution. This design approach provides possibility of generating infinite kinds of forms, leading to the liberation of architects’ imagination. It also provides more liberalization and diversification for architectural geometry design.

3) Internal and External Factors Interactively Affect the Formation of Architectural Geometry: In emergent design, both internal and external factors interactively affect the formation of architectural geometry. Taking into account the internal and external factors interaction, geometry is designed as a complex morphological system, as comprehensive results of the variety of complex factors in the external and the variety kinds of internal mechanism and demands. In the design, a variety of internal and external factors are set as a parameter or parametric value, and the computer is used to generate the emergence of architectural form, so that the geometry will be adaptive to the external environment, a variety of conditions and internal dynamic requirements. For this reason, the design of architecture geometry will carry more information and will also have more effects.

4) Computer Simulation and Modeling: As the emergence theory emphasizes the importance of the model, the formation of the architectural geometry will also be heavily influenced by the impact of modeling, both in the computer and in a physical way. Physical modeling is a good way to test and improve the concept, space, structure and material; while computer modeling and simulation can explore a variety and crossing methods of generation forms by setting the limited generation rules and adjusting the interaction between the subjects in the main system, therefore achieving the optimized selection of architectural geometry more intuitively from a number of simulated patterns [5].

B. Characteristics of Architectural Geometry in Emergent Architectural Design

1) Cluster Effects: In many emergent designs, due to the break of control from pre-planning or pre-design, a large number of discrete units interact in the non-linear way, under the effect of centerless control and cluster intelligence, to reproduce the spontaneity of the “subject” ’s nonlinear interaction. This will generate complex architectural geometry systems in a “bottom-up” way.

2) Adaptability: In the emergent design, architectural geometry is generated under the influence of internal and

external factors, with the "self-organization" approach to flexibly build the generation and development, based on various parameters of the external environment and internal requirements or parametric analysis of the logic of the program, which can also be adjusted according to the program. Therefore, architectural geometry can be regarded as "organisms", with adaptive ability and self-regulatory function to adapt to external environmental conditions and various internal requirements [6].

3) Geometric Autonomy and Unpredictability: Emergent design deals with variable relationships rather than results. Therefore, geometry is the autonomy production of the setting program, the result of which is unpredictable. The core content of the emergent design is a geometric operation of the prototype to meet the target of design. In such process, what architects operate is to control the generation rules of the prototype and a set of various parameters, rather than the form itself. Therefore, the results of such operation are often infinitely number of solutions rather than a single solution.

4) Complex Geometries with High Resolution: The concept of emergence in architectural design is a research on complexity in architecture. Such complexity is a dynamic, stable and orderly structure, which is away from equilibrium. This structure shows the behavior of infinite diversities. The complex mathematical relationship for complex geometries with high resolution exists due to the use of computer technology as well as emergence theory. Such complexity is just like the variety of complex composition and microstructure in nature, which is beyond the usual cognitive experience. Logistics behind the design can be very sophisticated. Complicated parameters and high-level operations by computer can generate highly complex and multi-dimensional geometries with high resolution, producing blinking and bizarre shapes (Fig.3, Fig.4).

Figure 3. Picture from "Minimaforms" project (From "Minimaforms")

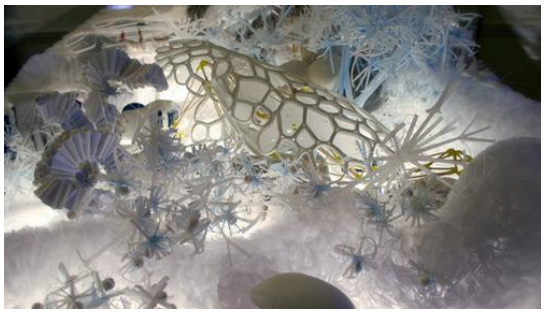

Figure 4. Picture from "Minimaforms" project (From "Minimaforms")

V. Advantages and Concerns

A. Advantages

1) Development of Aesthetic Standard: Due to the complexity of science and involvement of information technology into daily life, the human aesthetic shifted from simplicity to complexity, from the simple, symmetrical, and regular artificial geometry to complex, chaotic, self-similarity natural forms gradually. Emergent design is widely promoted in architecture as a design strategy is human's pursuit of individuation. In today's society, the architectural merits of the monument such as "abnormal" forms and "scream" forms are emerging, and the "spectacle" has become the darling of the culture of the consumer. Through emergent design strategy and with the help of advanced digital technology, avant-garde architects create architectural wonders one after another, to meet people's advancing aesthetic-psychological need, which also conveys the aesthetic qualities of today's architectural design and technology [7].

2) Architectural Geometry Becomes More Adaptive to the Environment: Whether the new geometry and the potential of new design methods of emergent design can bring more value to the generation of architectural forms depends on whether the setting generation rules can be combined with the real external factors faced by each design process. In emergent design, logic of generation should be consistent with integrity and environment. By adjusting rules in order to adjust the dynamic system, it can be adapted to greater environmental systems.

B. Concerns

1) Design should Not Be Separated from Actual Function and Construction: Design should not be out of the actual function and construction. Architects should not be too addicted to the pursuit of virtual images on the computer, of the relationship between the advocate algorithm and magnificent form inquiry, ignoring the actual construction. In fact, the influence of the emergent design should exist at various stages in architecture, from the generation of the design prototype, physical evolution, and construct a logical, component processing to site construction. If the unique architectural can be constructed in reality, its geometry will be more meaningful.

2) Architect should Not Be Replaced to Design and Decide Architectural Geometry: "emerging" is a way to present some results rather than a way to take away designer's creativity. Even though it may be a fundamental subversion of design ideas and design patterns, emergent design, after all, is only design strategy, whose significance is only involvement rather than the substitute for architects. Architects' involvement is required for the setting of initial rules, defining conditions and choosing final geometric forms through the filtering modes. Therefore, no matter what level design tools will reach to, the architect's duties like designing and choosing geometric forms, can never be an alternative.

3) Architectural Connotation Should Not Be Eroded in Geometry Design: The essence of architecture is the space

for people and its most fundamental characteristic is to satisfy people's material and spiritual needs, with various meanings of human's activities. The creation of an ideal environment is expressed in specific spatial organization. Such expression is attached to people's values and ideals of life, and different aspects of people's real lives. In this way, the characteristics of architectural geometries are generated, which also constitute the essence of architecture. Any architectural geometric formation will lose its meaning if not meeting the nature of architecture. Emergent design should not focus too much on the form and appearance, nor give up the connotation of building ontology, thereby bring more meaning to architectural geometries.

VI. CONCLUSION

In conclusion, emergent design in architectural geometry need to be based on a right analysis of the environment and design proposal of the project, on the proper choice of logic or algorithm after deep research, and on avoiding the negative issues for concerning in design procedure. In this way, the generation of architectural geometry can be more logic and close to nature, with more intelligence, adaptability and fantastic original forms in geometry. Therefore, emergent design in architecture can generate positive influences on architectural geometry, if utilized in a reasonable and logic way.

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