Architectural bionics and the search for optimal solutions in the unique structures’ design

I A Mayatskaya¹, S B Yazyeva¹, A P Lapina¹, V V Davydova²
¹Don State Technical University, 162, Sotcialisticheskaya str., Rostov-on-Don, 344022, Russia
²Russian State University of Tourism and Service, 99, Glavnaya str., Cherkizovo, Moscow region, 141221, Russia
E-mail: irina.mayatskaya@mail.ru

Abstract. The problem of the building structures’ optimization is considered in architectural bionic modeling on the bionic principles’ basis. The architects realize that the plastic of buildings can be completely arbitrary, but nature provides them with the best solutions. For this, it is necessary to study the structural laws of natural objects and use the ideas for both the structural elements and the entire structure when designing. For the further use of various materials in construction, it is necessary to take into account the variety of architectural solutions. Bionics makes it possible to find the most unusual in form and optimal in structure designs for the design of a wide variety of structures.

1. Introduction
Creating strong and reliable structures of unique buildings is the most important task of construction design. This process is closely related to the search for optimal solutions. One of the modern sciences is developing in this direction is architectural bionics. Many modern architects use bionic principles to design the unique structures [1-3]. In the world, architects often construct the buildings where they use the forms and principles of the construction of natural objects. Such architects as Zahi Hadid, Gottfried Böhmer, Jem Utzon, Renzo Piano, Gottlieb Eliel Saarinen, Aldo Rossi, Frank Owen Gehry and others can be noted (Figure 1).
The harmony of the lines’ beauty and the usefulness of the forms used in nature is a source of inspiration for many architects [4]. The first bionic-style architect was A. Gaudi (Figure 2). He has experience in working in this direction before, for example, in the construction of churches. But in the construction of these buildings only the elements in which we see the application of bionic principles (Figure 3) were used. And Antonio Gaudi applied these methods to the entire structure, becoming a unique brilliant architect.

Figure 1. Opera House, Sydney, Australia (architect Jem Utzon)

Figure 2. Sagrada Familia at dusk, Barcelona, Spain (architect Antonio Gaudi)

Figure 3. Facade of the temple, Barcelona, Spain

Modern architects and designers working in this direction use mathematical modeling methods using modern software systems. Changing the certain parameters, they can choose the best design option in terms of harmony, strength and reliability of the structure.

2. Architectural style in a modern urban environment

The architectural style in a modern urban environment is defined as the city architecture totality taking into account historical and natural features [4-7]. Most often, cities were built on the banks of the rivers (Figure 4). The cities are constantly evolving. Unique constructions arise inside the already existing complex of buildings and the task of architects is to harmoniously fit this object into the architectural ensemble of the city. The construction is in process (Figure 5).
Figure 4. View of London, UK

Figure 5. View of London, UK
In our urban world, the objects that stand out in the urban style, and most often they are built on the basis of bionic principles, appear. So, R. Piano in the design and construction of the center of Paul Klee in Bern (Switzerland) skillfully combined the wave structure of the facade with the surrounding natural environment, making this structure a part of nature itself. Most of this building is underground. Similar structures were built in Russia, for example, the Zaryadye park in Moscow (Figure 6).

Figure 6. «Zaryadye» Park in Moscow, Russia.

When designing modern structures, the architects take into account such a combination of architectural elements that gives the structure itself a unique look. Although nature tells architects the harmony of lines and the constructive combination of architectural elements, but only creative thinking allows this to be achieved. Not blindly copies the structure of natural objects. It only reduces the value of the architectural heritage.

Let us consider the examples of creating the unique structures in the bionic style of the world-class architects. G.E. Saarinen often uses the properties of symmetry, asymmetry in the architectural elements of buildings. His solutions to window openings are interesting. It uses the most diverse form and their combination, making the structure unique. It is necessary to note how the natural environment is harmoniously combined (the object stands on the lake) and the architecture of the Hans Otto theater itself by architect G. Böhm. An unusual composition of the shells is bright red in the form of flying flower petals, a transparent glass cylindrical element and the water surface of the lake. At the same time, all the functional premises necessary for its operation are located in the building.

Architect R. Piano is considered to be one of the founders of environmental architecture, which is also based on bionic principles, in the construction of unique buildings. He applied environmental design and introduced environmental technologies in the construction of the Jean-Marie Tzhiba Cultural Center in Noumea (New Caledonia). This complex impresses with its architectural solutions, making it fantastic.

Architect F.O. Gehry is one of the most famous, who applied the most diverse forms, materials and spatial composition in his structures, which immediately became unique. His buildings with a block composition are interesting. This is the Norton House (California, USA), the MARTa Museum (Herford, Germany), the Vitra Design Museum (Germany) and other buildings.

In the architecture of the Solomon Guggenheim Museum in Bilbao (Spain), the bends of glass walls are combined with undulating surfaces covered with titanium sheets, and the construction of the Walt
Disney Concert Hall in Los Angeles (USA) also uses a similar structure, but steel sheets are used. Although the structure of these objects is similar, they are completely different and unique in shape.

A. Rossi used the elements in the form of cylinders, parts of an ellipsoid, a hexagonal cylindrical shell, symmetry properties in the construction of objects. For example, the library of the school, Fagnano Olona (Italy); Teatro del Mondo, Venice (Italy); the Berlin Block complex, Berlin (Germany); Monte Amiata complex, Milan (Italy); Bonnefanten Museum, Maastricht (Netherlands) and the Schützenstrasse complex, Berlin (Germany).

Architectural bionics is a very interesting direction in which unusual forms and compositions resembling the forms of nature are combined [7,8]. Among the modern buildings it is possible to find the most bizarre designs. Figure 7 shows a structure that resembles a leaf flying over the surface of a lake. This building blends harmoniously with the city’s park environment. On this site are concerts of symphony orchestras around the world. The harmony of nature, music and architecture.

![Figure 7. Venue for concerts of symphony orchestras](image)

The development of architectural bionics has led to the appearance of buildings in architecture using a wide variety of lines and surfaces. This makes the building unique in shape. But modern architects are not limited to this. They use as a structural element a combination of the most interesting in structure and properties layered structures when designing both inside and outside the building. In this case, a wide variety of materials are used: polymer composites, metals, glass, wood (Figure 8).

![Figure 8. Glass structures of modern buildings](image)
Glass structures are widely used in the construction of skyscrapers [9]. One of the first architects who used these trends was R. Piano. His most famous skyscraper is Shard in London (UK). The skyscraper received the name “The Shard” due to the architectural elements on the top of the building in the form of fragments.

The architectural appearance of the modern city is changing. The architects design the buildings and structures of increased number of storeys. An example of a harmonious combination of skyscrapers and the environment is the Moscow City complex, Russia. Figure 9 and 10 show other examples of such a combination.

![Figure 9. Modern metropolis](image1)
![Figure 10. Skyscrapers in urban space.](image2)

3. Summary
In architectural bionics, it is possible to search for new, functionally justified architectural forms and create new rational designs, the harmony of nature and architecture [10].

Bionic-style buildings are completely out of the scope of the traditional perception of buildings. During the construction of such unique objects, attention is paid to new designs of facades, coatings, interior space and materials.

The main components of architectural bionics are the search for optimal solutions; the principle of saving materials and finding new ones; the principle of maximum environmental friendliness; principle of energy saving; harmonious combination of structures and nature. It is necessary to search for new forms and technologies, developing this direction.

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