

Bionic architecture: back to the origins and a step forward

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Abstract. The article reviews research in the field of architectural bionics and its historical background. The article considers the development of bionic architecture from its origin till the present day. It was established how various functional elements of live forms, nature as a whole, and architectural shape formation interact and correlate. The basic factors, influencing the shape forming elements of the architectural composition, were identified. The main terms, associated with bionic shape formation, were indicated. Modern trends in bionic architecture were considered. The examples of outstanding architectural specimens and their creators were given. The concepts of architectural bionics and bionic architecture were defined and differentiated. The article considers the development of the bionic architectural style and determines the historical background of its development. The issues of fractal geometry are also addressed by reviewing the French scientist B. Mandelbrot's treatise "The Fractal Geometry of Nature". The conclusions were made about the advisability of using fractal algorithms in architectural morphogenesis. The article considers the principles of bionic architectural design that contribute to the development of architects' imaginative and analytical thinking and allow them to apply innovative methods of shape formation in town planning. It was concluded that one of the most important conditions for the optimal functioning of an artificial environment is its organic unity with natural environment, as well as mimesis (deliberate imitation), which is an objective prerequisite of the bionic trend in architecture.

1. Introduction

Once humans themselves were a part of nature, who obeyed its laws, and adapted to its harsh conditions. Gradually evolving into "homo sapiens", they learned from nature, imitated it, listened to it, and followed its signs in order not only to survive, but also to improve their life, using the methods and principles of nature. This is understandable, because constructive forms of nature are well adapted to the environment, and proven over centuries and millennia. Over the past decades, the world has witnessed the emergence of unusual architectural forms resembling wildlife forms, for example, sea shells, flower petals, tortoiseshells, plant stem structure, and many other bionic forms. Presently, it is "architectural bionics" that systematically and purposefully studies laws and principles of form generation in wildlife which are reproduced in architecture.

Bionic architecture and architectural bionics are not identical, because architectural bionics is only a part of bionic architecture; its essence is to imitate natural forms in architectural generation of forms. Bionic architecture is an architectural style based on the organizational, structural, and functional principles of natural objects [1].

2. The creative role of bionic architecture



The word bionics, which nowadays defines the applied science aiming to apply properties, principles, functions, and structures of nature in technology, derives from the Greek word βίον (vion) – “living.” Bionic architecture is bionic mastery of architectural forms based on the principles of nature, i.e. growing, changing, and moving buildings, adapting to the ground, underground, underwater, and air environment. Architectural bionics is a creative science, as it synthesizes scientific research and practice, uses the organizational means and principles of nature when creating an artificial habitat. A creating human has long begun to solve not only aesthetic, but also functional, and technical issues in architecture. And there is evidence to this in the world history of architecture. According to the available archaeological data, the first bionic generation of forms in architecture was applied in ancient Egypt during the reign of the III-VI dynasties of the pharaohs (circa 2707-2150 BC), when they began to construct columns similar in their proportions and shapes to a lotus flower (Figure 1).

Later, in ancient Greece, they applied an order system with plant elements in stucco molding, which decorated columns and pediments. The talented architect and engineer of Ancient Rome Mark Vitruvius Pollio (1st century BC) described in his book “Ten books on architecture” how the famous Corinthian order was invented.



Figure 1. Capital of a temple in Egypt.

According to him, a pupil of the Greek sculptor Polykleitos, Callimachus, once noticed a basket on a girl’s grave in Corinth. It was covered with a square plate, and acanthos (acanthus) leaves grew from under the plate following its contours, which put him onto the idea of creating a capital, surrounded by acanthus foliage. This is how the new architectural order, called Corinthian order, appeared. The great architect of the Italian Renaissance F. Brunelleschi took a bird's egg shell as the basis for the construction of the Florence Cathedral dome. The unofficial title of “father of bionics” belongs to Leonardo da Vinci. This great genius in the history of civilization was the first to use the experience of nature in the construction of man-made machines. The pioneer in using the principles of bionics in construction of buildings was the great Catalan architect of the early 20th century, Antonio Gaudi. Gaudi was first to not just introduce decorative elements of nature into architectural structures, but to put the buildings into the environmental shape. New generations of people still admire Gaudi’s brilliant architectural masterpieces (Figure 2).



Figure 2. Park Güell in Barcelona. Architect A. Gaudi.

Le Corbusier, an innovator in the field of organic spatial environment, was also attracted by nature. Le Corbusier's creative work managed to unite biological and technical principles, to rise above the level of traditional representations of "organic architecture" and to approach the level of bionic principles in architecture. Corbusier considered an architectural structure as a plastic form, full of light and shade, "moulded" building material, as an organism whose life originates in the primary cell and then spreads throughout the vast space. He fills this continuous creative process with the idea of humanity, kindness, and democracy [2]. Structures, in which the bionic architecture reproduces the regularities of living beings' bioengineering and the physical rules of heat exchange, heat transfer, material distribution, and the formation of structural systems, began to appear later. A typical example of bionics in architecture is the use of culm structure in the construction of high-rise buildings. Cereals have a high degree of strength and sufficient flexibility, which allows their relatively thin stems to bear the weight of the inflorescence, and withstand the wind, and other negative weather factors.

In other words, people got interested not only in the beauty of natural forms, but also in their rationality. Having carefully studied the design of the famous 300 m Eiffel Tower, which has long become the symbol of Paris, architects and biologists made an unexpected discovery: the elegant design of the Eiffel Tower exactly reproduces the structure of a shin-bone, which can easily bear the weight of the human body! Thus, what was consciously sought after by the inquisitive thought of a talented engineer, had been "reasonably" created by nature in a millennium-polished living organism. Not long ago, scientists have found that a swan's skeleton is arranged in exactly the same way as the reinforcement of modern reinforced concrete structures. Just as glass fiber increases the strength of laminates, the skeleton of irregular protein fibers that are rich in iodine gives strength to a swan's soft body. Hyaline, tip-pointed needles perform the same function as the steel reinforcement in concrete. Therefore, a swan's skeleton, consisting of longitudinal and transverse "beams", can withstand significant loads [3]. And there are many examples of this kind, when people and nature are unanimous and embody their ideas in a creative process.

3. Metaphor as a principle of form generation in architecture

In nature, function and form are closely interrelated and interdependent. Research results in the field of architectural bionics prove to be useful in solving the issues of architectural form generation. If we literally define the concept of form generation, it is the process of generation of new forms and structures. In Russian and foreign practice, it is highly important to search for generative capabilities of new constructive systems [4-10]. Impulses of organic form generation are natural forms, such as landmorphic, zoomorphic, anthropomorphic, and also the principles of structural organization of natural structures. Presently, the ideas of organic form generation are often combined with the concept of contextuality and ecological approaches, aiming to achieve harmony between an architectural object, the natural environment and human. These trends are still focused on expressiveness of the latest designs and technologies, demonstrating increasing interest in ecological problems. In the framework of this trend, unexpected metaphors emerge, emphasizing the similarity between architectural designs and living organisms, a kind of "exoskeletons" that evoke associations with fantastic animals. These principles can be clearly seen in the works of N. Grimshaw, H. Rashid, R. Piano. Those designs which are based on the principles of fractal geometry can refer to the true organic form generation. This idea, which has been implemented today in numerous experimental projects with the help of computer design, appeared in architecture after the treatise of the French scientist B. Mandelbrot "Fractal geometry of nature" had been published in 1977. B. Mandelbrot was the first to write about the fractality of architecture, mentioning the shape of the Paris Opera building [5-14]. Reproduction of the laws of nature in architectural form generation on the basis of fractals is truly an excellent tool of bionic architecture in the modern world (Figure 3).



Figure 3. Amazon Office in Seattle.

4. Bionics in modern architects' works.

Bionic images are used within the framework of landmorphic architecture, where attempts are made to reproduce the natural landscape, imitate geological layers, and crystal rocks (P. Eisenman, Z. Hadid). "Nature, frozen in stone", that is how people call the park Güell of the above mentioned architect and modernist Antonio Gaudi. He was one of the first to practically apply bionics. A. Gaudi's architecture is so naturally vital that it is difficult to say whether it is in the constructions of his buildings or in the exterior décor where the designs of bionic architecture prevail, or it was simply a whim of the modernist artist embodied in the architectural poetry of life. How can architecture be so versatile and lively, and designs so flexible and elegant? Before Antonio Gaudi, no one dared to realize such a bold fantasy. One of the most authoritative representatives of the modern architectural movement is F.L. Wright. The architect's creative principles are based on the integration of the architectural object with the landscape: "... Each building intended for a person must be an integral part of the landscape, its feature, which is closely related to the area and is its inseparable part." [6]. He embodied this vision in many of his works. The famous house over the waterfall was built in Pennsylvania, USA, according to F.L. Wright's project in 1935. Norman Foster also turns to bionic forms. A well-known British architect is one of the founders of the high-tech style in architecture. He created unusual architecture, using not only new materials, but also the forms that were new at that time. The British master's projects and plans are ahead of his time. He is an innovator and revolutionary in shaping the architectural view of megalopolises around the world (Figure 4).



Figure 4. 30 St Mary Axe. Architect N. Foster.

Famous Zaha Hadid told that in her architectural projects she tried to create natural smooth lines reproducing natural silhouettes. She considered each project individually, taking into account the peculiarity of the scenery and landscape. "Each of my projects is a kind of landscape. It is very important how you arrange the necessary elements in this landscape, what kind of topography it will have, what the incidence of light will be. The architect should think about whether a person will easily navigate in it, whether they can easily find a way back if they want to go back and look again at something what they have already seen. A project must contain a significant amount of strange ... " [7,11,13].

A striking example of bionic architecture is a unique complex dedicated to the scientific development "City of Arts and Sciences", designed by the famous Spanish architect Santiago Calatrava [8]. From a bird's-eye view, it seems that this futuristic complex with its bizarre buildings as if growing out of the pool water is formed by giant structures resembling natural forms: a whale's skeleton, a giant eye, and a lotus flower. Snow-white buildings are reflected in the smooth waters of pools and ponds, framed by countless trees, flower beds, and winding paths of the boardwalk and greenhouse. The ensemble fascinates people of different age, nationalities, education level, who daily fill its ever changing natural and artificial objects with an amazing variety of possibilities for learning various aspects of science, technology, nature, and art (Figure 5) [15].



Figure 5. "City of Arts and Sciences", 1998. Architect S.Calatrava.

5. Conclusion

Architectural bionics has both analytical and practical functions. It aims to significantly contribute to the formation of a modern urban landscape and ecological balance between nature and human. The ecological aspect of the considered issue is also noteworthy. Humanity has imperceptibly "pushed" itself out of nature, having created its anthropogenic environment. Innovative bionic architecture searches for a way "back to nature," and provides its peaceful coexistence with humanity [9,10,12]. Architectural bionics will help people make their dwellings more comfortable, make cities brighter and cleaner, and make the entire world of architecture beautiful and fascinating [11].

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