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STRUCTURAL FORM GENERATION USING INTERACTIVE GENETIC ALGORITHM

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Abstract. Structural form design could be considered as a bi-objective problem which should satisfy both the efficiency criterion of structural engineering and the aesthetic criteria of architects. This research tries to introduce Interactive Genetic Algorithm (IGA) in the problem of structural form design. It combines the structural analysis performed by computer and aesthetic evaluation by architects into a bi-objective IGA process, in order to generate structural forms which are preferred by the architects and at the same time structurally optimal. In this research, the structure generated consists of two kinds of members, truss and beam. Generation and evolution of structure is based on a triangular element composed of several members. Through experiment of the IGA structural form design system, it is found the structure forms are optimized as the evolutionary process proceeds, and the aesthetic preference of architect is also transferred from generation to generation. It is also revealed that the two criteria have mutual restrictions, which resulted in compromised results.

Keywords. Bi-objective optimization; structural form; interactive genetic algorithm; subjective evaluation.

1. Introduction

Architects and structural engineers are working based on different criteria of their own profession in building design process, and the two criteria often conflict with each other. Although structure is considered as one of the main aspects of architecture, it is not easy for architects to employ it as a positive factor that adds value to their design. On the other hand, structural engineers always have to realize ideas of architects which may not be structurally efficient, and they usually act passively in design processes. The confliction of architecture and structural engineering resulted in low efficiency, waste and restriction in architectural creation.

Structural form design could be considered as a bi-objective problem which needs to satisfy efficiency criterion of structural engineer and at the same time the aesthetic criterion of architects. Since architects and structural engineers are thinking in very different ways, it is not easy that someone can employ knowledge of both professions in creation of structural forms. Development of computer hardware and structural simulation software in recent years raises one possibility that computer may assist architects in early stage of design by providing multiple alternatives of structural forms for them.

The interactive genetic algorithm (IGA) method combines the advantage of human in subjective evaluation and that of computer in searching, and provides an interactive method of subjective design. In an IGA process, the designer evaluates a group of design proposals generated by computer by scoring them, then the computer generates new design alternatives based on the scores using genetic algorithm (GA), and then the designer evaluates again. As the interactive process goes on, some preferred designs could be achieved effectively. (Figure.1)

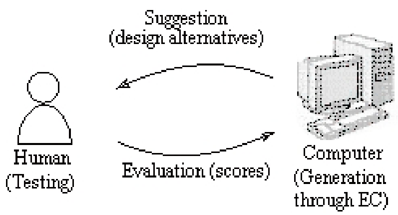


Figure 1. Mechanism of IEC method

In this research, it is expected the IGA method could provide a frame work which allow architect and computer working together on the bi-objective problem of structural form design, in which computer organizes the interactive evolutionary process and performs structural optimization, while architect influences the evolving of structural forms by providing subjective evaluation of them. The structural forms in IGA process are expected to evolve into some alternatives that satisfy both the criterion of structural optimization and that of human subjective evaluation.

2. Past studies

There are a lot of researches that apply IGA in various subjective design problems. Aoki and Takagi (1997) applied it to 3-D CG lighting design, and compared its efficiency in helping professionals and non-professionals. Experiment shows the method effectively works in assisting amateur designers. This result suggests that IGA may help architects in structural form design since they are amateur in structural engineering. Matsushita and Munemoto (2004) use IEC and CG in searching for façade glass attributes which performed ideally in day and night. The colour, reflectance, and transmittance of glass are adjusted according to the designer's subjective evaluation. Huang, Matsushita and Munemoto (2006) try to apply IGA method in Chinese apartment interior design to help the non-professional residents in performing interior design by themselves. IGA process is adjusted to and proved significant in improving searching efficiency. A recent research of Tollena (2010) employed IGA in collecting information for prioritizing the requirements for a software system, and the result outperforms GA.

On the other hand, there are a lot of researches on structural form generation. Xie and Steve (1997) use an ESO method to generate structural form by eliminating low stressed material in an evolutionary process. This method has been developed and applied in real project in recent years. Kawamura and Ohmori (2001, 2002) propose a topology optimization method of frame structures by GA. In order to produce structural topology which is stable and without needless members, the generation of structural form is based on triangle units, not members. Experiment show the method can generate various frame structure topologies and is effective in optimization. In this research, the method of Kawamura and Ohmori (2001) is employed in generation of structural form. Different from the above-mentioned IGA researches that focused on the subjective criterion, and the structural form generation researches that optimize structural form according to structural engineering criterion, the present research is a human-computer interactive process that optimizes structure forms according to two criteria, and intended to find out structure forms that are both structurally optimized and appreciated by the architect who operates the system.

3. Method

3.1. STRUCTURAL FORM GENERATION

In this research, the frame structure generation method proposed by Kawamura and Ohmori (2001) are employed to generate structural form. The basic elements are not members, but triangular elements composed of 3 members in planar situation, or a tetrahedron frame connects 4 nodes in 3-dimensional situation. The advantage of this method is the frame structures generated are guaranteed to be structurally stable and with no needless members that are not properly connected to the main structure.

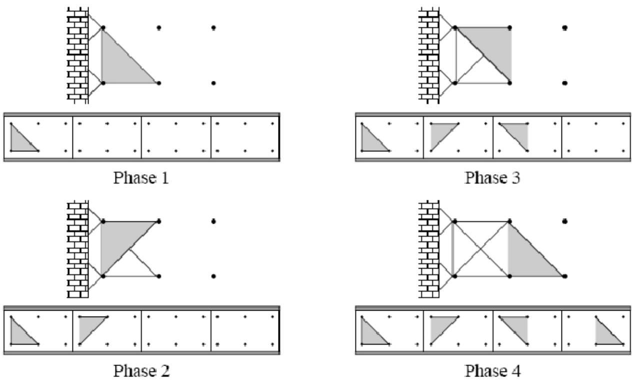


Figure 2. Truss topology consisting of triangles (Kawamura and Ohmori, 2001)

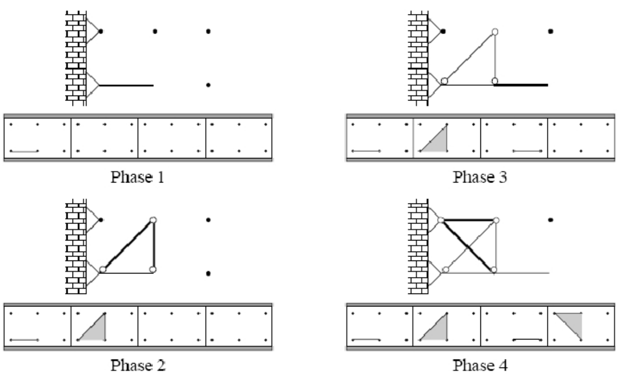


Figure 3. Hybrid topology of truss and beam members (Kawamura and Ohmori, 2001)

Figure 2 shows the generation process of a truss structure. In each phase, the triangular truss element is added according to the condition that two of its nodes are supported joints, or already connected to existing members. Figure 3 shows how a hybrid topology which consists of truss and beam members is generated. When adding a beam member, it must be connected to an existing beam member to make it stable. If only truss members are connected to it, one of the truss members will be changed into a beam member. The generation process ended when all supported joints and loaded joints are connected by the elements.

Structural design is a complex problem, and in this research, the structural forms generated are only expected to be heuristic for the architects in conceptual design stages, and further analysis and design need be carried out by professional structural engineers to achieve the final design results. In addition, the structural analysis in this research only considers elastic analysis of a static load condition in order to focus exploration on the bi-objective optimization process. This simplification also benefits the research by reducing time for structural analysis and making the length of the interactive process acceptable for architects. Structural analysis is performed by Opensees[1]. An iterative process is programmed to call Opensees to find out proper section radius of each member. The evaluation of structural efficiency is based on the weight of the structures.

3.2. HUMAN-COMPUTER INTERFACE

IGA system usually provides a human-computer interface which allows multiple alternatives be displayed simultaneously on computer screen for compare and evaluation. In this research, the interface is developed based on Rhinoceros 3D modelling software. Various structural forms could be displayed in 16 juxtaposed views. The models could also be viewed 3 dimensionally, and each view could be extended to the whole interface to allow detailed observation if needed. A panel for controlling the evolutionary process and input evaluation of structural form alternatives is programmed using C# language (Figure 4). Architect can select their preferred forms by checking the CheckBox.

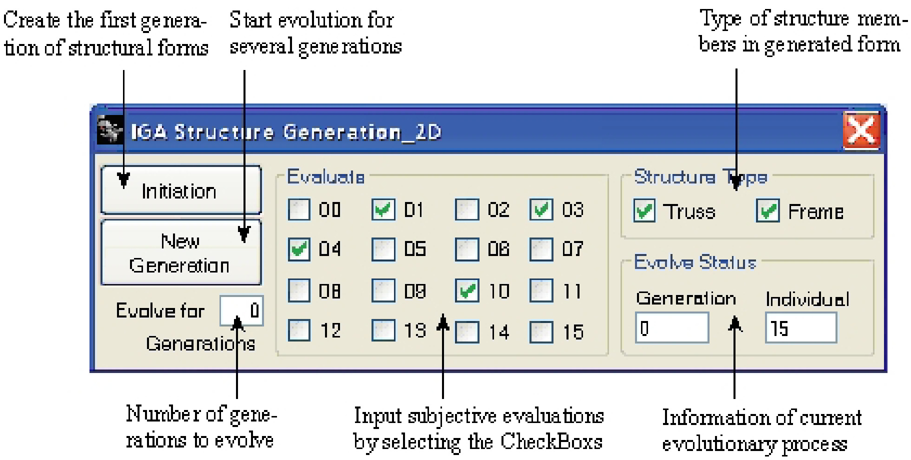


Figure 4. Panel for inputting evaluation and controlling evolution

3.3. EVOLUTIONARY PROCESS OF BI-OBJECTIVE IGA

In process of the bi-objective IGA, both the rational evaluation of structural efficiency by computer and the subjective evaluation of spatial form by architect will lead the evolution. In order to combine these two criteria, the fitness function of IGA takes the sum of both evaluations. In IGA process, human fatigue refers to the phenomenon that human users get tired when evaluating alternatives repeatedly generation after generation, and it is one of the most crucial problems for IGA application. From the research of Kawamura and Ohmori (2002) it is understand the GA optimization could last for hundreds of generations, which makes evaluating of every alternative in the process impossible. In the IGA system, the user can chose to evaluate every several generations to reduce his work.

Another problem of bi-objective optimization is that the two criteria could be independent, and even contradictory, and it will be very difficult to find an optimum solution if this happens. In a common design process, if the architect understand structural design problem very well, it will be much easier to develop a good scheme from both the view of architecture and structural engineering. In this research, the structural forms are sorted by structural evaluation before displayed in the interface. With this procedure, the architect could easily know which alternative is structurally more efficient, and the price he needs to pay for the selected form if it is not the most efficient one. In order not to lose good alternatives in IGA process, the best one is copied directly to the next generation.

4. Experiment

In this research, a structural generation problem is proposed as shown in figure 5. The 12 nodes are set with designated positions, load and support conditions. In the generation process, elements are added to connect these nodes to form a structure. Structural symmetry is employed to reduce amount of computation.

4.1. SINGLE OBJECTIVE OPTIMIZATION

In order to verify the efficiency of the IGA system in structural optimization problem and to provide a comparison for bi-objective evolutionary process, a GA process without subjective evaluation is performed. Figure 6 shows the first and final generation of the structural forms, and figure 7 shows the evolution of structural weight through the process. The white members are beam members that bear axial force and bending moment, and black members are truss members that bear only axial force. It is revealed the structure form evolves effectively, and the weight of the structures decreases significantly in early generations.

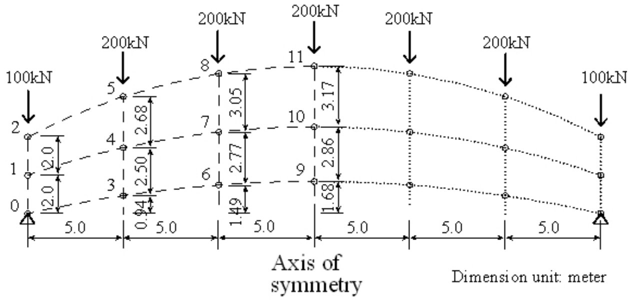


Figure 5. Designated node positions, load and support conditions

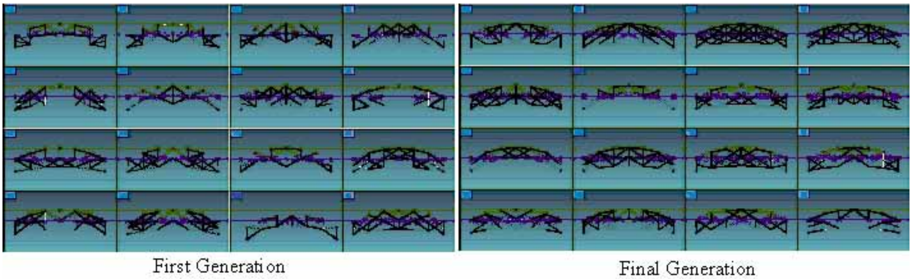


Figure 6. The process of one-objective GA

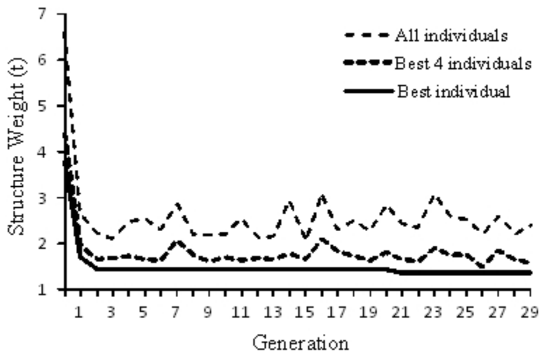


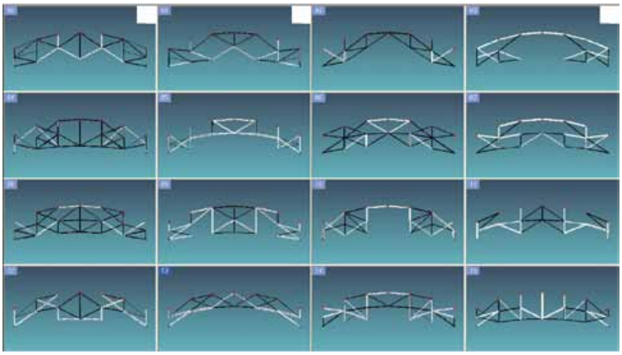
Figure 7. The process of one-objective GA

4.2. BI-OBJECTIVE STRUCTURAL FORM GENERATION

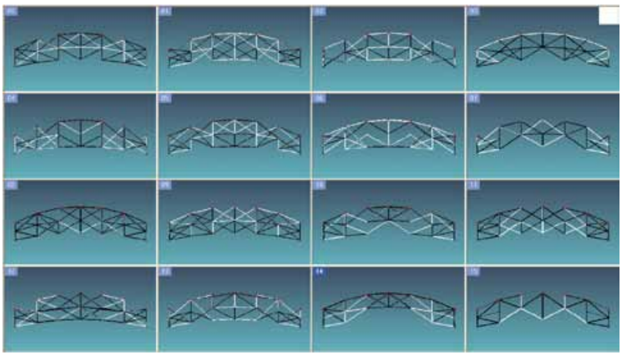
An architectural student is asked to use the system to find ideal structural form for himself. He is told the alternatives displayed are sorted by their weight, so the upper ones in the interface are structurally more efficient than the lower ones. He is also told to select several alternatives in each generation according to his own preference, and the alternatives are expected to evolve towards some results that are good both in structural efficiency and his own aesthetic preference.

The architectural student reports that his objective in the process is to find some structural that has a complete arch form at the top, and he wants the lower-middle part to be empty to provide more interior space. He also tries to avoid selecting alternatives in the lower part of the interface because they are not structurally efficient. The evolution process is shown in figure 8 with white squares marking the alternatives he selects, and the evolution of structural weight is shown in figure 9.

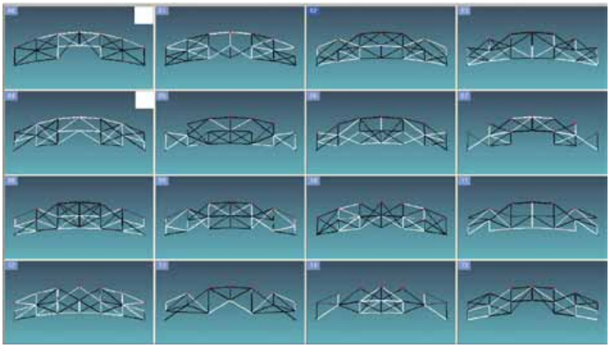
It is found that certain topologies of structural form preferred by the student are transferred through generations (figure 8). At the same time, weights of the structures decrease through the process (figure 9). But since it is a bi-objective process, the two criteria have restrictions on each other. In later generations the two criteria compete with each other. The student does not find a result that ideally satisfies his objective, and the weights of structural forms do not decrease significantly after generation 1.



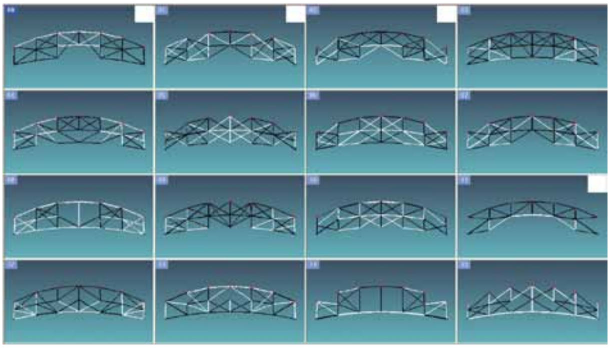
Generation 0



Generation 1



Generation 3



Generation 5

Figure 8. Evolution process of bi-objective generation

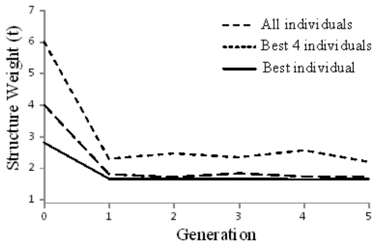


Figure 9. Evolution of structural weight of bi-objective generation

5. Conclusion

In order to help architects in the bi-objective problem of structural form design, this research tries to use IGA to combine the structural analysis performed by computers and aesthetic evaluation of architects. The method of triangular units is adopted to generate structural form. A human-computer interface is developed to allow 3D view of the structural forms and evaluation of them. Through experiments of the bi-objective problem solving process, it is found both of the two objectives affect the optimization, and the two objectives have mutual restrictions. In later generations the two criteria compete with each other, and the achieved result is a compromise of them.

Since understanding of structural problem is important for architects in their creation, the alternatives are sorted before displayed in the interface in order to let the architects know the structural price they need to pay for a certain scheme. Because of this measure, the bi-objective IGA system is also meaningful in the aspect of architectural education. Mutual restriction of criteria is very common in bi-objective problems. It is not expected the proposed IGA system can find a solution for such restrictions. In fact, the system can be helpful for people in understanding such problem, and thus be helpful for people in solving it.

Endnotes

1. The Open System for Earthquake Engineering Simulation (OpenSees) is a software framework for simulating the seismic response of structural and geotechnical systems. It has been developed at the Pacific Earthquake Engineering Research Center.

Acknowledgements

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