

The Heritage of the Laboratory of Architectural Bionics and the Latest Trends in Architectural Morphogenesis*

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Abstract—The article describes architectural bionics that was formed in the 1960s in the USSR as an independent direction in the theory and practice of architecture. It has become an organic synthesis of the classical theory of architectural composition and modern technical bionics located at the interface of the natural sciences, cybernetics and engineering. The main feature of architectural bionics consists in its integrated approach of taking the animate nature as part of general spatial environment in which architecture should be organically integrated. The aesthetic component of architectural bionics is its main difference, both from building bionics, and from modern biomimetics. Architectural bionics has become one of the few architectural phenomena of the 20th century that have arisen in Russia and are recognized worldwide.

Keywords—*architectural bionics; biomimetics; morphogenesis; theory of architecture; history of architecture aesthetic; animate nature*

I. INTRODUCTION

A wide interest in the morphogenesis of the animate nature in the theory and practice of architecture throughout the world arose in the early 1960s. It became a logical continuation of various biological analogies, such as organic, classificatory, anatomical, ecological, Darwinian, etc. that existed in architecture for a long time [1].

Already in the 1920s and the 1930s, the so-called “biotechnics” of P. Geddes, L. Mumford and R. Franc é was popular, having had a noticeable influence on architectural projects by F. Kiesler and K. Honz k. In the 1940s F. Severud in America and V.F. Razdorskiy in Russia published their works, which actually anticipated emerging bionics as a science.

In the 1950s the ideas of “biotechnics” were supported by

*The Reported study was funded by Science and Technology Development State Program of the Russian Federation for years 2013-2020 Program of Fundamental Research of State Academies of Science for years 2013 – 2020, within Program of Fundamental Researches of Ministry of Construction, Housing and Utilities of the Russian Federation and Russian Academy of Architecture and Construction Sciences, the Research Project 1.7.1.

new successes in the field of copying the methods of the animate nature by means of engineering, medicine and cybernetics. In 1958 J.E. Steele proposed the term ‘bionics’ “as the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues.” [2] The ideas of bionics were disseminated worldwide thanks to a conference in Dayton, Ohio, which was held in 1960. This conference was attended by seven hundred scientists — biologists, engineers, mathematicians, physicists and physiologists, including Soviet specialists A.I. Berg and B.S. Sotskov [3].

In 1963 at the next conference in Dayton, O. Schmitt proposed a similar term “biomimetics” [4], which subsequently gained a wider meaning, going beyond the fields of medicine and robotics, on which bionics initially focused. Later, some other terms, such as “biomimicry” [5], have been introduced into scientific use, meaning practically the same as the terms “bionics” and “biomimetics”. Modern German researchers G. Pohl and W. Nachtigall identify three main areas of modern bionics/biomimetics as a scientific discipline, “The subjects of biomimetics can be summarized by the three fundamental disciplines of structure biomimetics, process biomimetics, and development biomimetics.” [6]

II. ORIGIN OF ARCHITECTURAL BIONICS

In the 1950s, bionic/biomimetic ideas began to penetrate into the field of construction and architecture. This was stimulated by the emergence of new constructive systems and especially spatial structures, created by outstanding engineers of those times. As a result, many specialists in various fields of knowledge had an interest in researching the fundamental principles underlying such constructive systems.

They found that the morphogenetic principles manifested in the modern spatial structures are also used by the animate nature, but in much more complex and multifunctional systems. This fact was a starting point for the beginning of systematic scientific studies of the biological principles of the structural organization of living matter from an engineering and architectural point of view and the emergence of numerous architectural projects and technical

inventions of “nature-like” “biotectonic”, “biomorphic” structures and other ideas of this kind.

The scientific approach to architectural and structural studies of nature in the early 1960s led to the creation of interdisciplinary teams of researchers, including the German research group Biology and Construction headed by Frei Otto (1925-2015), as well as a group of Soviet specialists headed by Yuri Sergeevich Lebedev (1921-1992), who laid the foundations of architectural bionics.

In addition to the general similarity of goals, there were differences between the two teams. If the German group had set itself, first of all, engineering and design tasks, then the Soviet was focused on solving the complex problems of architecture and building industry and was initially created as a new school of architectural science.

Yu. S. Lebedev began to study the relationship of architecture and the animate nature back in 1958, together with arch. V.V. Zefeld. The first results of their joint work were published in 1962 in the article “Structural Systems in Architecture and Vegetable Kingdom”. In this article the authors formulated the methodology of borrowing the structural principles of plants by the architect based on the general laws of mechanics and analyzed functional analogies between building and vegetation structures. They considered outward forms of the both kinds of structures as results of interaction between the gravitation and the forces of growth and development. Lebedev and Zefeld rejected two possible extremes in approaches to the morphological connection of architecture and nature. They attribute to the first extreme the mechanical transfer of the biological laws of nature and its forms into architecture in isolation from the historical development of society, its constantly changing needs and possibilities. The other extreme is expressed in the belief that in its tectonics architecture has no connection with nature and is created without taking into account its laws.

The authors of the article defined their task as follows: “Studying nature and, in particular, plant tectonics is one of the means that should contribute to the progressive development of structures in architecture and the implementation of its main task by architecture, rather than turning it into an appendage of the plant world. To accomplish this task it is necessary to study those principal aspects of the natural environment that would correspond to the historical needs of society and the possibility of technical use. The goal of this article is not so much in specific constructive proposals, as in an attempt to draw the attention of architects and engineers to the study of structural formations in the plant world so that they also have this material in their creative work.” [7]

By the end of the 1960s, the borrowing of constructive and partly functional principles of animate nature for the practical use became a stable tendency in architecture and building. The theoretical understanding and description of all the accumulated material together with its embedding in the general context of the history and theory of architecture were urgently required. This task was formulated and creatively solved by Yu. S. Lebedev, initiating a new interdisciplinary scientific direction which he called “Architectural Bionics”.

Main principles of architectural bionics were formulated by Lebedev in the period of 1962-1968 and were taken as a basis in his dissertation of 1968 titled “Architecture and Bionics (Research of the Problem of Utilization of Morphogenetic Regularities of the Animate Nature in Architecture)”. Based upon this dissertation the monograph “Architecture and Bionics” was published in 1971. In this book Lebedev extended the theory of architectural bionics and especially aesthetic analysis of modern architectural forms inspired by animate nature. Lebedev impartially criticized ‘biological naturalism’ that was just superficial copying of natural shapes without understanding of their functional origin in nature and their suitability in architecture. The monograph “Architecture and Bionics” became the theoretical basis for the further development of architectural bionics in the USSR and in other countries [8].

In 1970, a laboratory group on architectural bionics began work at the Research Institute of Theory, History and Perspective Problems of Soviet Architecture (NIITI, now NIITIAG). At the same time, the base of architectural bionics as a new science was developed. It included the background of architectural bionics, the general characteristics of its current stage, the substantiation of its laws, and the main aspects of its method, bionic modeling issues, and future development prospects.

Architectural bionics in the early 1970s received scientific recognition, becoming part of the officially recognized scientific directions in the USSR. Thus, in the article “Bionics”, published in the 3rd edition of the Great Soviet Encyclopedia (1970), only the possibility of using bionics in construction and only for a separate example of the internal structure of the bone is mentioned. The article is concerned with bionics as applied to the field of building only in a single phrase: “Analysis of the bone structure, providing its greater lightness and strength at the same time, can open up new opportunities in building industry” [9].

Just after a few years, the article “Bionics” from the Encyclopedia of Cybernetics (1974), writes about architectural bionics the following: “In recent years, another new scientific direction has emerged in which bionics collaborates with architecture and building technics, namely architectural bionics. Using models of nature as samples, such as plant stems, living leaf nerve, eggshells, engineers create durable and beautiful architectural structures: houses, bridges, movie theatres, etc.” [10].

By the early 1980s thanks to the long-term efforts of the team of like-minded persons (architects, engineers, biologists, mathematicians and artists), architectural bionics has finally emerged as a new direction in architectural science and practice. In 1984, the Central Research and Experimental Design Laboratory of Architectural Bionics were organized and became the coordinating center of research in the field of architectural bionics in the USSR and some socialist countries.

III. THEORY OF ARCHITECTURAL BIONICS

Today at the beginning of the 21st century architectural bionics is of particular importance because it considers the

holistic system that consists of animate nature (environment), architecture (technology) and humans. Due to this global approach both the social and technical aspects of society and the surrounding nature are able to develop in harmonic unity.

The following main directions of architectural bionics as a science and creative method in architecture have been developed:

- the basic theoretical considerations;
- methodology of research works and methods of bionic modeling in architecture;
- the history of the use of forms of nature in architectural practice, including in traditional architecture;
- problems of the morphogenesis of animate nature;
- issues of life support of living systems, thermodynamic factors;
- phenomena of natural standardization and unification;
- the problem of using natural manifestations of harmony in architecture, such as plastic of form, proportions, rhythms, symmetry and asymmetries, tectonics, colors, etc.;

- studies of tectonic forms of animate nature, the principles of their transformation and the ability of natural structures to accumulate elastic energy;
- issues of harmonious formation of the architectural in natural environment (the environmental aspect of architectural bionics).

Each of the directions of architectural bionics has a relatively independent meaning, but all of them are aimed at solving a single task of improving architectural forms and harmonizing them. The fundamental direction of research on harmony in architectural bionics is the interaction of function and form, including the interaction of form as an object in the environment. It is this interaction, understood as a dialectical unity that provides an objective basis for the identification and practical use of aesthetic, harmonic principles in architecture and in animate nature.

In 1975, Yu. S. Lebedev schematically presented the structure of architectural bionics ("Fig. 1"). Science of architectural bionics includes theory, method and applied researches. A characteristic feature of architectural bionics is that in it animate nature is connected with architecture by functional, utilitarian and aesthetic (imaginative) associations.

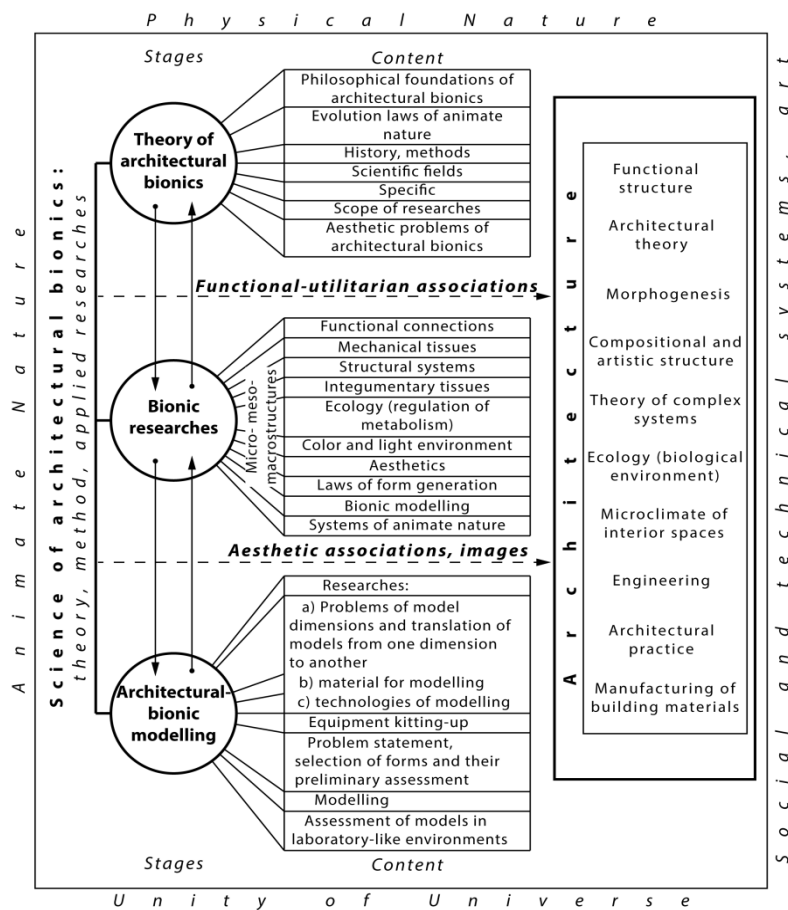


Fig. 1. Structure of architectural bionics by Yu. S. Lebedev [11].

Architectural bionics was considered by Lebedev as part of the theory of architecture. It borrowed its origins and most of its language from the classical theory of architecture. The language of technical bionics in it is auxiliary and is aimed at enriching and expanding the main language of architectural theory. The aesthetic component of architectural bionics is its main difference, both from building bionics of the 20th century, and from modern biomimetics and biomimicry.

In the mid-1980s, Lebedev proposed a concept of the continual development of architectural space in complexity and integrity of the architectural environment. This concept allows translating the problem of harmony in architecture from the language of abstract, aesthetic categories, describing the individual means of harmonization, to an objective, concrete and imaginative language of the expression of harmony that can be formalized. The model of continuous development of architecture space is the space of animate nature, as the highest and most perfect of the known forms of organization of space in the world continuum.

The Lebedev's concept is based on the architectural bionics method, which translates the morphogenetic patterns of the space of animate nature into architecture. "The method of architectural bionics, in contrast to purely quantitative, mathematical methods, unites the abstract and the concrete into one whole: the mathematical laws of form and its emotional image, utilitarian and aesthetic aspects of architecture. It creates a potential basis for the synthesis of science and art, which makes it possible to effectively solve practical problems of architecture." [12]

The concept contains a system of laws (principles) of the continuity of the formation of the space of animate nature oriented to the solution of architectural problems. These principles are consistent with the structure of the physical space, which, together with animate nature, constitutes the space of geobiocenoses. The concept of continuity is interpreted by Lebedev "in the relativistic manner, as its victory over discontinuity in the process of their common struggle. In structural or species relations, animate nature is discontinuous. However, all its spheres are subject to the same basic laws of development, there are no fundamental, qualitative differences between them. The space of physical nature is differentiated into qualitatively different spheres (for example, gravitational and electromagnetic spaces). The distinction between spaces of animate and dead (physical) nature follows from the difference of their essence. For example, in the world of physical nature there is movement, but there is no development, which is characteristic of animate nature." [13]

The space of inorganic nature is the first step in the development of living space that is the space of a higher degree of organization and complexity. Physical space serves as a substrate on which and in which animate nature develops, therefore, laws inherent in the physical world, such as the laws of mechanics, also operate in animate nature. Consequently, it is methodologically correct to consider the spaces of the living and physical, as well as the artificial world in the complex, which is the goal of architectural bionics.

According to Lebedev, a continuously developing space is a constantly self-improving, dynamically balanced, individualized system, elements of which are oriented towards the fulfillment of a common goal. For a continuously evolving space it is characteristic a qualitative variety of consistent forms (consistent polymorphism), based on the reproduction of typical elements (serial homology), on self-regulation, and on the laws of thermodynamics. The continuity of the space in which humans exist must be based on the unity of the physical space, the space of animate nature and the artificial space created by humans. It should become a new, higher form of space in the evolution of the world.

IV. INFLUENCE OF ARCHITECTURAL BIONICS ON THE MODERN THEORY OF ARCHITECTURE

Architectural bionics has become one of the few phenomena in 20th century architecture that have arisen in Russia and are recognized worldwide. P. Gruber, an Austrian researcher from Institute for History of Architecture and Arts, Building Research and Preservation at Vienna Institute of Technology, acknowledges that "the first book on "Architekturbionik" was published by the Russian Juri Lebedev in the 1970s and presents a comprehensive collection of then up-to-date architectural developments worldwide, which relied on principles derived from nature." [14]

Gruber considers herself as a continuer of the line of research begun by Lebedev, which she directly declares: "The author's Ph.D. thesis on "Architekturbionik" is the first strategic search in biomimetics in architecture carried out since Lebedev's groundbreaking work" [15]. In her Ph.D. thesis, Gruber also recognizes the priority work of Lebedev: "The Russian Juri S. Lebedev in the 1960s wrote the only comprehensive work done so far on 'Architekturbionik'. Recent developments in biomimetics in Germany and the UK occasionally touch architecture, but no comprehensive effort is being made." [16]

Gruber's Ph.D. thesis is called "Biomimetics in Architecture (Architekturbionik) — The Architecture of Life and Buildings". In 2011 Gruber published a monograph with the same title, in which she formulated the goals and objectives of her research and their main differences from Lebedev's studies. In the introduction to his monograph, Gruber writes: "The aim of the project biomimetics in architecture — architecture of life and buildings — is innovation in architecture. The purpose of investigating the areas common to architecture and biology is not to draw borders or make further distinctions, or even to declare architecture a living organism, but to clarify what is currently happening in the overlapping fields. The accumulation of knowledge of individual examples is less important than the investigation of the methodology of translating knowledge gained from nature into technical solutions. The objective is to employ biomimetics as a tool in architectural design." [17]

Thus, the goal of Gruber consists primarily in architectural innovations using bionics/biomimetics as a tool and in the development of a methodology for working with

this tool. Attention is drawn to the fact that the goals and objectives of the Gruber biomimetics do not include artistic and aesthetic problems in architecture, which, along with technical issues, are an integral part of Lebedev's architectural bionics. Lebedev defined the architectural bionics "as a branch of science devoted to the study of the laws and principles of the formation of objects and systems of animate nature with the aim of using them to improve technical tools in architecture, create new architectural forms, and enhance the artistic and aesthetic impact of architecture." [18]

At the same time, the Gruber's monograph is of great interest, as it includes examples of the use of the bionic approach in architecture and building in recent decades, which certainly complements the publications of Lebedev, the last of which date back to the early 1990s. Among her predecessors in the study of the relationship between architecture and biology, Gruber highlights Lebedev's work as having no precedent before her own publication, that is, at least until 2008. It should be noted that the only source of Gruber was the German translation of the second edition of Lebedev's monograph "Architecture and Bionics" (1977), published in the GDR in 1983 under the name "Architektur und Bionik". The second edition of the monograph by Lebedev was a popular version of his first edition (1971), based, in turn, on his PhD thesis (1968). Werner Nachtigall repeatedly referred to and quoted in Gruber's works, in turn, quotes the same German translation of Lebedev's "Architecture and Bionics".

Despite the fact that Gruber often quotes the works by Frei Otto, she did not mention the Catalog of the joint exhibition "Nature-like constructions. Architectural Bionics", held in 1983 in Moscow in the Schusev Museum of Architecture. The materials of this exhibition were published by the Institute of Lightweight Structures in the IL series under the name *Leichtbau in Architektur und Natur* (Lightweight Structures in Architecture and Nature) and included an independent part dedicated to architectural bionics, written in both German and Russian [19].

Unfortunately, most of the publications on architectural bionics remain unknown not only abroad, but also in Russia. Today, Russian-speaking readers know mainly the collective monograph 'Architectural Bionics', published in 1990, but written and prepared for publication as early as 1983. It actually reflects the world experience of architectural bionics and related directions of the late 1970s. Nevertheless, this publication today, at the end of the second decade of the 21st century, is of undoubted interest both for theorists and for practitioners of architecture and building.

V. ARCHITECTURAL BIONICS AND THE LATEST TRENDS IN ARCHITECTURAL MORPHOGENESIS

The main searches in the architectural morphogenesis at the turn of the 20th and 21st centuries were largely focused on the use of various computer modeling technologies for complex curvilinear forms resembling living objects. New concepts of interrelationship of architecture and nature are formed, based on dynamic processes, such as growth,

development, evolution, metabolism, for which it is possible to build algorithmic models translated into programming languages.

A typical example of such new "natural-computer" theories has been the numerous projects and publications of the "Emergence and Design Group" established in the second half of 1990 in the UK. M. Weinstock, one of the founders of this group, notes the importance of studying natural processes for understanding the principles of the appearance of forms. "It is process that produces, elaborates and maintains the form or structure of biological organisms (and non-biological things), and that process consists of a complex series of exchanges between the organism and its environment. Furthermore, the organism has a capacity for maintaining its continuity and integrity by changing aspects of its behavior. Forms are related by morphogenetic tendencies, and there is also the suggestion that some, if not all, of these characteristics are amenable to being modeled mathematically." [20] At the same time, Weinstock takes into account the need for research and physical models characteristic of the architectural-bionic method: "Strategies for design are not truly evolutionary unless they include iterations of physical (phenotypic) modeling, incorporating the self-organizing material effects of form finding" [21].

Obvious parallels can be traced between the latest trends in architectural morphogenesis and architectural-bionic methods. To study these parallels, in 2004, the members of the "Emergence and Design Group" interviewed F. Otto. They discussed Otto's modeling techniques with his technology of form-finding in the context of their common interests in natural systems. Otto emphasized the importance of studying the forms and structures of living nature for architects and at the same time pointed out the complexity of such forms and structures. "We need to study biological structures much more. ... Living structure is completely different to artificial technical structures that are shaped by simple geometries. The structure of living nature is very complex. In living structure every element is different. ... Irregularity is important not only in biology but also in technology, and is a field that has not been researched enough... It is necessary that we architects try to understand living nature, but not to copy it. This is one very important task for the future." [22]

Structures of living nature as one of the sources of project knowledge are also considered by supporters of the so-called "New Structuralism" in architecture. They also point to the works of F. Otto as a model of biological research with architectural goals, emphasizing that "biological sources of material structures such as biomimetic organizational principles and studies from developmental biology such as were undertaken by Frei Otto at the Institute for Lightweight Structures and are still today of great interest to architects." [18, p. 18]

The Laboratory of Architectural Bionics under the direction of Yu. S. Lebedev worked closely with the F. Otto' Institute of Lightweight Structures, which resulted in a number of joint exhibitions, conferences and publications. Otto approved the achievements of Lebedev and his team.

The introduction of information about the achievements of Russian architectural bionics to the global scientific use can expand the range of sources of design knowledge for modern architectural morphogenesis.

VI. CONCLUSION

Architectural bionics as a new scientific and practical direction in architecture and building science did not arise randomly and not as a result of copying foreign samples, but was an organic continuation and a result of almost half a century of creative and theoretical searches of many Russian and Soviet architects and engineers. Architects such as N.B. Sokolov (1929), M.Ya. Ginzburg (1939), I.V. Zholtovsky (1953) spoke on this issue. Practical and design searches for opportunities to use the laws of animate nature can be found in the works of V.G. Shukhov, K.S. Melnikov, A.K. Burov, V.E. Tatlin, N.A. Krasilnikov, and others.

The results of research obtained in the Laboratory of Architectural Bionics in the term of several decades allow proposing a new approach to extremely important, fundamental problems. The task of solving the entire scope of engineering, social-functional, and artistic-aesthetic tasks of architecture creates the need for a comprehensive scientific and artistic method of architecture. The bionic method can enrich creative methods of architects not only with engineering “patents” of animate nature, not only with a variety of spatial forms, but also harmonious images that consonant with the human soul, going back to the humane perception of the eternal beauty of nature.

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