

# AN INTRODUCTION TO BRIDGE DESIGN BASED ON BIONICS

CHEN FEI and SHA SHA

Transportation College, Southeast University, 2 Sipailou, Nanjing, Jiangsu, 210096,  
P.R. China. E-mail: [ord@seu.edu.cn](mailto:ord@seu.edu.cn) and [jyshasha@sina.com](mailto:jyshasha@sina.com)

## ABSTRACT

After billions of years' survival of the fittest according to natural selection, thousands of living creatures have enriched the earth. Their evolution has inspired human endeavours. Bionics, which is the science of imitating life forms in the construction of technical devices, has achieved great success in many areas. In recent years, some architects have built buildings that incorporate the characteristics of living beings, and these have appeared in the public view. Compared with traditional buildings, they have certain advantages in function, resources and many other aspects. The bridge is a kind of structural form, but has all too often been neglected. Designers usually regard the problems of bridge construction without considering the living aspect, which makes it difficult for any breakthroughs to be made in the structure and shape of bridges for a long time. Moreover, bridges hardly satisfy the increasing transportation needs and aesthetic demands any longer. By looking at sculpture and painting, bridge designers are seeking innovations. We can use the successful combining of bionics and building design as a reference and try to combine bionics and bridge design in practice. This paper discusses the concept of bionics and introduces bionics as a method in the structural shape of bridges.

*Keywords:* Bionics, Structure, Bridge

## 1. INTRODUCTION

It is said that architecture is a monument to human civilisation because it inspires human ability to use materials, is a repository of culture and society and encapsulates the artist's vision.

The bridge is a form of architecture. People have for many years explored the structure of bridges and constructed hundreds of thousands of bridges over great rivers. Some of them may look ugly, fantastic, boring or have nothing to be said for them, yet bridge designers have persisted in their endeavours.

When we read of the history of bridge construction, we cannot help but admire those designers who have made innovative efforts. But innovation in modern bridge design is becoming more and more difficult. Sometimes after racking their brains, designers are forced to complete their new projects by copying existing bridge designs. Some copies are ugly, and designers feel that there is an urgent need to consider innovation in bridge structure. This is an age that emphasises efficiency and standards, but we should not neglect aesthetic aspects. Our vision should not be restricted to the standard diagrams and the original designs. We should pay attention to the vastness of nature and everything that can inspire us. Designers are searching for a point at which to combine bridge design with sculpture, painting and architecture. Combining bridge engineering with bionics is one of the effective approaches to innovation. Based on the projects in which the authors have

taken part and previous experience, the successful experiences have been applied to the combination of architecture and bionics and some primary analysis of the combination of bridge engineering and bionics has been attempted.

The aim of this paper is to discuss the concept of bionics and the introduction of bionics in the structural shape of a bridge. The concepts of bionics, bionic materials and their application to bridge engineering are presented.

## **2. BRIEF REVIEW OF BIONICS**

### 2.1 The Concept of Bionics

Bionics is the science of imitating living organisms in the construction of technical devices (Yan Changzhu, 1994). Bionics arose through a combination of research in biology and technology, and is nowadays being used in the design of technological devices in the fields of physics, chemistry, medicine, genetic engineering, mechanics, etc.

The effects and benefits of bionics have also led to a focus on artificial hands, organic generation of electricity, new sports equipment, artificial intelligence, artificial neural networks, etc., which are all fresh alternatives. Bionics not only provides greater convenience, but also widens people's horizons. It gives them a chance to take a fresh look at their surroundings and the hundreds of thousands of living creatures that interrelate with humans in the environment. By discovering and imitating the specialisations of living creatures, our designs and inventions will become more rational and even closer to living nature.

### 2.2 Applications of Bionics in Architectural Engineering

When bionics started developing rapidly in many realms of science and technology, bionic architecture was also a growing field. Although it began later than it did in other areas, the impetus and speed of its development were surprising.

Generally, specialists use two definitions of bionic architecture:

- The architectures that imitate the appearances and functions of living creatures
- The architectures that imitate a structure's appearance, structure and functions (CCTV International Channel, 2004)

The combination of bionics and architecture is just like the combination of bionics and other disciplines, where architects are also inspired by various living creatures. For example, caudexes (although there is a great disparity when we compare some caudexes' root diameter with their height, they can withstand strong wind), eggshells or shells (although they are very thin, they can withstand great pressure before breaking), the skeletons of living creatures (they are even tougher than steel), the skull of the woodpecker (it has the closest similarity to the anti-earthquake skeleton), the spider's web (it has more than five times the ductility and rigidity of steel), and so on. These characteristics may seem commonplace, but they are a great source of inspiration to architects.

According to the different bionics principles, existing bionic architecture can be divided into four types:

1. *Arch form structure*: The inspiration comes mainly from the spinal column of animals. The merits of this type are economical use of materials, and that it is solid and handsome.
2. *Thin-shell structure*: The inspiration comes from various crustaceans and skulls. The

characteristic is that internal force is distributed along the surface. The whole external appearance is harmonious, springy and mobile.

3. *Puffing structure*: The inspiration comes from plant and animal cells. This type can be used for tents, restaurants in open country, gymnasiums, etc. This type of architecture looks very graceful and charming.
4. *Spiral structure*: The inspiration comes from the leaf of the plantain. This type of architecture makes use of the principle of sunlight regulation, giving the structure the most abundant sunlight (The TOM Network).

Many bionic architectural designs have been and are being constructed. They not only have the required architectural functions, but also have a strong visual impact.

It is said that the Church of La Familia Sagrada in Barcelona, Spain, marked the start of modern bionic architecture. It is interesting that this great building was started 120 years ago, but is still unfinished because of financing problems, and it is estimated that it will be 100 years under construction. Its designer, Anton Gaudi, died 70 years ago. The inspiration for its shape is the plant.

The latest museum in Tianjin is another masterpiece of bionic architecture. The swan's spread wings provided the inspiration for the mechanical principle of the structure and forms the framework of this huge building. This thin-shelled building combines an artificial lake with its entrance hallway to give a pleasing appearance. Under the night sky, the museum in Tianjin is like a swan spreading its wings before taking flight.

The novel appearance of the Beijing Olympic Assembly Room has received many favourable comments from many experts. The inspiration for its shape and design comes from the structure of the bird's nest.

Another world-famous example is the Daidaimu Gymnasium in Japan. Its inspiration comes from the whirlpool. It is named after the classical work of cable structure. The gymnasium was built some decades ago, but its structure and appearance are still highly praised all over the world. It embodies bionic principles compared with conventional architecture and provides inspiration to designers for the form of structures.

### **3. APPLICATIONS OF BIONICS IN BRIDGE ENGINEERING**

Bridge aesthetics is a branch of architecture. Its connotation and form need updating with time. The bridge is an architectural form that is easily neglected. However, the bridge is very important in shaping a city's view and displaying local customs. The combination of bionics and bridge design will surely promote the development of sculpture and function in bridge engineering. This paper analyses a number of examples from all over the world.

#### 3.1 Applications of Bionic Building Materials in Bridge Engineering

Bionic building materials are those that imitate the structure, chemical composition, colour and ecosystem of living creatures' bodies and are used to design and manufacture new materials that satisfy the human need for form and function (Jiang Dongqing, 2003). It is currently one of the foremost research fields worldwide. Bionic building materials can be applied widely to each kind of architecture. This section mainly introduces the bionic building materials that are used in bridges for which there are a great many research results.

##### *3.1.1 The Structure of Bionic Building Materials*

In Japan, scientists have mixed about 1% additives made up of long-fibre molecules with common concrete. This kind of fibre intertwines to form a net that imitates the shape of a spider's web. This increases the adhesiveness of the fibre molecules and binds the components of the concrete. This concrete can cure under the water and is easy to apply in underwater engineering.

Scientists have discovered by investigating the shells of the Queensland nut the reason why the nut is so difficult to crack. This is because the unyielding shells contain bundles of fibres in all directions taking up almost the entire surface. The property of this kind of structure is that there is no weak point to allow cracks to spread. If a building material whose structure is similar to the structure of these shells can be developed and applied to bridge structures, the safety and stability of the bridge will greatly increase.

Some scientists in other countries are of the opinion that through research into the engineering of living creatures, they can for example mimic the structure of reefs in the sea that are produced by anthozoans to build piers and docks. A metal net of the structure can be placed in the sea, and the molluscs will fill in the grid and gradually ossify. At the same time, a composite structure composed of corals and conches can also be made. Such a project appears to be unrealistic at present because it will take a long time. But some huge future construction projects, such as large bridges over the sea, may adopt this method for some underwater components that are difficult to construct. Because the materials are derived from nature, they will not have the problem of a design time limit that is an inevitable problem with general bridge components. The structure will be permanent and become firmer and more stable with time.

### *3.1.2 The Colour and Quality of Bionic Building Materials*

In recent years, latex paint for bridge protection in the beauty spots of our country have been produced in the colours of nature, such as lilac purple, vanilla yellow, ivory white and the light green of vegetation, etc. These natural colours can satisfy the need for an aesthetic appearance.

Scientists in England have already developed a kind of flexible cement that has various uses. This cement has strong anti-impact and anti-cracking properties.

### *3.1.3 Chemical Components of Bionic Building Materials*

It has been found that the way living creatures draw on materials in nature to constitute their bodies is not as complex as the way humans use materials for construction. Many elements are used by humans which makes the components and proportions very complex. Furthermore, many materials have to be heated to a high temperature so that they can be shaped. But many living creatures only adopt a few of the elements to constitute various materials, the configurations and functions of which are outstanding. For example, the anti-strain ability of a conch shell is much higher than that of cement and reaches 100 megapascals, but its composition is actually very simple. It is composed of 95% limestone and 5% protein, and yet is a solid object that does not need heat to manufacture. In the USA, a kind of high-strength and water-soluble cement has been developed. It is composed of a polymer of water-soluble furfural-hydroxyketone. Its components and the manufacturing techniques are very simple and it can be used to rapidly repair highways and bridges.

### *3.1.4 The Function of Bionic Building Materials*

At present, the bearing materials mainly used in bridges are steel, lumber, stone, concrete and a combination of steel and concrete. Their elasticity modulus and rigidity are very high. Distortion due to external force can hardly be detected. Most materials may destruct suddenly when the external force approaches the load limit, so it is difficult to devise preventative measures against failure. One of the functions of a living creature's body is to protect itself from external forces. Some of the more advanced functions of bionic materials that imitate the functions of living creatures are to adjust and repair themselves. This means that the material can adjust its carrying capacity and distortion capability according to the size and shape of the external load. The material itself may have a growth and metabolism similar to that of living creatures, and damaged sections can repair and reproduce themselves. Thus the life of buildings will increase greatly and their stability will be improved.

Currently there are two types of material of this kind being developed. One is passive intelligent material and the other is active intelligent material. An example of passive intelligent material is the intelligent concrete developed at Illinois University in the USA. This kind of concrete repairs itself. The designers place numerous hollow fibres in the concrete that are filled with adhesives for crack repair. When the concrete cracks, the hollow fibres also crack and the adhesives are discharged to repair the crack, preventing the crack from spreading. Active intelligent material is produced when optical fibres, microchips and transducers are placed in the concrete. If there is any damage to a bridge, the device automatically alerts to the need to reinforce the bridge.

### 3.2 Bionics Makes it Possible to Develop New Bridge Structure Designs

How did the bridge come about? Perhaps its original form was just a tree trunk over a river. The arch bridge was then developed, including the arch structure that appeared in buildings. This form was derived from the skeletal structure of animals such as dinosaurs. The weight and volume of the mammoth is great, just like the dinosaur, so their legs must have had a very good skeletal structure to distribute force. People at that time discovered these properties and through investigation and imitation they eventually worked out the arch structure which was economical in its use of materials, convenient to apply and graceful in appearance. The other forms of bridge structure that appeared later were inspired by nature. The rope bridge, including the cable suspension structure system, came from the spider's web, which is very slender but can cross a very wide span. The principle of the stayed cable bridge was developed according to the body movements and bearing forces of a weightlifter. Long-span bridges commonly use box girders and hollow plate girders to improve their bearing force performance and support dead weight. We also find examples in nature. The reason why bamboo can increase in size and be useful is that the interior is hollow. The bones of birds and reeds are also hollow. They are light but they have great anti-bending and anti-breaking properties. Thus we can draw the conclusion that when people try to create excellent forms for bridges or buildings, their core elements have already appeared in nature for a long time. More rational bridge forms are now being investigated. Combining the process with bionics appears to be promising.

### 3.3 Continuous New Designs for Bionic Bridges

It is difficult to make a breakthrough in bridge structure design. It may be easier to try to design bridges anew by imitating living creatures. New designs can make the traditional forms of bridge structure sparkle and meet people's ideas of aesthetics.

The Rainbow Bridge in China is very famous. Its designer imitated the shape of a rainbow and created the beautiful design. It is a bridge located in Jiangxi province. It was built during the southern Song dynasty more than 800 years ago. It is situated in the countryside where there are ancient villages, showing a powerful vitality and ancient charm.

Moreover, in the collective project of foot bridge design in Foshan City in Guangdong Province, the two best projects out of the five participant projects are all bionic designs. It is obvious that the bionic bridge designs, regardless of their intrinsic beauty or their surroundings, are superior compared to ordinary bridge designs and will win the praise of experts and the public.

The first is a theme called “cat’s cradle”. This theme is novel, beautiful and grand. The bridge is composed of an inclined bridge tower, main cables, back stays and main girders. The combination is very light and daring. The bridge connecting the pier looks like the side of a human hand. The inspiration comes from the game of “cat’s cradle” played by children.



**Figure 1. Theme and archetype of the footbridge design in Foshan City.**

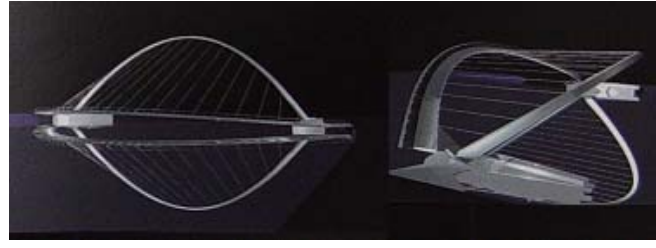
The other theme is a shell. The bridge tower is very stylish and enduring. The thin-shelled structure is just like the beautiful and eternal shells in nature.



**Figure 2. Another theme and archetype of the footbridge design in Foshan City.**

There are also bridge designs in other countries that use bionic methods. The bridge across the Tyne named “The Blinking Eye” was judged the best architecture of the year in England recently, and was the first bridge to win the honour. The jury said that this bridge opened a new era of the history of bridge construction through its outstanding modernism and added new sparkle to the Tyne which was famous for its bridges. It is a movable bridge and its opening and closing mechanism faithfully imitates the characteristics of the human eyelid. The “Blinking Eye” became a classic work of the world’s bridge designs as soon as it was completed.





**Figure 3. “The Blinking Eye” and its archetype.**

#### **4. BACKGROUND TO THE COMBINATION OF BRIDGES AND BIONICS**

The first problem to be solved is: bridges and large buildings need to withstand many forces of nature, such as wind, earthquake, rain, snow, humidity, etc. There is the paradox that we usually use the concept of resistance. However, whether resisting the effect of wind or the effect of an earthquake, there is the problem that the stronger the structure is, the greater its resistance is and the greater the counterforce of nature will be. It is very difficult for a human to resist nature. If we think about nature and apply the concept of minimising resistance, the bridge structure will be more rational and safer. This has already been studied and put into practice. Attempts are being made to eliminate the temperature expansion joints on bridge structures to make the structure integral and unified. When the temperature changes, the structure expands or shrinks uniformly like the lungs in the process of breathing, which is called the structural system of breathing. This bionic principle can also be related to the movement of the human skeleton and its ligaments. When people move, the skeleton is subjected to impact forces, but in most cases there are no injuries because of the elasticity of the ligaments. If this principle can be applied to the bridge structure, the impact of the external force will be minimised to some extent. There is still much work to be done to solve the problem, including research into the materials, structure and design. Bionics may bring about a brand-new concept of bridge design.

Another problem to be solved is as follows: Nowadays, the choice of appropriate colours and shape of the bridge is usually made after deciding on the bridge type to make the bridge fit in with its surroundings. In many cases, this cannot disguise the harm to the environment caused by the bridge nor can it achieve the desired purpose. The concept of organic construction put forward by some architects may be the solution to the problem. This view is also derived from bionics, which states that when we build something of a fixed shape, the shape is mechanical. An organic shape in nature changes constantly with organic growth. Organic construction refers to construction that develops from the inside towards the outside. It is consistent with the environment in which it exists and is reconciled with its natural surroundings. Its aim is holistic. The organic construction form is born of the natural environment and does not appear like an artificial addition. Bridges and constructions that adopt this design concept consequently fit in harmoniously with their surroundings. A successful example of such a bridge cannot be found at the moment, but where buildings are concerned, designers have been successful, for example the villa of flowing water. Bridge designers need to learn from architects and from nature. One day bridges will be organic thanks to research by the experts and become pleasing aspects of the scenery which blend faultlessly with nature.

#### **5. CONCLUSION**

The Director of CAS, Mr Luyongxiang, said when he spoke at the Xiangshan science conference that after billions of years' evolution, living creatures provided a natural treasure-house for human innovation. Nature grows according to natural laws, not according to limited calculating skills. The baffling factors in construction designs are all

temporary. Along with the development of materials, techniques and the level of the design, the design of bridge structures will finally catch up with and even exceed the structure of living creatures in nature. A study of living creatures will be a permanent task for humans!

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