Proceedings of the 6th International Conference on
Computation of Shell and Spatial Structures
IASS-IACM 2008: "Spanning Nano to Mega"
28-31 May 2008, Cornell University, Ithaca, NY, USA
John F. ABEL and J. Robert COOKE (eds.)

Computational Morphogenesis
Its Current State and Possibility for the Future

Hiroshi OHMORI*

*Nagoya University
Furo-cho Chikusa-ku Nagoya 464-8603, Japan
Email hero@dali.nuac.nagoya-u.ac.jp

Abstract
Computational morphogenesis is the word that is generally used for expressing those techniques or ways of thought by which the configuration or the system itself of the structures is generated mainly through the usage of the computers, which is realized on the firm foundation of both FEM as a tool of numerical analysis and various kinds of method based on relatively newly developed algorithms for structural optimization. Recently, it has been getting a considerable number of users such as structural engineers or engineering architects for the structural design of the actual buildings as well as the proposal for the architectural competitions. In this contribution, such state-of-the-art around the computational morphogenesis especially in Japan and the future prospect of the computational morphogenesis will be presented.

1. Introduction
From the viewpoint of structural design, it can be undoubtedly said that recent extraordinary rapid development of computers has been drastically changing their position at an unbelievably high speed. We already have had the simulation tools with which even highly complicated structural problems such as those containing geometrical as well as material nonlinearities should be simultaneously involved and, furthermore, even the cracking or the breaking of the materials should be correctly taken into account. Admirably precise computer simulations of the breaking process of reinforced concrete structures are good examples which clearly explain those situation. Moreover, it should be noted that truly innovative achievement in the field of structural topology optimization appeared in 1988, the fruit of which is called homogenization design method achieved by Bensoe and Kikuchi[1]. The author believes that it was really a breakthrough paving the way for utilization of structural optimization into the structural design, where methods based on the topology optimization are indispensable and essential. On the other hand, in almost the same period, Genetic Algorithms, one of the most efficient schemes for the arrangement optimization problem, has been developed and a lot of researches of the application of the algorithm have been started including those in the structural optimization. Genetic Algorithm has very distinctive characteristics such that it can deal with discrete variables with ease and, furthermore, plural solutions can be simultaneously obtained besides the best solution in the large. These characteristics of Genetic Algorithms are important when they are utilized as a tool of the structural design.

In this contribution, the present states of computational morphogenesis is surveyed where the fundamental methods such as truss topology optimization by Genetic Algorithms and both size and topology optimization by extended ESO (Evolutionary Structural Optimization) method are presented and, as the application of those methods, several projects, some of which are actually realized and the others proposed for the international competitions are shown. Moreover, methodology for the life cycle design (LCD) of structures is presented which are realized through the usage of Genetic Algorithms as the arrangement optimization tool in 4-D space, that is, the four dimension composed of three coordinates in physical space besides time. This is also a part of Computational Morphogenesis and the significance of LCD hereafter is expected to grow for the near future.

2. Computational Morphogenesis of Structures

2.1 Truss Structures

Genetic Algorithm (GA) is one of the most effective optimization methods, which enables us to handle discrete variables. Owing to this characteristic, we can handle the standardized structural elements from which the optimal combination for the objective structures is investigated. Another advantage on using GA is that it gives pleural optimums beside the single best optimum solution, characteristic of which is very suitable for the process of structural design because the users or the designers can choose their preferable solution from those solutions proposed through the optimization process. Figure 1 shows the typical results for the truss dome and the truss roof structures, where the topologies as well as the combination of those structural elements are generated through the optimization process by GA (Kawamura *et al.* [3]).

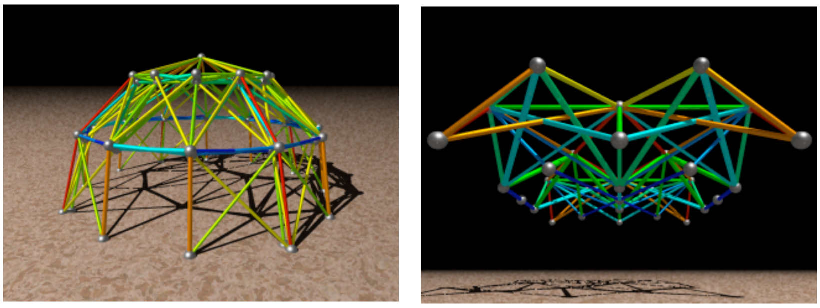

Figure 1: Truss Dome and Space Truss Structures Generated by GA

2.2 Continuum Structures

The author has proposed the Extended ESO (Evolutionary Structural Optimization) method by which we can obtain the solutions satisfying the constraint conditions required from the viewpoint of planning or other non-structural requirements. The Extended ESO method has been developed through several modifications on the original ESO method which has had been proposed by Xie and Steven [5]. Figure 2 shows the result of the shell structure having the minimum volume subjected to the concentrated load at the apex, where the limit of the displacement in the vertical direction at the loading point is provided (Cui *et al.* [2]). As shown in the figure, we can see that pursuing the minimum volume structure, through the use of the Extended ESO method, generates the organic configuration.

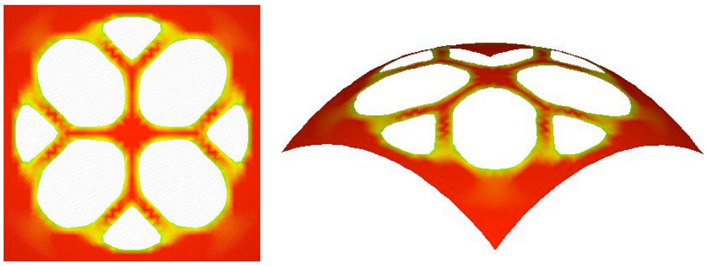

Figure 2: Shell Structure Generated by Extended ESO Method

The Extended ESO method which was originally developed and utilized for 2-D problems has been extended to the 3-D problems. In Figure 3, 3-D arch structure supporting the upper plate subjected to equally distributed load is shown, which has been generated through the 3-D extended ESO method.

On the other hand, the proposed Extended ESO method has been already applied to the structural design of the actual office building structure, the walls of which are designed based on the configuration generated by the extended ESO method as the initial design. Figure 4 shows the wall of the building as well as the intermediate process of the Extended ESO method (Ohmori *et al.* [4]), where we can see how the wall configuration has been changed through the modification process.

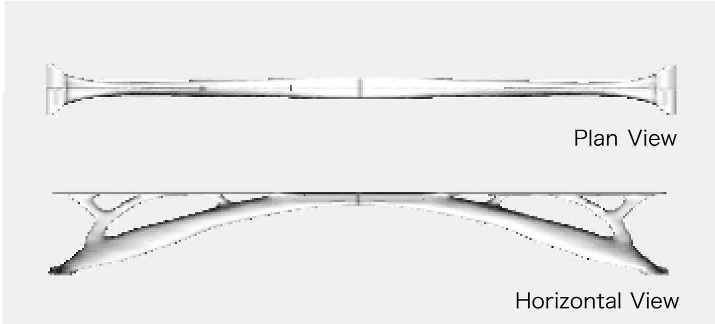

Figure 3: 3-D Arch Structure Generated by Extended ESO

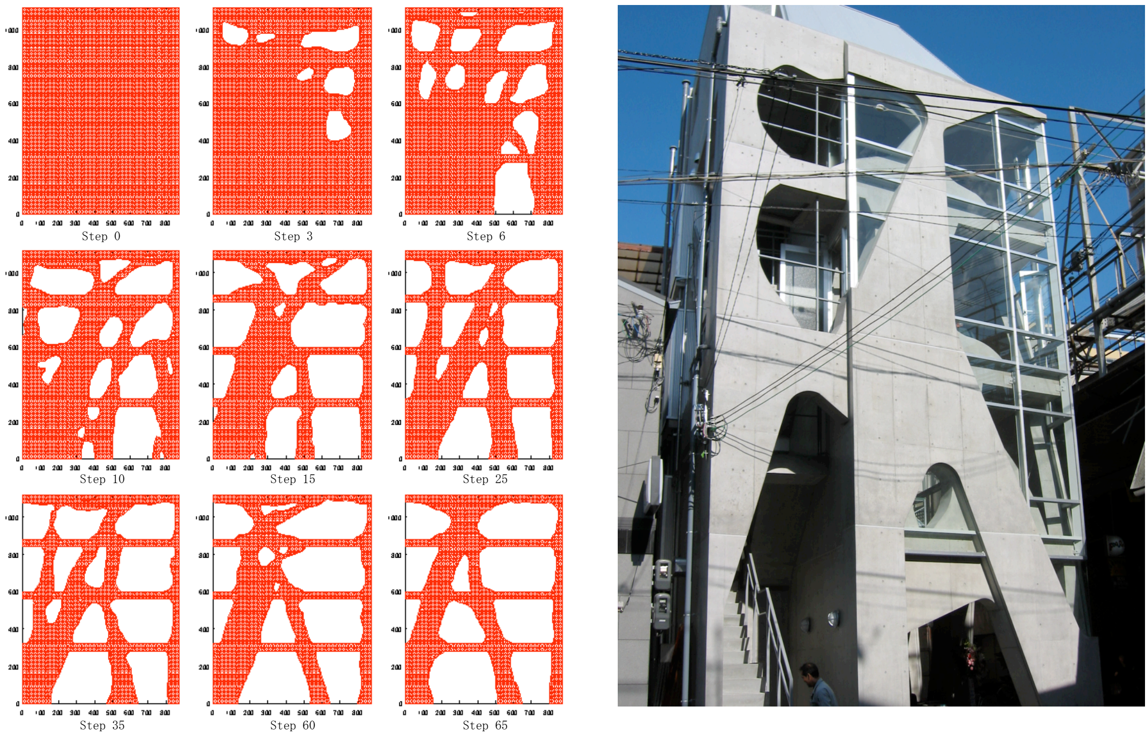

Figure 4: Structural Design of Wall through Extended ESO (Akutagawa Puroject)

3. Life Cycle Structural Design

It can be pointed out that most of conventional structures have been designed so that they can meet the requirements mainly coming from the initial performance from the viewpoint of their function, appearance as well as cost. However, the recent situation surrounding our environment has been drastically changing, that is, all industrial products should be produced as those whose impacts on the surrounding environment are reduced and controlled as possible as they can. Design of the structures is not an exception. Namely, we, structural engineers and designers, are requested to develop the design processes by which so-called sustainable structures are realized.

In this contribution, the authors propose the design method of the sustainable structures through the use of the optimization method by genetic algorithm, by which the optimal combinations of the structural elements as well as the optimal scenario of repair and preservation of the structures are obtained as the optimized solution (Figure 5). Generally, there are several objectives which have a trade-off relationship each other in life cycle design problems such as cost and structural performance. In those cases, the multi-objective optimization method can be effectively utilized and the multi-objective genetic algorithm is probably the most suitable technique for the

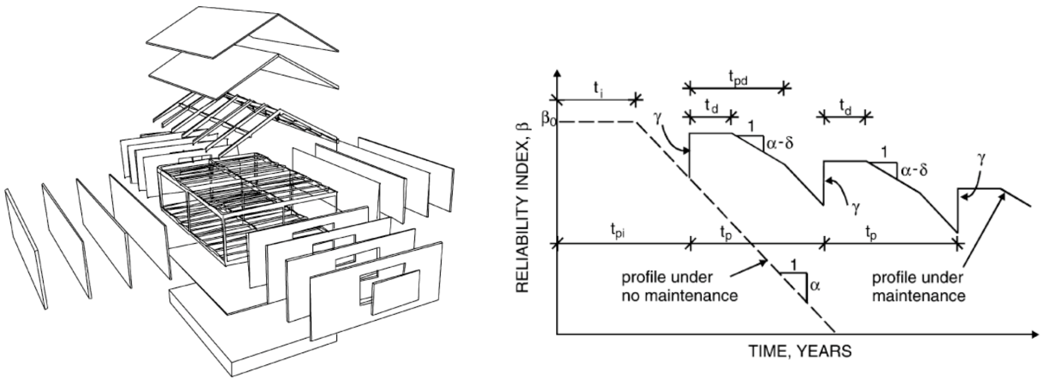

Figure 5: Life-Cycle Design of Structures

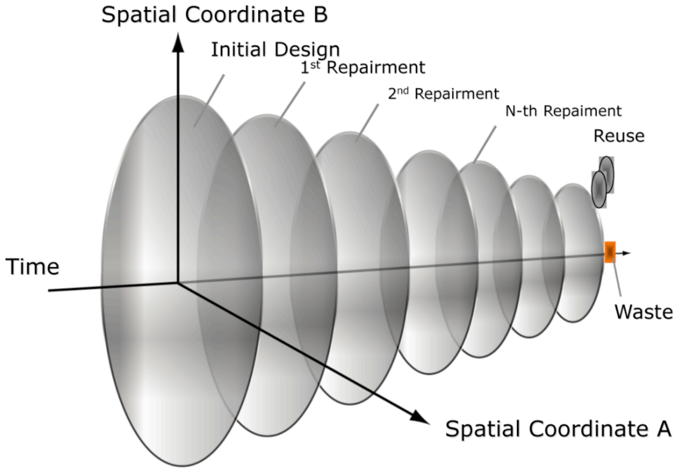

Figure 6: Arrangement Optimization in Time-Space Continuum

present problem. Figure 6 shows that the present multi-objective optimization problem toward the sustainable structures can be conceptually resulted in the optimization problem of the arrangement of the variables connected with the combination of structural elements as well as the time interval scheduling of the repair and preservation.

References

[1] Bensoe MP and Kikuchi N. Generating Optimal Topologies in Structural Design using a Homogenization Method, *Computer Methods in Applied Mechanics and Engineering* 1988; **71**: 197-224.

[2] Cui C, Ohmori H and Sasaki M, Computational Morphogenesis of 3D Structures by Extended ESO Method, *Journal of the International Association for Shell and Spatial Structures (IASS)* 2003; **44(1)**: 51-61

[3] Kawamura H, Osada S and Ohmori H. Genetic Creation of 3-Dimensional Truss Structures, *Journal of the International Association for Shell and Spatial Structures (IASS)* 2000; **41(3)**: 163-175.

[4] Ohmori H, Futai H, Iijima T, Mutoh A and Hasegwa Y. Computational Morphogenesis and its Application to Structural Design, *Proceedings of International Symposium on Shell and Spatial Structures, Theory, Technique, Valuation, Maintenance, Bucharest Poiana Brasov, Romania* 2005, 13-20.

[5] Xie YM and Steven GP. *Evolutionary Structural Optimization*, Springer Verlag, 1997.