Review of the research on “structural bionic” method of large sculpture

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Abstract. This paper presented the basic concept of bionic sculpture and summarized the application status of “structural bionic” theory in large bionic sculpture field. Introduced the development trend and challenges of large bionic sculpture and pointed out that the sculpture’s "structural bionic” can bring higher mechanical performance of the new structure and system. The evaluation method and structure design for large bionic sculpture are urgently needed. Finally, prospected the market of the large bionic sculpture.

1. Introduction
Bionic architecture is based on the constitution of some biological function-organization and image, to explore the construction law of scientific and reasonable in nature. Through the application of the research means to enrich and perfect the building, this research can also promote the architecture structure and construction function and reasonable composition of efficient design layout. Architectural bionics believes that the nature already has a corresponding solution for the problems that encountered in the construction of human. It is the main research subject to find and make use of the constitution rules of the biology (including human being) and apply it to the practice of architecture.

As a special kind of bionic architecture, large bionic sculpture belongs to bionic architecture broadly, which mainly focuses on two aspects: “bionic configuration” and “bionic structure”. At present, the “bionic configuration” sculpture mainly focus on the ornamental features and seldom consider the structural stress. The “bionic structure” sculpture focuses on the imitation of the internal constitution of the organism, which promotes the development and utilization of the new and efficient structure form in the field of sculpture.

2. Research status at home and abroad
The “bionic structure” based on engineering mechanics principle, Getting inspiration from the research of organism on morphology and properties that including different structural levels (micro, meso and macro), and then simulating the material, structure, system which can achieve the function of the traditional structure cannot be achieved. Finally providing a new design thought to improve the utilization efficiency of engineering structure[1]. Both the sculpture and the generalized architecture must rely on the structure, and the structural bionics has become a very rapid branch in the development of bionics.

The development and application in the field of “bionic structure” began at the beginning of the last century. The structural engineers created a series of new bionic structural systems by using modern
technology. At present, the research achievements in the field of “bionic structure” have gradually moved towards engineering practice:

(1) Tree structure [2-3]: the branches of the tree are graded to form more branches and the mechanical load is very reasonable. Meinhard v.Gerkan and Karsten Brauer[4] according to the principle of tree structure designed of the Stuttgart airport lounge in 1980, see figure 1. The tree structure can save the material with beautiful shape and easy to get the larger space by the smaller rods. Nowadays the utility model is widely applied to the supporting system of the exhibition hall, the venue and the large span space in foreign countries.

(2) Membrane structure [5]: there are many bubbles in nature, such as soap bubbles. In 1967, Freiotto [6] according to the working principle of the bubble structure designed the West German Pavilion in Montreal, Canada, with light and transparent organic film as the top. Pioneered the commercial use of membrane structure. The dome stadium in Tokyo, Japan is also a typical case of membrane structure design, see figure 2. In recent years, many scholars study on the structure of this new form, such as: Wang[7] Combined with the modal analysis and fold analysis to study the design elements that the flexible membrane space structure, asymmetric tension distribution, vibration characteristics and the distribution of fold detailed.

(3) Suspended-cable structure: the spider web is soft and flexible, so it can make full use of the tensile properties of the fiber structure. Inspired by the spider web that people designed a very economical suspended-cable structure [8]. The suspended-cable structure is characterized by the fact that all the “components” are drawn to ensure maximum material properties, while the structure has a smaller structural weight and a greater economic span. The appearance of suspended-cable structure promotes the development of suspension bridge. Japan in 1998 built a span of 1991 meters of the Akashi kaikyo bridge[9], which have two main cables each about 4000m in length and 1.12m in diameter, consisting of 290 thin strands and weighing about 50 thousand tons. So far this bridge is still the world's first suspension bridge, see figure 3.

(4) Shell structure: the shell of the scallop can bear the enormous pressure of the sea water, the wavy of the geometric surface make the shell obviously improve the compressive strength under the same thickness. Dong Shilin [10] from the structure of deep Scallop’s shaped shell, proposed a new type of shell structure -Scallop shell structure, the surface of this structure is wavy, which have graceful shape, material saving and reasonable structure stress.

(5) Grid structure [11-12]: The vein of Wang Lian’s leave interwoven looks like reticulation, which bear the organization overall load, this structure stress is very reasonable. Philip Cox and Richardson Taylor [13] according to the structure of the imitation grid designed the court Museum of Sydney Olympic Games--“Stadium Australia”.

(6) Imitated bamboo cylinder structure: hollow bamboo body to ensure the overall stability of compression, the bamboo joint ensure local compression and stability of bamboo and increased the level of lateral stiffness and bending stiffness[14]. Li Zuyuan [15] follow the characteristics of bamboo structure designed the Taipei 101 building, the height of Taipei 101 building is 509 meters, which have 101 floors on the ground and 5 floors underground, from the beginning of the twenty-seventh layer every 8 layers with transverse truss around the column, similar to the role of bamboo, which greatly improves the rigidity and stability and seismic performance of the building,see Figure 4.
In China, the research on the bionic structure of large sculpture started late. In recent years, the scholars mainly focused on the study of the mechanical properties, design theory and methods of bionic building (or sculpture). Zhou Qingqing [16] analyzed the swallow shaped space truss structure static performance, stability and dynamic performance and evaluated the safety of the structure, she explore the impact of support form and different support conditions on the performance of structure and get the optimization design of support and support for building . He Yong Jun [17] based on bamboo’s excellent mechanical properties validated the rationality of hoop layer arrangement in imitation bamboo type parking structure. Zhang long [18] studied the application of structural bionics in the design of large span buildings. It is pointed out that the principle of systematic and scientific design should be followed when Structural bionics in the design of large span buildings. Zhang Qian [19] presents a new system of forest structure with the ability of structural synergy based on the method for finding the shape that based on continuous broken line cable element with 3D tree structure. Wang Ke [20] have done topological optimization for crane boom based on Wang Lian as bionic prototype and analyzed the optimization model’s statics and modal characteristics. It is proved that the bionic design method is effective in the optimization of the truss cantilever structure. Based on the theory of bionic design, Wang Qunwang [21] proposed the imitation bamboo tower structure and analyzed its static and dynamic characteristics and stability based on the bionic design theory. It is proved that the bionic design theory applied to the design of tower is scientific.

To sum up, the “bionic structure” focuses on imitating the structure or structure of various biological prototypes. The natural environment determines the diversity of organisms in order to adapt to the external environment and structure evolve also vary, so the “bionic structure” is different from the general structure design, it has a strong personality and pertinence, it is difficult and not have to follow the rules of the existing structure, in fact, there may break the traditional concept of bondage and achieve a major breakthrough in the form of force structure when do personalized structure bionic
design according to the different biological prototype the bionic structure design, in the history it appeared similar precedent such as tree structure and shell structure etc.

3 Development trends and challenges
In recent years, with the development of large bionic sculpture market, the prospect of sculpture industry is very considerable. At present, large bionic sculpture is developing towards modernization and complexity. However, the stress analysis, fabrication and installation, design method, evaluation and acceptance for large sculpture still rely on traditional experience for a long time, so it is difficult to adapt to the development trend of large-scale and complicated bionic sculpture. Specific performance:

(1) Bionic sculpture often designed by the artist dominantly. They only focus on the external shape of the bionic sculpture and ignoring the bionic structure, which often lead to the existence of security risks or construction materials unreasonable use of bionic sculpture.

(2) The organism’s perfect external form is not only an art, but also a result of its adaptation to the environment. This form often with a reasonable degree of mechanical efficiency. In the future the “bionic configuration” which belong to the field of large bionic sculpture in addition to emphasizing the ornamental value, should also analyze the macroscopic mechanical properties of sculpture shape in order to get highly ornamental value, at the same time try to retain the mechanical logic its biological prototype.

(3) The large bionic sculpture is a special kind of building, there is no uniform design and evaluation methods and implementation steps can be followed, it cannot be directly applied to various types of design specifications. There is an urgent need for large bionic sculpture to develop a “performance goal” control system (such as seismic index, displacement control index) and establish a design method and general steps for large bionic sculpture to guide similar engineering practice.

To sum up, there are still a series of important problems in the field of large-scale bionic sculpture. It requires based on structure bionics theory and using advanced methods and means of modern mechanical engineering field to develop the large-scale bionic sculpture’s design and evaluation method in system, which can guide the similar engineering practice and stimulate the healthy and rapid development of sculpture industry chain.

4 Conclusion
At present, the research on the structure of the large bionic sculpture field in our country started soon, although the “bionic sculpture” belongs to the category of building broadly, the exterior and interior structures are significantly different from the traditional buildings (such as buildings, bridges, etc.). Bionic sculpture is a kind of special building [22]. Compared with the traditional building the bionic sculpture can mimic a variety of biological prototype that almost covering all the life body in the nature. This is a very promising field of innovation and development direction in structural engineering and bionics. Personalized bionic structure design process of large sculpture, most likely getting the new structure of higher mechanical efficiency, the general design and evaluation methods should be improved, the resulting of social and economic benefit is very considerable and also can promote the transformation and development of traditional large sculpture industry.

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