Teaching of Generative Design and Its Profound Influence

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Abstract. The paper presents the teaching process inducting students who knew little about computer programming and concept of generative design originally into theoretically comprehend and ability of computer programming researcher of generative design. Meanwhile, some tools based on principle of ‘Complex Adaptive Systems’ are introduced in the paper.

Keywords: Complex Adaptive System; generative design.

The generative design, which is one of the very important branch in the CAAD research and shows originality for architectural design, will certainly extend the methodology of architecture. Unfortunately, generative design teaching integrated multidisciplinary collaborative thinking in unconventional ways is currently lacks methodologies and teaching experience in Chinese universities. All the available books of computer science related to generative algorithm, such as computer graphics, computer algorithm and computer programming are originated from mathematics, and they are inapprehensive fields for Chinese architecture students. In principle, through the optimal combination of relative algorithm and architectural elements, methods of generative design can edify architects’ inspirations, which is difficult or impossible in traditional approach. It is a creative system tends to practice in art, and transforms the generating system into a new production instrument.

CAS Based of Generative Design Teaching: Upside-down Thinking Methods

Generative design needs designers transform relative algorithms and make full use of infinite storage power of computer to the generative implement of which the computer programming is indispensable. Architects must mobilize the efficient performance of computer; excavating the proportion in architecture that will successfully fulfill by computer; seeking for both differentiation and compounding between programming strategy and their professional experience. They need to lucubrate into the processing core of computer program, meanwhile, probe into the relevant programming algorithms. Consequently, transitional or ultimate frame of results were exported from tools of generative design. The exploration requires supports from multiple disciplines rather than only the field of architecture and it participates in architectural design at the early stage of architectural design process. Architects must be aware of both architectural mechanism and datum transform of computer program, and bring forward mutual solution for the architectural task.

Based on the model and theory of the Complex Adaptive Systems (hereinafter referred to as CAS), as well as the coding practice and pedagogic research, our teaching tries to work up a system of framework and research platform for the new methodology of architectural design. The fundamentals and programming practice, such as Cellular Automata Systems,
Genetic & Evolution Algorithms, Multi-Agent System and etc, which constructs main algorithms of CAS, were explored their characters of thinking in process of translation from generative art to the field of architecture (see fig. 1). Integrating scientific keystone of architecture and computer science, the teaching of generative design applies to the research method combined with architecture analysis, theories study and computer programming. Meanwhile, taking the advantage of research approach from Chair of CAAD, ETH Zurich, analyzing of evolution mechanism of generative art and domestic situation of architectural design, the fundamental frame based on CAS of generative art in architectural design was established. Furthermore, the methodology will be extended to other aspects of Architecture.

Generator design differs from traditional design approaches, and designers don’t interact with his theme such as materials and products directly but via computer generative tools. The thinking mode of generative design is not only the abstraction from traditional artistic creation but also an impregnation of philosophy of mathematics and symbolic logic, and productions of it are immanent to the variance and reproduced. **Generative design requires architects to survey the relative element in architectural design, which manifest architectural design system as an accommodating system that mutually cooperate with other architecture of agents via translating the modeling process form perspective of architect-oriented to angle of architecture-oriented. CAS model in architectural design extracts diversiform genre and tremendous amount of architectural essentials into congregation of agent that materialize the characteristic of Complex Adaptive Systems. Accordingly, all agents of architecture appear to be ‘unconscious’ and ‘selfish’, while in a whole they take on the real nature of Complex Adaptive System, and the integrated performance transcends the accumulation of a single agent. As a new way of research, CAS models will find its broad foregrounds in architecture of generative design.**

**Process of Generative Design Teaching**

Many problems existed at the first step of teaching generative design, but the most important factor was how to bring the students to understand the concept of **generative design. There is little introductory textbook in the field in China, and any generative cases of design are based on rather vague notions. Frequently, generative design used to illustrating by naming underlying programming paradigms, which is very useful for students to understand its concept and incite their research. Nevertheless, after they implement their issues or tough problems, essential notions and methods are established. In 2006, our teaching cooperation of generative design with Chair of CAAD, ETHZ Switzerland led to a derivation of pedagogic suggestions as an early step on the way towards generative architecture teaching in School of Architecture at Southeast University, China.**

Eleven students attended our teaching research in 2007, and none of them understood the concept of generative design in the beginning. Furthermore, each student knows nothing about computer program. We only could begin our teaching from learning computer program of Flash ActionScript2.0. At the same time, any papers or books from Switzerland, Italy, England and America were translated and researched for the students to understand the
notions of generative design and research methods.

By computer programming, the students’ exercises were based on models from MAS of ‘Cellular Automata’, ‘Genetic Algorithm’ or ‘Multi-Agent System’, such as the case of ‘game of life’ and others. For their final works, the students were divided into four groups, and they finished four different tools showed as follows for generative design. The flowchart in fig. 2 can present the relationship between models of MAS and their final works.

**Tool of ‘Cube1001’**

‘Cube1001’ (see fig. 3) is an extension of generative tool named ‘happyLattices’ achieved by ‘Group2006’. It implements layout of small urban district which the site has orthogonal character. By running evolution, each lattice presented as a building unit space has requirements to get its ‘fitness’ of daylight. ‘Cube1001’ employed algorithms but provided possibilities for developing complex frame and new methodology for early stage in architectural and urban design.

Based on the theories of Cellular Automata, several regulations in accordance with the requirement of architectural design are constituted. In pursuit to represent architecture space, ‘Cube1001’ stipulates the several rules for the states of the ‘Cells’; for instances, ‘Null Space’ which marked with ‘0’, and denotes partial exterior space of buildings (white units in fig. 3); ‘Solid Space’ which marked with ‘1’, and denotes that of buildings (black unit in fig. 3); ‘Constant Space’, which marked with ‘-1’, and denotes the invariable preestablishment of the site before the designer’s execution of the program, such as pre-setting of buildings, roads or rivers. These attributes are immutable for the circulation of programs, yet they infect their adjacent cell space with certain rules (blue unit in fig. 3).

Seeking for the peculiar running formula of the program, our group went through continuous debugging, and eventually established the dynamic processing regulations according to different floors of building, for example, for the ground floor we set regulations as follows:

**Step_1:** Initialize all of the lattices of the site, all the Constant Space remain their preset attributes, others are divided into Solid Space (mark ‘1’) or Null Space (mark ‘0’) randomly;

**Step_2:** Ground on the Step_1, survey all the lattices for whether they answer for these conditions: each lattice has at least one facade open outside, these sides can either be preestablished as Constant Space or be generated in Step_1 as Null Space. The
current cell will turn into a courtyard (Null Space) if there is no facade opened outside.

Second and third floors take different but similar program rules.

Differentiating the space unit of the site and characteristics of the dwelling pattern on the basis of the execution results of ‘Cube1001’, series of residential plan were organized. Such as 1_ABCD, 2_ABC, 2_D and etc (see fig. 4 left). Through operation of rotation or mirror, the overall site of exterior and interior space will be emerged, as shown in figure 5 right.

The Cellular Automata System provides efficient generating methodology for abundant forms and elements of iteration. The next task of ‘Cube1001’ is to take roots in applying model of Cellular Automata into layout of large-scale public architectures and residential areas of high density. The model furnishes the development of large-scale public architectures with design strategies and simultaneously satisfying the demand of high speed and efficiency in the process of architectural design. In comparison with traditional design approach, the model reveals its sensitivity in environment changes for architectural specific function, which enables real projects benefit from it.

‘KeySection’: Simple Genetic Algorithm Based

Applied with simple genetic algorithm, ‘KeySection’ focused requirements on light environments of interior space. With knowledge from field of architectural physics, ‘KeySection’ shows possibilities for computer program to ‘deduce’ reasonable building shapes. By the traditional methods, it will spend much time to ‘optimize’ a suitable shape possessed comfortable interior environments of daylight. ‘KeySection’ applied new approach to design of both interior and exterior space.

The architectural space of courtyard handles a specific efficacy for the interior environments of daylight; moreover, form of section plane of the courtyard is one of the most crucial elements in influencing the lighting demands. ‘KeySection’ start off from the designing of the section plane configuration in courtyard space, and employing simple evolution algorithms to optimize the interior lighting environment as well as the exterior architecture figuration. One of the results that generated by ‘KeySection’ presented in fig. 5.

Based on relative theories from field of architecture physics, the generating tool divides interior space of building into several precisely arranged subspaces (see fig. 6A). After influence of the daylight and reflected light from opposite building are considered, these factors will be transformed to correlating data. The program sets the related goal function for its optimization, and the best resulting solution will be recorded. As presented in fig. 6B, the interface of program and its optimized results which concerned single and multiple courtyards took the

Figure 4
Apartments in whole site ‘Assembled’
As a result contains a 3-dimensional positive physical form and that of negative form of the courtyard (see fig. 7).

With the algorithm of simple genetic, and commence at optimizing architectural section to fit the lighting requirements for both courtyard and interior space, ‘KeySection’ provides a new methodology that take roots in rational mathematic computation, which in return creates optimized architecture space and form by integrating with program practice. The results generated by ‘KeySection’ are the sufficient embodiment of the fact that architecture is an interlaced art of both rationality and romance.
**High Density House Design of Multi-agent Based Generative Tool: ‘HighFAR’**

‘HighFAR’, which based on the principle of Multi-Agent System (MAS), achieved an intelligent generative tool with the focus of layout of high ‘Floor Area Ratio’ (FAR). The tool applies agents to building elements; every agent can find its suitable position automatically in order to reach global high of getting apartments layout of high FAR. During its running time, the influence of sunlight and minimum distance between each other must be considered. The program employs a real project site; but it used an untraditional method for its design.

‘HighFAR’ integrates multi-possibilities and generates high-level residential district planning with a huge superiority. From requirements of architecture, all the buildings must keep a defined distance (for fire protection, sunlight requirement or others), but the distance should be set within a rational distance in order to get state of high FAR. The tool of ‘HighFAR’ employed kinds of attractive and repulsive forces between every two agents until they get a global balance. Each two agents compare distance with a defined parameter of distance. If the distance is less than the defined parameter, the two agents will shift toward opposite directions along the line of the two agents. Furthermore, every agent of building has its sun shadow, and all agents drop their shadows on the ground according to shape and height of the buildings, hence, the shape of the shadows becomes kinds of ‘forbidden zone’ for other agents, which means every other agent can’t be located in the ‘forbidden zone’; otherwise, it can’t get enough sunshine. The number of agents on defined site must be settled as more as possible, which is a condition for generating high FAR planning layout.

The ‘domain’ of each agent, where other agents can’t enter, contains two parts: one part is a radius district which keeps other agents away (Fig. 8A); another part is building shadow district of polygon (Fig. 8B), the ‘domain’ of each agent which standard by ‘forbidden zone’ is the combination of the two parts (Fig. 8C).

Provided that one agent is located in others ‘forbidden zone’, it must move to opposite direction until they get separating state (Figure. 9).

Base on the generative results as a sketch and any other application of software, such as AutoCAD, Photoshop and etc., it is a simple work for architects to implement the remained works of architectural drawing. They are presented in figure 10.

The development of ‘HighFAR’ reflects that generative design is an interdisciplinary integration and innovation. From perspective of computer program algorithm, multi-agent system and simple genetic algorithm are key contents for developing of ‘HighFAR’.

**Real Project of ‘CeilingMargin’**

‘CeilingMargin’ was programmed for a real project of ceiling accomplished in 2007. The students must swap their thinking method between computer programming and practical operation. Applied with CNC machine of laser-cutter for its manufacture, the ceiling was made of wood (component of skin) and steel (component of support). ‘CeilingMargin’ focuses students’ mind both on generative algorithm and final accurate production.

‘CeilingMargin’ focus on the production and manufacture for a ceiling in a lobby of reconstruction project which endures a low building net height. Due to the transformation of architectural function, the repaving of complex pipe network of water and electricity made the lowest net height only...
2.87 metres remained. Without the new ceiling, those disorderly and unsystematic pipes would be exposed with a contemptible figure; further, by using even ceiling will hide those pipes with brought about sense of space oppression. However, by intercalating the ceiling with differentiated elevation, and reasonable avoidance for the pipes, it is an effective choice to drive up net height to the furthest.

After comparison of multiform architectural scheme, a form of curved surface that is displayed in fig. 11A was taken ultimately. The continuous 3-dimensional curved surface casually avoids the pipe nets and crossbeam as it seems, seeking to obtain the average highest of the overall ceiling. It is comprised of equally dissected virtual agent points, which varies in height of z coordinates yet remains a symmetrical change. The girders vertically support the upper arrays of plank slices which are in landscape orientation, where no identical girders or plank slices exist. Because they are piece-formed, manufacture by laser-cutter is conveniently employed.

‘CeilingMargin’ make use of a simple algorithm, nevertheless, by simulating base data of geometry, it overthrow the traditional thinking method of ‘top-down’, in which the programming regulations must be able to manipulate the construction details and its manufacture, and the steps in dealing with script must be independent while mutually related, which eventually formulates complete digital producing chains. The script language takes part in the budget process of the project, where an integrated solution strategy is included.

The setup of the ceiling is carried out by the construction worker under the guidance of the research
group. In order to facilitate the installation, each component was cut an identical number in advance (as shown in fig. 11B2, B3), the members of the research group only need to control the worker’s construction from the process of its assembly. In the process of installation, because of the fragile intensity of the plank slices, planks rupture occurred constantly, the workers has to use glue and bolt to repair the broken pieces (see fig. 11B4). In addition, the error in construction is beyond the precise computation of program, in many conditions, crude yet agile ways of construction were employed to establish the final ceiling of ‘CeilingMargin’.

‘CeilingMargin’ have an uncomplicated program structure, but through programming practice, investigation of architecture material, manufacture of component pieces and installation process, the architecture generating research group acquired much more practice experience than mere programming. On the other hand, the achievement of the ceiling indicates that architectural design stepped into concrete practice form the figure constitution of programming. In the research of ‘CeilingMargin’, application of software is not the ultimate target of coding, as the algorithm will become an inherent tool for architectural design. Design of program and architecture bring out the best in each other, where architects explored new measure for design that will be expansion of the methodology for Architecture.

**Profound Influence of Generative Design Teaching**

Originated from creativity, and incarnated in ambiguity, architectural design, thought as a ‘black box’ operation, is generally reckoned as a sort of program. It is closely bound up with creativity and renovation. The design approach itself is going through the constant vicissitudinous process, along with the intervention of information technology, the revolutionary theories, which systems and techniques made novelty. Besides its production, the methods are going through a transformation as well. In respect of Architecture, visualization process of forms and their elements are integrated in the architectural design, which are constantly threshed among many inquiries. Those who sensitive to new techniques tend to detect new strategies to meliorate their design methods. Generative architectural design combines field of Architecture, Computer Science, Linear Algebra, Computer Geometry, Artificial Intelligence, and Complex Adaptation System etc, integrating techniques and way of thinking, and eventually adopted to architecture design practice. Several generative application software based on models of Complex Adaptive System are being developed recently in our school. As the final results and targets, the powerful generative tool will apply to real estate practice in China.

Science revolution usually betides at the coexistence of tradition and renovation, architectural generative design appeal to a conversion of thinking pattern. The transformation is of compact mutuality with progress in science, which will bring about collective cognition diversification in one field. Based on traditional conception, new theories and models endowing new discipline with connotation call for a brand new way of comprehension.

**References:**

