Proceeding of Shanghai International Conference on Technology of Architecture and Structure (ICTAS 2009)

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同濟大學出版社
TONGJI UNIVERSITY PRESS

图书在版编目(CIP)数据

2009 中国上海国际建筑科技大会论文集 = Proceeding of Shanghai International Conference on Technology of Architecture and Structure(ICTAS 2009). 1:英文/中国土木工程学会等主编. —上海:同济大学出版社,2009. 9

ISBN 978-7-5608-4168-7

Ⅰ. 2… Ⅱ. 中… Ⅲ. 建筑学 - 国际学术会议 - 文集 - 英文 Ⅳ. TU - 53

中国版本图书馆 CIP 数据核字(2009)第 174111 号

Proceeding of Shanghai International Conference on Technology of Architecture and Structure(ICTAS 2009) (Ⅰ)

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责任编辑 高晓辉 宋 磊 责任校对 荆 华 封面设计 陈益平

出版发行 同济大学出版社 www. tongjipress. com. cn
(地址:上海市四平路 1239 号 邮编: 200092 电话:021 - 65985622)
经 销 全国各地新华书店
印 刷 江苏句容排印厂
开 本 889mm × 1194mm 1/16
印 张 54
印 数 1—530
字 数 1 728 000
版 次 2009 年 9 月第 1 版 2009 年 9 月第 1 次印刷
书 号 ISBN 978-7-5608-4168-7

总 定 价 360.00 元

2009 Shanghai International Conference on Technology of Architecture and Structure

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Preface

The 2009 Shanghai International Conference on Technology of Architecture and Structure (ICTAS 2009) is held in Shanghai, China, October 15 ~ 17, 2009, hosted by Division of Civil Hydraulic and Architecture Engineering of Chinese Academy of Engineering, China Civil Engineering Society (CCES), Tongji University, Chinese State Construction Engineering Corporation.

As World EXPO 2010 will be held in Shanghai, many new types of structures are expected to be constructed for the EXPO, the theme of this conference is "Theory and Practice of Large-scale Public Building and Infrastructure". It supplies a platform for experts, professors, scholars, engineers and technicians to exchange the knowledge and experience for large-scale public buildings and infrastructure planning, design, construction and management, reveal the technology achievements in construction of large-scale public buildings and infrastructure, improve the city construction level and push forward the process of city sustainable development with keynote lectures, technical sessions and technical tours.

This conference proceedings volume contains 172 papers from over 150 contributors, including the invided keynote papers by some very prominent experts in their respective fields. It provides an opportunity to all contributors to share your latest research works and findings. The major areas covered at the conference and presented in this volume include:

- Planning, design and construction technology of large-scale public building and infrastructure;
- Construction management and informatization construction technology of large-scale public building and infrastructure;
- Strengthening and retrofit of large-scale public building and infrastructure;
- Application of green building technology;
- Application of new structure style, technology and material;
- Large-scale public buildings, infrastructure construction and the city sustainable development

It is our pleasure to present to you the proceedings of ICTAS 2009. Furthermore, we would like to thank all the keynote speakers who make splendid presentations, authors who present papers, participants who take part in the conference, whose support and encouragement is essential in facilitating this conference ICTAS 2009. Finally, we wish all delegates an enjoyable and unforgettable conference, a pleasant fellowship and conviviality gathering amongst friends and colleagues.

Conference Organizing Committee of
2009 Shanghai International Conference on Technology of Architecture and Structure

CONTENTS

Structure Engineering

Computational Morphogenesis
Present State and Perspective for the Future

OHMORI Hiroshi
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Abstract Computational morphogenesis is the word which is generally used for expressing those techniques or ways of thought by which the configuration or the system 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 architects for the structural design of the actual buildings as well as the proposals 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 extraordinarily rapid development of electronic computers has been drastically changing their position, that is, from tools to partners for the structural design. We already have had the numerical simulation tools with which even highly complicated structural problems can be solved, such as those in which the geometrical as well as the 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 has appeared, the fruit of which is called homogenization design method achieved by Bensoe and Kikuchi[1] in 1988. The author believes that it was really a breakthrough paving the way for utilization of structural optimization into the structural design, where the methods based on the topology optimization were essential as well as indispensable. On the other hand, in almost the same period, Genetic Algorithms, one of the most efficient method 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 such a distinctive characteristic that it can deal with discrete variables with ease and, furthermore, more than one moderately good solutions can be simultaneously obtained besides the best one in the large. These characteristics of Genetic Algorithms are very essential when they are utilized as a tool of the structural design.

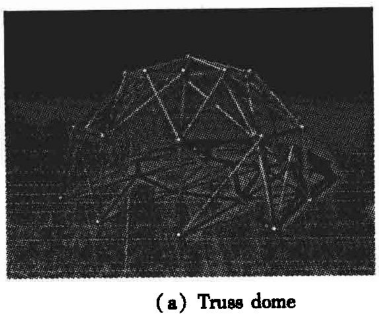
In this contribution, the current state of computational morphogenesis is reported from the works done by the author, where the fundamental methods such as truss topology optimization by Genetic Algorithms and both size and topology optimization by the extended ESO (Evolutionary Structural Optimization) 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 competition 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 dimensions composed of three coordinates in physical space besides the fourth dimension, time, which is also a part of Computational Morphogenesis and the significance of LCD hereafter is expected to grow for the near future.

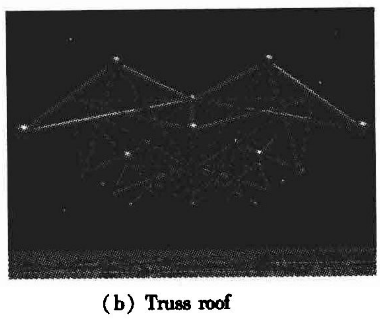
2 Computational Morphogenesis of Structures

2.1 Computational Morphogenesis for Truss Structures

2.1.1 Development of Numerical Tool

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 searched. Another advantage on using GA is that it gives us plural 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(s) from those proposed through the optimization process. Fig. 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 as the optimum solutions through the optimization process by GA (Kawamura et al. [2]).





(a) Truss dome (b) Truss roof

Fig. 1 Truss structure generated by GA

2.1.2 Structural Design of Truss Structure for Optical-Infrared Telescope

The optical-infrared telescope is one of the typical telescope observatory system especially used for the extremely large telescope such as one of the largest one in the world, Subaru in Hawaii first-lighted in 1998, the main reflector of which weighs 22.8 tons and the effective diameter is 8.2m. The astronomers have been actively continuing their scientific observation of the universe and those newly found knowledge begin to make the astronomers to desire for the higher efficiency and higher resolving power toward further understanding of the universe. Under these circumstances, there are several plans of construction of the extremely large telescope in every region of the world. For one of those projects, we have been dealing with the construction project of 3.8m in diameter optical-infrared telescope at Okayama in Japan.

The optical-infrared telescope is as typically shown in Fig. 2, where a large partial spherical mirror which is 3.5m in diameter, weighs more than 4 tonf. In its usual operations, the large partial spherical structure are planned to turn around both the vertical as well as the horizontal axes. Therefore, the supporting structure of the large mirror has to support those observatory facilities safely as well as stably. In addition to those functions, supporting structure is requested to be as light as possible so that the operation of the telescope can be done smoothly and preferably allow the specular reflector to displace in a homologous manner under the gravity load during the star watching.

Fig. 3 illustrates one of the optimal truss structures realizing good homologous displacements as well as requirements for lightness, which is obtained through the optimization procedure by use of GA.

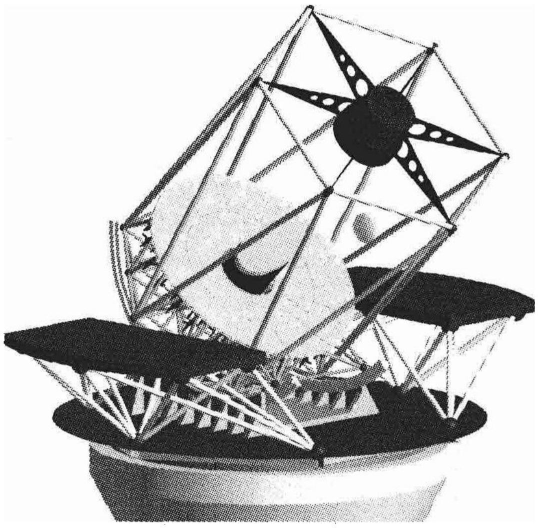


Fig. 2 Optical-infrared large telescope

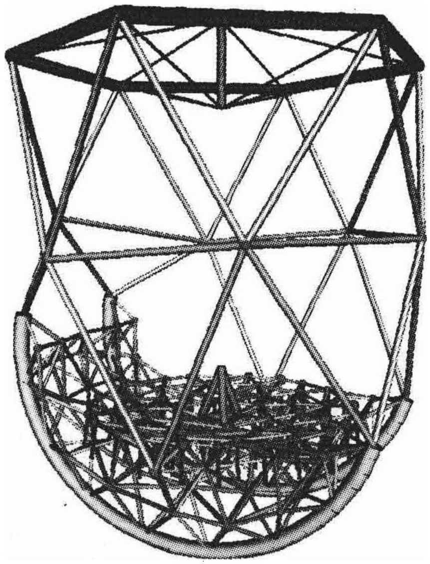


Fig. 3 Truss structure with homologous deflection for optical-infrared large telescope

2.2 Computational Morphogenesis for Continuum Structures

2.2.1 Development of Numerical Tool

The author has proposed the extended ESO (Evolutionary Structural Optimization) method by which we can obtain the solutions of structural systems satisfying the constraint conditions required from the viewpoint of planning or other non-structural requirements besides structural rationality. The extended ESO method has been developed through several modifications on the original ESO method which has had been proposed by Xie and Steven[3]. Fig. 4 shows the result of the shell structure having the minimum volume subjected to the concentrated load at the apex, where the

Fig. 4 Pin-supported partial spherical shell with rectangular plan generated by extended ESO method

limit of the displacement in the vertical direction at the loading point is provided (Cui et al. [4]). 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 which seems to be out of human foresight.

The extended ESO method which was originally developed and utilized for the 2-D problems has been extended to the 3-D problems. In Fig. 5, 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.

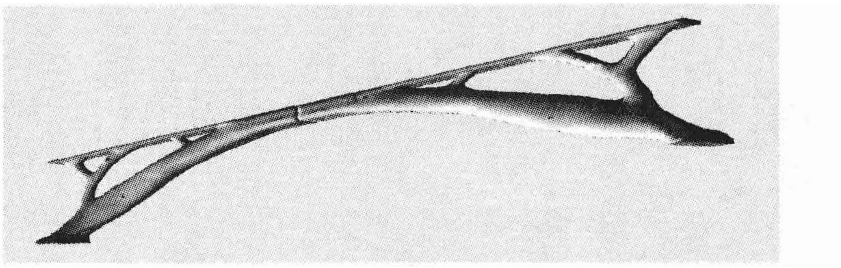


Fig. 5 3-D arch structure generated by extended ESO method

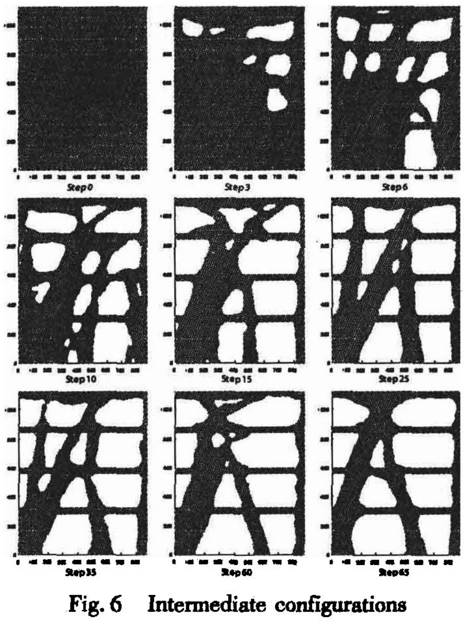


Fig. 6 Intermediate configurations

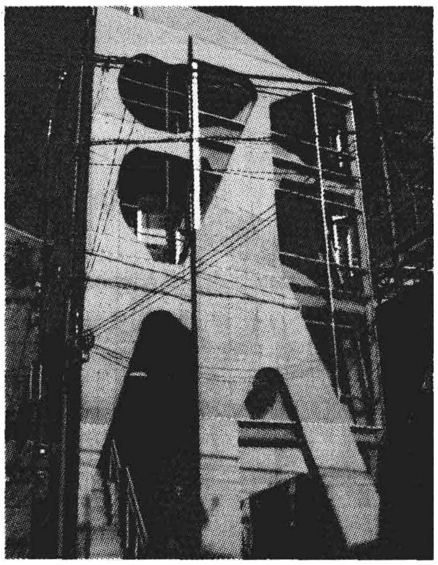


Fig. 7 Akutagawa project

2.2.2 Application to Structural Design

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. Fig. 6 and Fig. 7 show the wall of the building as well as the intermediate process of the extended ESO method, where we can see how the wall configuration has been changed through the modification process.

On the other hand, the extended ESO method developed for 3-D problem has been utilized for the international competition of structural design. Fig. 8 shows the outline of the structural proposal for Firenze new terminal project having 400m in its length, 42m in width and 20m in height, where the light weight aircraft can take off and land on its upper portion and complex facilities are to be planned in its huge lower space under the upper huge plate portion. Fig. 9 depicts the evolutional process of the extended ESO method for this structure. In order to save the computational load, the initial structure is taken as shown as step 0 in the figure, which is simply supported at four points. In the evolutional process, one can observe that the structure gradually changes itself toward the final organic structural form.

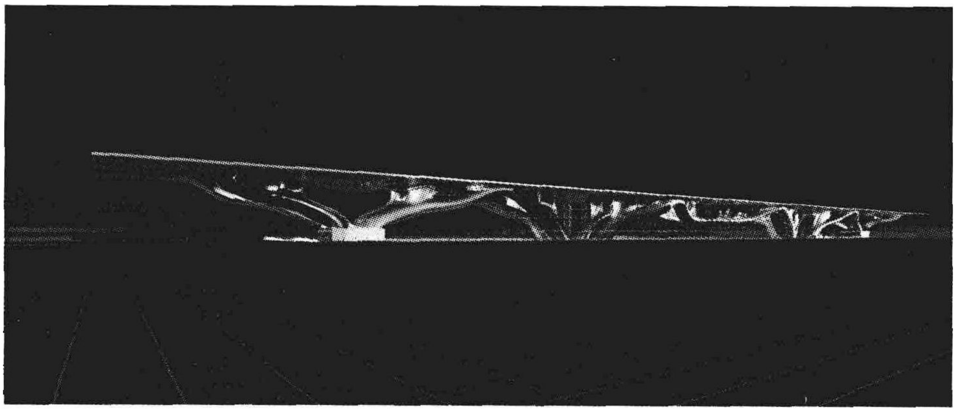


Fig. 8 Proposal for firenze new terminal by extended ESO method

3 Computational Morphogenesis for Life-Cycle Structural Design

3.1 Fundamental Idea

It can be pointed out that most of conventional structures have been designed so that they can meet the requirements mainly for the initial performance just after the completion of the structures from the viewpoint of their function such as appearance as well as cost of construction. 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 be. 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.