Discussion on Theories of Bionic Design

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Abstract

The term “bionic” was first coined in the mid-twentieth century, which is aimed at applying biological studies to technical aspects such as architecture, industrial design, and material science. Related researches on bionic study were mostly carried out by the Westerners, and so as the design cases in forms of bionic product and architecture. This research is particularly aimed to review and analyse the Bionic-related literatures in both the Eastern and Western world, and its content first starts with the definition and literature review of Bionics, then expands into analysis of the subjects in Bionic context, including the scientific realm of Biology, philosophical thoughts of Metaphysics, and to the designology and architectures supported by actual design cases. Further, this research enlarges the domain of Bionics, including the more general notion of the origin of mankind, the organic architecture which is inspired by the environment, and the concept of Feng Shui, etc. This research aims at the more systematic induction and is to review and construct the knowledge of bionic-architectural theory, and to discuss the contexts and case studies of bionic architecture, contemplate the significance of bionic architecture, and its potential development and contribution in the future.

Keywords: Bionic/Bionics, Bionic architecture, Organic architecture, Feng Shui

1 Introduction: what is bionics?

In consideration of the global trend of environmental protection, the disciplinary focal point also tends to work on the issue of sustainable development. However, though the researches of sustainable design and green design have been increased, the subjects of these researches yet were mostly undertaken from the aspects of material, structure and form; and the application of 'bionics' to architecture or design seems to be treated as a new, contemporary idea. In contrast with the former researches, this study takes a different angle to discuss bionics in the progress of the development of human beings. Bionics has been shown in different ways in the development of human beings, and we can therefore coexist with nature by the development of bionics. This study will use the hypothesis above – that bionics is the foundation of the development of human beings – to seek the existence of bionics in different fields, and construct the basis of bionic architecture.

1.1 Definitions of bionic terms

Bionics: The term 'bionics' can be traced back to the 1950s. An American major, Jack E. Steele, coined this term in 1958 and further expanded its usage in 1960 with many other bionics scholars at the first bionics seminar, held in America. This seminar marked bionics as a formal subject and laid the foundations of bionics. ◦ At that time, 'bionics' referred to transferring technologies into life-forms, also known as biomimetics, biognosis, biomimicry or bionical creativity engineering. Later, the term was also applied to bionic design, which is the harmonious relationship between the human and nature in industrial design, and also a major path to systematically study and improve the way of life.

Biomimetics: The new word 'Biomimetics' is a combination of two words, 'Bio' and 'Mimicry'. Mimicry is a special word in biology for studying animal behaviour. This means animals can mimic a certain organism, in terms of appearance, colour or behaviour, to benefit their subsistence. Biomimicry puts focus on the interaction between the organism and its environment. Janine M. Benyus suggests that animals' mimicking behaviour is in fact formed accidentally by the animals' need to adapt to their environment, not a great system of nature. The

two words mentioned above are quite similar. They both refer to the method of studying the nature of an organism. Bionics can also be regarded as the study of the wisdom of nature and the science of imitating the special skills of creatures.

1.2 Other words related to bionics, and their definitions, are as follows:

Bio-inspired Design

Human beings tend to look for answers from nature when they come across technical problems. They are often inspired by animals' traits, which can result in bionical design. That is why these solutions are also named by scientists as bio-inspired design.

Biological Analogies

In the book, 'Changing Ideals in Modern Architecture 1750-1950', the innovative architect Peter Collins included a chapter in which he discussed the idea of 'Biological Analogies'. He proposed to take the ideas of the functions of nature, structure and form, and biological evolution, and apply them to design, calling this application Biological Analogies. Although the term is not identical in meaning, it can be taken to refer to the broad sense of Bionics.

Biodesign

There are also arguments in favour of separating purely formal bionics from biology. The academic Mike Jones, in his book on Jocelyn de Noblet, proposed the word 'biodesign' to refer to the transformation of a product's appearance from the forms that developed from the environmental adjustment of organisms. But this idea is closer to Biomorphology than the general definition of bionics we're talking about here.

1.3 Knowledge system of bionics

The so-called 'bionic' is to mimic the information extracted from the function, structure and movement principle of organisms, and 'Bionics' is a subject to systematise the knowledge of bionic after the examination of the deliberate observations and selective extractions by the bionic experts. The process of the application of

bionic knowledge can be divided into three stages (table 1):

Table 1: The process of the application of Bionics (collected by this study)

First Stage **Knowing the essence of organism activity** **→ extract the information**	Second Stage **Information extracted** **→ data Model**	Final Stage **Data Model** **→ new system**
Through observe the significance of specific activities of the organism	Extract information from the organism's activities, and transfer the information to data, then establish the data model.	Import the data model to the new system, and build the connection between the 'organism information' and the 'artificial object'.

2 Bionics Studies

2.1 Categorisation of bionics

Two Taiwanese scholars, Hai Shan Wang and Jia Ming Yei, divided **Biosimulation** methods into four types:

Information bionics:

Through imitating organisms' information systems, including how they restore, extract, transfer and sense, we can create new information systems.

Control bionics:

Through imitating functions such as orientation, navigation, move control and feedback regulation of organisms, we can create new control systems.

Mechanical bionics:

Through imitating the mechanical structure and principles of organisms, we can create new mechanical systems and structures.

Chemical bionics:

Through imitating organisms' catalytic actions, synthesis, and energy transformation, we can create chemical products, such as high-efficiency catalysts, and develop chemical technology and new energy.

From the statements above, we can know that the methodology of bionic design is based on the idea of organisms' characters. Through the process of immersion, experience, transformation and application, the

principles of organisms that have been discovered can therefore decoded and transplanted as the foundation of the artificial objects, in which bionic is usually applied to the aspects of information, control, mechanism and chemistry.

Janine M. Benyus in his book of 'Biomimicry：Innovation Inspired Nature' puts a lot stress on ecology, Ethology, Evolution, Molecular Biology and Energetics; further, he states that if we want to seek sustainable development, we have to learn from nature and apply it in our life and technologies. He proposed four steps to mimic and apply the natural lives to our life in the future (table 2):

Table 2 Steps of organism mimic（collected by this study）

First Stage **Bio-Based**	Second Stage **Immersion**	Third Stage **Integration**	Fourth Stage **Transformation**	Final Stage **Production**
Get into the field of biological research	Scrutinise observes and experience	Combine the related fields	Diversified transformation and application	Achieve the goal of green industry

3 The development of Bionics from Biology to Design

To product a bionic design, and to pass down the experience effectively, the knowledge of bionics has to be accumulated as any other developed technology, and build up the whole bionic architecture knowledge by systemised into structure and formal statements.

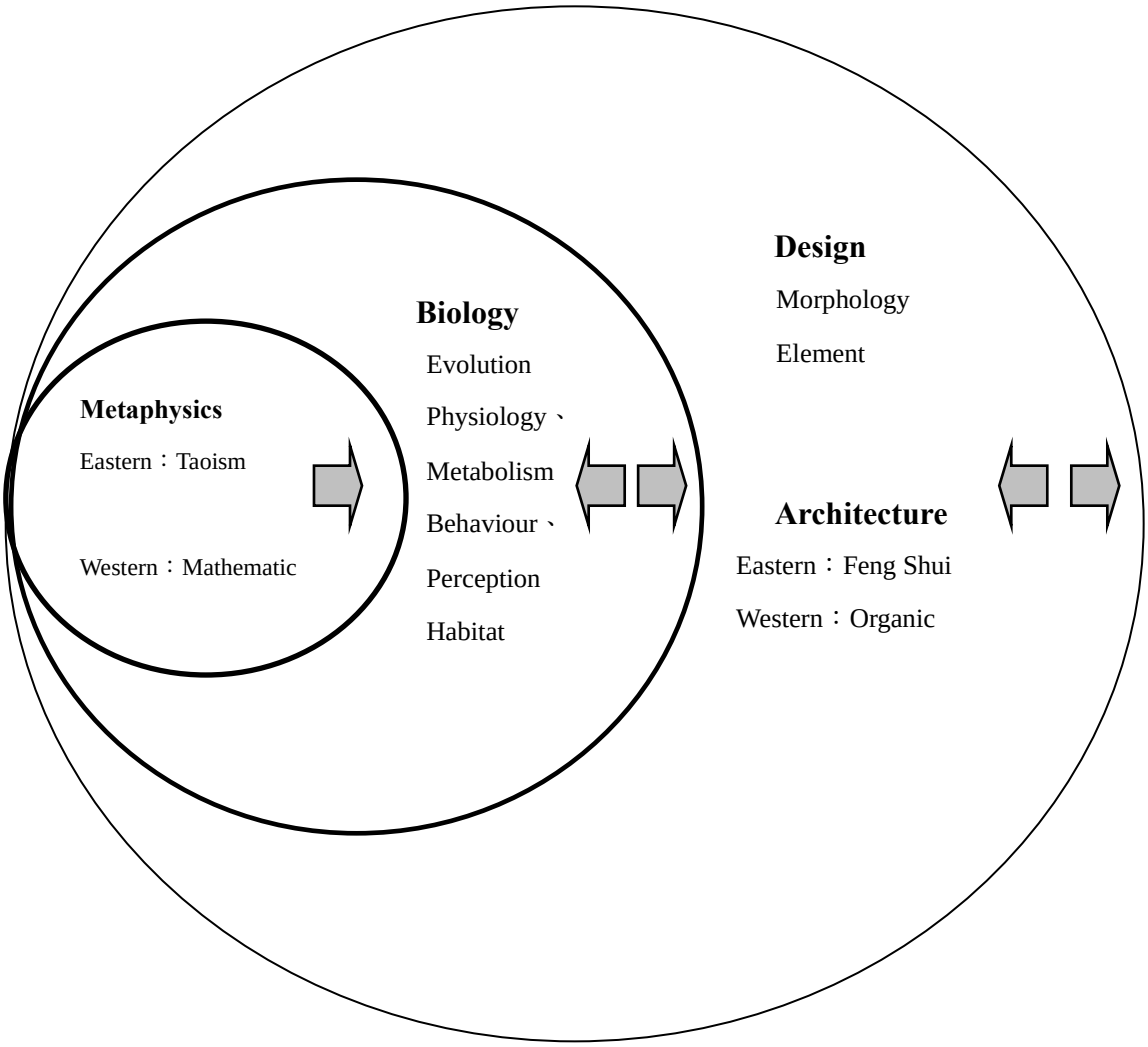

Figure1 bionic theory chart（collected by this study）

3.1 Bionics and biology

From evolution to communication

According to Aristotle, the operation of nature is done for an end, for its 'final cause', and for its 'intrinsic finality', and entities are therefore formed and have the tendency to practice its final goal. This does not only reflect the value of natures, but also of the organisms and their functions.

The Taiwanese scholar Chia-Ming Yei states that 'the history of scientific technology is such a trifle compared with the billions of years of biological evolution. On the 5 billion square kilometre surface of earth, the evolution of nature designs, produces and offers the vast environment and opportunities for the life system, that makes the living creatures we see now self-regulated as a highly matured system; and this is what the

technological product today cannot catch up with. That's also the reason for the spring of bionics.'

The fact that humans are at the top of the hierarchy of nature is not because our organs or functions are better developed, but because we are lucky to have the ability to use logical and analytical thinking, and because we have developed the expression system that we call 'language'.

So, if we dare to say that man is the paragon of animals, we should be aware that the statement is based on the fact that we modified the natural environment to suit our intelligence, but not because we are superior to others. Moreover, biological researches nowadays still cannot give a definite answer on animals' intelligence, although we can at least infer that dolphins are supposed to have the ability to learn and understand complex language. Thus, if we know how to use the receptivity and intelligence that have been evolved in animals for centuries, maybe we can get inspiration for the creativity of formal logics. The fact that humans are at the top of the hierarchy of nature is not because our organs or functions are better developed, but because we are lucky to have the ability to use logical and analytical thinking, and because we have developed the expression system that we call 'language'.

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Generally, 'sense' refers to the messages that we perceive through our sight, hearing, smell, taste, and touch; among which the most significant are sight and hearing, for they represent almost 90 percent of the total messages perceived, and other sensory organs are unable to take abstract messages as words and symbols.

If we take 'the love of animals' as an example, and examine how the concept of biology is applied to the

bionic design, then we will surprisingly find that plenty of information relating to sense and intelligence is derived from it.

Animals are like humans, in that the best genes have survived the long history of evolution. Although the preserved perceptions and intelligence structure of animals may be inferior to human beings, they are better adapted to the much more complex circumstances of the natural environment than human societies are. And the wisdom that has evolved from evolution is also something we humans can learn from.

Advanced biological technology is now conducting invasive experiments on human bodies by biotech and other technologies. However, it is proceeding with an instrumental crisis, and bionical design that takes its ideas from organisms would lose its essence if we only see its forms and outer characters. So, if we can establish an interdisciplinary mechanism, it will be a leading tool for both bionical knowledge development and for expert design, and would further accelerate the progress of design knowledge.

3.2 Bionics and Metaphysics

From Taoism to shape grammar

Science of thinking can be parts into ‘formal thinking’ and ‘abstract thinking’. In the Eastern world, formal thinking can be traced back to Taoism in China that asserted by Lao Tzu and founded by Chuang Tzu, who further developed the theory of the elimination of figure and cognition. The spirit of art was then established as follow the nature and as an essence transcends all the entities in the universe.

From Lao-Tzu to Chuang-Tzu, human beings, in their own eyes, have been a start point rather than an end. This may be better explained by a quotation – that, ‘Human beings follow the Earth, Earth follows Heaven, Heaven follows the Tao, and the Tao follows the way things are.’ Although the philosophy of Taoism starts with human beings, the idea behind it is to break the limitations of anthropocentrism, and to find the centre of objects in the universe, in which the centre of objects is the absolute natural spirit of Taoism. What ‘the Tao follows the way things are’ is actually expressing the naturalness of spirit, and its character of inner freedom.

The Western discusses the mechanism of forms in mathematics, but before we explain the inner origin of forms, we have to first take an example to state the relationship between the rules of form and nature. In 2002, the American computer genius Stephen Wolfram published a book called, 'A New Kind of Science'. In the book, Wolfram claimed that, over the past 500 years, science in the Western world has developed in the wrong direction, and that science does not understand the fundamental structure of the world. He thought the fundamental structure of the universe is a computer. The computer here does not mean the piece of computer equipment we use every day, but an arithmetic mechanism that can turn limited rules into infinite variations, and also a branch of schools called Automata in mathematic fields. Taking the formation of space as an example, we can see that a cube has 26 major adjacency relationships. It has 6 planes, 8 points and 12 lines, and each relationship can be expressed as yes or no by the use of 0 and 1. So the 26 positions would have two to the 52 power possible arrangement. And if we see each arrangement as a rule, the rules could add up to a 17-digit figure, which is nearly an astronomical number. A similar idea of the universe can also be found in the famous book from ancient Chinese culture called 'the book of changes'; instead of 'universe as a computer' in Wolfram, the concepts of Lian-Yi, Si-Xian, and Ba-Gua in Chinese culture share similar ideas of the cosmos.

The rise of Taoism in Chinese culture was much earlier than aestheticism in the West. Taoism breaks the ideology of forms and proposes that following the laws of nature should be the goal of human beings. This is in contrast to the recent development of forms that use technology to surmount the limitations of form operation and even see technology and computers as being supreme. The two different ideological developments not only have an effect on philosophical thinking about forms, but also demonstrate that the change in human thoughts is indeed based on Tech-centrism.

3.3 Bionics on Designology

From Morphology to product design

Morphology is the study of form and structure, dealing with the configuration of objects and the figuration

of parts of the object. Morphology can be applied to any academic discipline. Although the study of biology and linguistics might seem to have little in common, morphology suits any subject when it comes to a discussion about the nature and structure of objects.

Bionical design involves the product idea and biological idea. A comprehensive understanding and a good combination of the two is the key to successful design.

Definitions of the elements of bionic design:

1. Product idea: the affirmation and description of the element of product in related to the design objectives
2. Biological idea: Relate to the objective natural attributes of organisms and the subjective cognition of design.

For the differences of the purpose and needs between the two ideas above – that is, the different characters of product idea and bionic idea, there also affect the design procedure towards to the directions as follows:

1. From biological idea to product idea

Bionical design, led by the biological concept, gets initial inspiration from the study, observation and discovery of natural lives, is supplemented with the ideas of bionics and biology, and finally proceeds to the product design stage, guided by biological concepts. During the design process of bionics, the designer often has to answer questions such as ‘what can be done’, and the concept of bionical design requires a certain level of proactivity and purposefulness, a quality that the process of bionical design shares with the study of bionics.

2. From product idea to biological idea

At the stage of the creative development of the product, if the purpose of the design is clear, then the idea of the product would gradually form. By this time, the process of bionical design and the study of natural lives has hopefully helped to answer the question, ‘what can be done’, and the concept of bionical design has been applied that corresponds with the purpose and idea of the product.

From the former statements of bionic ideas and techniques, it seems that we have already found how to apply bionics to design and achieved some goals. However, if we turn back to the core concept of this study – the 'thinking' of bionic design and its application in products – we would find that bionics cannot be limited as merely a 'technique' or presentation, but should be broaden to a deeper thoughts as a philosophy to help us break the dead end of product innovation. Thus, recently there are some scholars also proposed the thinking of bionic system, and hopefully can solve the problems encountered in different fields of product innovation.

4 Current status, categorisation and cases of Bionic architecture

4.1 Bionics on architecture

From Fenh Shui to organic architacture

The ideas that can be applied to space, architecture and environment have been developing for a long time, and the ways of practising have also existed as a philosophy for many years. The Feng Shui theory has lasted in Chinese culture for more than 5000 years. As well as an examination of the aesthetics of architecture, Feng Shui also investigates the character of formation and abstraction, which means science and aesthetics. More specifically, it is the unique study of human settlements constructed by the ancient Chinese based on the elements of nature. In accordance with natural phenomena such as geology, weather, terrain features, hydrology, landscape and environment that related to human social activities, the ancient Chinese combined the two major elements of human beings and nature in logic, and therefore could solve settlement problems by the laws of logic. The purpose of these logic laws was to keep the natural lives in their roles. There are three basic parts to the laws: one is the ontology of 'Qi', which is often translated as the 'energy flow'; the second is the notion of YING YANG WU XING, describing the interactions and relationships between phenomena; and the third is the notion of the change of seasons and orientations. If we look at both the theoretical pattern and the concrete operations of these elements, we can see that Feng Shui is essentially an ecological system.

In traditional Chinese thinking, human beings and the cosmos are in a correspondent relationship, and humans are the soul of the universe. The classic and encyclopaedic Chinese text, Lüshi Chunqiu, says: 'Every creature is the embodiment of Ying Yang, and Ying Yang is the creature of nature.' The analogy between human and nature sets up the elementary relationship between body and space, and this relationship is tightened up in the discourse of Feng Shui by analogy and imagination. When we talk about habitation in Feng Shui, it is treated and incarnated as a body that should be correspondent with nature.

From the ideas above, we know that in Chinese culture, Ying Yang is the source of the universe, and human beings are all generated by it. In other words, the thinking of 'heaven, earth, and human' in the traditional Chinese culture was derived from the concept of Ying Yang, and this thinking was then imported into the structure and configuration of residence. By the relationship between Ying Yang and human body, the allocation of the furniture and spaces were also analogised as the facial features and the complementarity of Ying and Yang. The view of 'heaven, earth, and human' hence became the main thread of developing the concept of residence.

From the discussions above, we can know that there are some common characters of architecture showed in both Western organic theory and Eastern Taoism thoughts. Both of the two discuss about the importance of life, and give rise to concern about natural environment by this discussion. Thus, maybe we can discuss architecture in the premises of 'human' and analogy to humans' body, skin, features, etc., while also contains the view of universe that comprised the category of being of the big universe (heaven) and the small universe (human). Besides, the thinking of life is also brought into the configuration of architecture in both Eastern and Western, and thus there can be established a harmonious relationship between human and the environment.

In the early 20th century, the American architect Louis Sullivan applied the concept of 'form follows function' – developed by the 17th-century biologist Lamarck – to architecture design, using it to design buildings as an organism. This significant application of a biological idea became a major design criterion at the time, and further influenced the field of industrial design.

For the architecture master Frank Lloyd Wright, who was also a student of Sullivan's, the application of

‘organic’ to architecture meant the use of the concrete cantilever as the form of arborescence. This idea was first proposed in 1908, and we can see that, although the ‘seed’ of ‘organic architecture’ was planted by Sullivan, Wright expanded on the theory and applied it to the whole structure of a building, rather than merely using it as a decoration or formality.

The form of ‘organic’ was taken from biology that means to connect with nature. In the 19th century, the British avant-garde architecture theory proposed the concept of correspondence between ‘form’ and ‘function’, and influenced the formation of the idea of organic, mostly in America and German. The representation in American is Louis Sullivan’s ‘Form follows function’ and Frank Wright’s early grassland domicile; in German, it’s represented by Hugo Haering’s theory and the practice of Hans Scharoun.

Bionic

Hugo Haering defines organic archaeology as blow:

1. Natural rules

   Archaeologists should think ‘actively’ how to response to the ‘basic needs’ of buildings and contribute to the harmonious coexistence of archaeology and Nature.

2. The organism of archaeology

   ‘Archaeology is the second layer of skin of human beings and houses are organs of lives.’ (Haring, 1925) This points out the need of archaeology will be changed by who, what, when and where.

3. The form of archaeology’s nature.

   The focus of archaeology will be discussed in separate units and the form of space will be explored by the traits of each self-evident unit. This means all attempts to apply human beings’ nature or other factors to the form of archaeology will be rejected. (Haring, 1925)

   In 1930’s, F.L. Wright claims that the ‘form’ and ‘function’ of organic archaeology are in consistence. Which means organic archaeology are:

   1. Following nature instead of conquering nature.

2. Trust natural rules instead of man-made rules.

3. Value personal emotions; and ‘human’ is the ultimate answer of architecture.

4. ‘Beauty’ is established in reasonable ways, not in absolute measures or proportions.

5. The relationship between the whole and the portion is blended rather than opposite.

4.2 Categorization of bionic architecture

Bionic architecture is based on the development of Bionics. In 1983, the German J. S. Lebedew published a book called ‘Architecture and Bionic’, in which he indicates that the problems occurred in architectures have already been solved in the natural system. A perfect protection system is evolved as high-efficiency and low-energy to favour the organisms in surviving from the evolution; and this system is therefore became the best example of coordinating with nature from the human societies in bionic architecture researches. (Yang and Lo, 2005) the development of bionic architecture today can be divided into four major genres as follows:

1. Pattern:

   Architects inspired by the varied patterns of natures, and apply these inspirations to architecture design; this technique usually leads the viewer to an interactively association with the building. The remarkable architects in this genre including: Antonio Gaudi’s Sagrada Familia, inspired by the shape of plants; and Frank Gehry’s Fish Dance Restaurant in Kobe, Japan, the shape of fish creates an unique phenomenon for the space, and became a landmark in Kobe.

Figure 2. Antonio Gaudi’s Sagrada Familia. (Source: http://www.flickr.com/photos/chiaheng/1238215985/)

Figure 3. Frank Gehry’s Fish Dance Restaurant. （Source：http://tw.myblog.yahoo.com/jw!CcPKaSeQQUKW9EG0olL./photo?pid=0&prev=12437&fid=64）

2. Structure:

Borrowed from organisms' forming structure and apply to the similar patterns of architecture. Through the understanding of the organisms' structure and mechanism of the forms, the control of shape and structure on bionic architecture can therefore be possible（Lebedew，1983）.

In 1851, The Crystal Palace finished in London; it imitates the vein tissue of water lily and human's thighbone, eliminates the region of stress concentration, and bear the maximum load by the minimum materials. Further, Nervi proposed the lattice grid (figure 5) that mimic from human body's bone structure, which can stiff architecture's strength in the thinnest tissue system. (Jian, 2007)

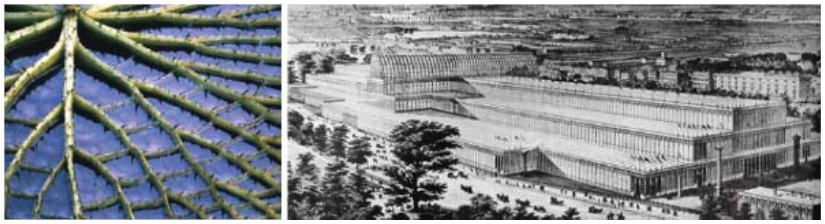

Figure 4. The giant water lily and the London Crystal Palace.（Schafer, 2003）

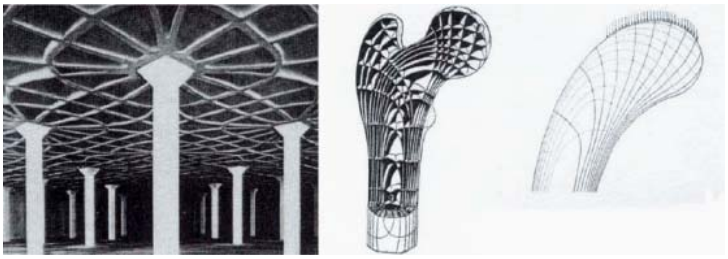

Figure 5. The column structure of Roman Gatti factory and the imitation of human body's thighbone.（Schafer, 2003）

3. Function:

The natural organisms have evolved for hundreds of thousands years, and have developed the complex, varied and high-adaptable abilities. Human beings can transform the different special functions found from different organisms, and apply to architecture designs.

The great German architect Teutonic Holst designed the famous sunflower-like rotating house. This weighed to 180 tons architecture is supported by a rounded track formed in six

pillars; the six drivers of the pillars can revolve the house 180 degrees, and make the house aiming at the sun all the time, and finally reverse to the first position in the night. This house has been regarded as a successful attempt of active solar ecological architecture. （Ryuu Gawa，1998）

4. Material:

Researchers have found from nature that some organisms' characters might be able to transformed into artificial materials, such as the material of bullet-proof vest was transformed from the tenacity of cobweb; and the 'bionic lotus leave membrane' was invented to keep away from the dust when applying on the wall by the character of lotus' leaves. （Yun Ching，2004）

In the field of architecture, the thinking of bionic architecture are derived from the strategies of 'mimic the nature' by the designers and professions. Although social diversities have always be seen as the character of free country, but the development of thoughts under the diversities somehow show the flaws of 'limitation' and 'segmentation' that obstructed the development of collective thoughts.

Although this study only discusses about the 'organicism' and 'the view of body' in bionic architecture, but we have found that the idea of bionic has the lateral interoperability throughout all times and countries; and this lateral interoperability can be further integrated into the vertical extensibility – that is, to extend the bionic idea to a deeper philosophical thoughts that makes Bionics as a specialized field, and can thus benefit the human societies.

5 Conclusion：The future of bionic architecture

5.1 Bionic design today

This research addresses the ideas, methodology and case studies of bionical design, and is divided into two parts on the application of bionic ideas. One is to apply the character of biology to the idea of product design; the other is the suggestion of 'back to nature' and seeks the related biological elements to solve the problems of designing.

5.2 The Metaphysics of bionic design

The idea of ‘back to nature and seeks the related biological elements to solve the problems of designing’, is not a new one; in fact, it has existed in human culture from the outset, and has been customarily used to solve problems ever since. Although it has been disengaged from designing in human culture so that it now seems a bit rusty and outdated, it has also been re-evaluated in the wake of interdisciplinary, innovative ideas and environmental consciousness in recent years. It can also be further broadened to represent as more systematic and internalised into the concept of design, in which its metaphysical thoughts and methodology are even mature. I believe the field of bionical design is still profound and broad, and is worth being further studied and applied in the future.

5.3 The crisis of instrumentalism

Tools have changed the relationship between humans and nature, and the course of tools is the course of human civilisation.

A crisis must exist in instrumentalism, for tools are only a reflection of speciality, and not of thought or creativity. In other words, tools should assist creativity, but should not dominate. Although the development of an instrument can have its advantages, we have to be aware that it is and should only be a technique. What we have to develop further is the essence and purpose of thoughts.

5.4 Follow-ups of the research

Are science and the humanities two souls without intersection?

In 1880, the English biologist Thomas Henry Huxley, in his famous speech about ‘science and culture’ – which partly intended as a declaration of war between science and the humanities – claimed that literature would inevitably be replaced by science. And in 1899, the American novelist Mark Twain asserted that the so-called humanities scholars barely knew what science was, while scientists seriously lacked knowledge of classical humanity. Then in 1959, the celebrated British physicist and novelist Charles Percy Snow gave his influential speech, ‘The Two Cultures and the Scientific Revolution’, in that year’s Rede Lecture in Cambridge. He spoke of the huge gap between scientists and humanists in their educational backgrounds, subject training, study objectives, and their methodologies and tools.

The basic ideas and value judgments of the two cultures are usually opposed to each other – or, rather, they are totally different cultures. What's more, the two groups of people mostly despise each other, and even disparage the ground that the other culture has always stood on.

To respond and to expand on this debate, the Taiwanese scholar Bei-Chang Yang asked the question, 'Is a single culture satisfactory?' He said: '…if single cultural knowledge is unable to solve all the challenges that human beings could be confronted with, then to acknowledge its insufficiency and take advice and edification from the other culture would at least expand the tunnel vision in each of them.'

So, the engagement of the two cultures should not be exaggerated as a 'cultural controversy', a 'science war', or even as 'anti-scientific hegemony', but should be seen as an opportunity to enrich the interpretations and to help solve aspects of different problems in both cultures. Even though the content of each subject would remain what it used to be, that would save a good deal of energy on pointless fights.

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