Changing Butterfly: a Large 3D Printing Work Based on Structural Mechanics

Kang Qiang Lin, Yang Cui and Chao Hao Su

ABSTRACT
How to realize mechanical butterfly-like shell and design efficient construction details for resembling, posed problems and challenges to the design and construction of a large 3D printing work. Firstly, through analysis of the synergetic mechanism of butterfly-like morphology and structural mechanic of Hypar shell, digital design methods and adjusting modes were well studied. Secondly, based on the features of additive manufacturing, adaptive methods of unit division and construction were proposed and discussed. Moreover, changing modes of lights were tested through the combination of photoelectric numerical control and corresponding details design. As a result, not only the construction of 3D printing work of large scale butterfly-like shell, but also more than 100 new changing patterns of lights were realized.

KEYWORDS
3D Print, Structural Performance, Parametric Design, Shell Structure

INTRODUCTION
In late November 2016, the Guangzhou International Lighting Festival, which is collectively known as the three international lighting festival with Sydney and Lyon, was held in the Flower City Square. The integration and innovation of technology and culture constitute a new proposition.

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Flower City Square, with the fragrance of flower attracting butterflies; 3D-printing is a new green digital construction technology with special modeling crafts and material property, and has shown a fresh visual feast of “butterfly-changing” vision of Guangzhou, combined with lighting and electrical technology.

1. FOCUS AND KEY PROBLEM

Thin shell, an efficient structural form, as far as possible to achieve a larger space with less material, is critical for the compact time of design and construction. Taking hyperbolic paraboloid shell as the carrier and 3D printing as the technical means, realizing the design idea of "Butterfly" and "Changing" will lead to the following key problems.

1) Under the mechanical mechanism of shell structure, how to effectively generate the butterfly texture in the mechanical sense?
2) Based on the special process of 3D printing and specificity of consumables, how to design and build the butterfly according to their characteristics?
3) In a static object, how to achieve "changing"?

2. THE DIGITAL CONSTRUCTION AND COOPERATIVE ADJUSTMENT OF FORCE AND SHAPE

2.1 Two important premises before design and build

1) to build up as much space as possible with less material;
2) The texture of the butterfly must be in the form of mechanical meaning, otherwise the structure may become invalid.

2.2 Qualitative analysis of the relationship between force and shape

Although the structural morphology includes geometric morphology, it is essentially a "mechanical form", that is the combination of form and force, which is derived from the equilibrium shape and force flow, or the form resistance. Therefore, to reconstruct the texture of the shell structure, the key premise is the relationship between force and shape[1].

Implicit arch and cable. Due to the geometry shape, Hypa shell is created by a straight line sweeping along the path of another orthogonal bus, so easily lead to misjudgment of the mechanics: the force is transmitted to the boundary along the straight line. In fact, the laws of physics are not the case, the force is always looking for the most favorable route of transmission: the superposition mechanism of arch-transfer-force and cable-transfer-force is formed in the two diagonal directions. When deformation is produced in an axial compression and tends to collapse, the phenomenon will be prevented by tensile stress on the other axis[2]. The mechanism of implicit "arch + cable transfer force" is an important basis for the design of texture.
2.3 The digital design and adjustment of force and butterfly

1) THE SUPERPOSITION ALGORITHM OF BUTTERFLY SHAPED REGION IN RESPONSE TO MULTIPLE PRINCIPAL STRESSES

Under the condition of gravity load, the mechanical properties of hyperbolic paraboloid shell are different from that of pure compression structure: it shows tensile and compressive regularity in two orthogonal directions. Therefore, the change region of the butterfly texture must be in response to the first principal stress and the third principal stress nephogram, and as a rule to the iterative solution algorithm based on the structural performance. (Figure 1)

2) THE ALGORITHM OF BUTTERFLY SHAPED REGION IN RESPONSE TO FORCE FLOW

The construction of the relationship between the force and the shape is more important in the response to the direction of force flow of the mechanical prototype. The introduction of Tyson polygon algorithm[3] is an effective way to solve the generation of butterfly wing micro texture of the context, but this process must be combined with the main stress vector direction, so that it is more conducive to the transmission of the main stress, maintaining the mechanical mechanism of the mechanical prototype. In this research, a genetic algorithm based on the finite element method is proposed to solve the adaptive intermediate mechanical topological morphology, and to judge the rationality by the first and third principal stresses nephogram.

Figure 1. Butterfly forming from parametric design process based on structural performance and test.
3. DIGITAL DESIGN AND CONSTRUCTION BASED ON ADDITIVE MANUFACTURING

3.1 The main features of additive manufacturing
   1) Printer size limits lead to limited print size.
   2) 3D printing is a layer by layer printing method to construct the object, so different precision, temperature, filling rate and other parameters affect the printing quality and mechanical properties.
   3) The inner hollow forming process is the most innovative and efficient one, which is different from the traditional manufacturing technology.

3.2 Unit division and construction

TOPOLOGICAL ALGORITHM BASED ON MOLDING SIZE
   Taking into account the overall aesthetic factors of the shell and the transfer path of the principal stresses, the results of a number of partition units are calculated by the topological algorithm[4,5], so that the projection size of the element component is controlled within the allowable range of printing.

CONNECTION STRUCTURE DESIGN FOR TENSILE ACTION
   The innovative design of the fastener connection mode, which is made up of eccentric wheel, double pole and rubber ring, solves the difficult problem of the connection between the two components of the edge surface, and greatly improves the tensile strength between the components. The embedded space required by the connection structure is reserved in the form programming process of each unit element, and each structure node is arranged staggered in the thickness direction of the connecting interface through a program to form a resistance bending moment. At the same time, the distribution density of the connection structure is simulated by the digital response to the first principal stress nephogram.(Figure 2)

Figure 2. Process of 3D printing and assembling.
3.3 Lightweight design of internal structure

Reducing weight is of great significance to reduce construction cost. The filling form and parameters of the internal structure affect the mechanical properties of the 3D printing components. Using the method of parametric design and 3D printing software to adjust the hollow structure, and finally to evaluate and optimize the mechanical properties of the different forms of the structure of the circular, grid, honeycomb and so on.

4. PHOTOELECTRIC NUMERICAL CONTROL

4.1 Skeleton mode and scale mode

Changing pattern of the whole butterfly at night, is presented by distinguishing and combination of Skeleton and scale modes of butterfly wings. Skeleton mode from the center to the end of four divergent wings, with more than 2000 micro LED downlight spot lights in an equidistant distribution; scale mode, embedded in the Skeleton, realize the surface light effect of permeability through the light control system of more than 400 independent units. Numerical integration is a key factor to affect the overall debugging and change control mode of lamps, more than 5000 LED lamps are embedded with a separate address code chip, connected to 30 independent controllers through line grouping, and integrated into computer control terminal. Finally, 100 kinds of butterfly changing pattern are designed and debugging through professional software of MADRIX.

Figure 3. Photoelectric numerical control and lighting debugging.
4.2 Wiring and construction
In irregular texture, wiring is a problem of both technology and appearance. The Skeleton mode is independent of serial mode, with reserved holes and slots in the branches which are formed in the process of 3D printing. Scale mode adopts partitioned series, considering both packet controlling and line number reducing. Each scale unit was designed as a "sandwich" structure, flat LED lamp string is fixed between two pieces of honeycomb clamping scales. (Figure 3)

5. CONCLUSIONS
More than 100 patterns of light and shadow have attracted millions of friends and photographers from home and abroad. People stopped to take pictures and share their beautiful photos through internet, enjoying a fresh visual feast! The use of 3D printing and development of numerical control technology, provide a brand-new carrier of organic integration of frontier technology and regional culture.

ACKNOWLEDGMENT
The research described in this paper is supported by Pearl River S&T Nova Program of Guangzhou (201506010038), the Open Funds of State Key Laboratory of Subtropical Building Science (2017ZB13) and Guangdong Engineering Research Center for Modern Architectural Creation (2016AZ03). The corresponding author is Chaohao Su.

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