

Research on the Similarities of Morphogenesis in Architecture and Nature

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ABSTRACT

This article highlights some of the patterns and trends of form building in the architecture of the early third millennium. An interdisciplinary approach, integrating different fields of science, contributes to the identification of morphogenetic parallelism in living and non-living nature, which is essential in the study of some aspects of architectural theory and practice. The study of the spatial possibilities of architecture, involving different methods of morphological analysis and changing the previous understanding of the functionality, provides new approaches to the formation of the architectural environment of the future. Further development of computer modeling methodology, including the use of cognitive technologies, and artificial intelligence, the study of which lies at the junction of technical and natural sciences, social and humanitarian areas of knowledge, is very relevant. Approaches that integrate modern technologies allow creating new forms of virtual architecture, potentially applicable for real construction. This should contribute to the creation of a comfortable, ecologically, and aesthetically harmonious living environment.

Keywords: morphogenesis, architecture, nature, interdisciplinarity, information technology

I. INTRODUCTION

Natural morphogenesis is carried out by self-organization in inanimate nature, biological morphogenesis is directed by genetic programs, while in architecture, the generation of new forms is a creative process with the deliberate or intuitive application of some laws of natural form building. In the process of modeling the form, a rather simple set of rules can lead to the appearance of complex patterns. Computer modeling and the use of cognitive technology is applicable for the analysis of architectural forms to identify patterns of morphogenesis — both common to non-living and living systems, and specific features of architectural form-finding. Visual images, models, and metaphors of the concepts of modern science can be applied not only to architectural theory but also to the practical work of architects in order to find architecture adequate to the natural and historical context.

The research of underlying mechanisms of architectural morphogenesis and the form itself in the light of modern scientific and technical achievements is relevant for the theory of architecture. The interdisciplinary approach pushes the boundaries of scientific research, helps to reveal the parallelism of architectural and natural morphogenesis, the common features of form building in living and non-living nature, and specific features of the morphogenesis of different systems. For a deeper understanding of the regularities of architectural morphogenesis, it is necessary to enter the vast field of the research of dynamic nonlinear systems, the properties of which are not reducible to the characteristics of their components, and show the newly arising, or emergent features. Interdisciplinary research may include, in addition to the theory of architecture, mathematics (topology, catastrophe theory, and fractal geometry), biology, crystallography, computer and cognitive technologies using artificial intelligence, as well as some applied areas of knowledge like geoinformatics, engineering, and construction geometry. The tasks put forward include the analysis of existing architectural forms, search for algorithms, and adequate models of architectural morphogenesis, the use of topological approach, application of information-computer technologies in experimental architectural design.

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The use of modern scientific achievements in the field of architecture theory, the creation and application of new digital technologies allow us to speak about the emergence of a new interdisciplinary field of scientific research capable of changing the principles and concepts of architectural space creation. The study of commonalities and distinctions of the morphogenesis of architectural and natural objects, the application of modern technologies in architecture and design should promote the solution of problems of organic interaction between architecture and natural environment, contribute to the creation of comfortable, harmonious, and ecologically friendly architecture.

II. MORPHOGENESIS IN NATURE AND ARCHITECTURE

Architectural morphogenesis involves the transformation, which cannot always be exhaustively described in the language of traditional Euclidean geometry and, like natural forms, are more adequately analyzed using concepts and terminology of non-Euclidean and fractal geometry and topology. Such an approach helps to reveal general features of the morphogenesis in living and non-living nature, similarities and differences between natural and architectural forms.

Euclidean geometry, created in the III century B.C., is represented by straight lines and circles on the plane. The geodesic line on the plane is the shortest path between two points, but on the spherical surface, it is a part of the circle formed by the section of the sphere by the plane passing through its center. Spherical geometry is the geometry of geodesic lines on the surface of constant positive curvature; Euclidean geometry is the geometry of geodesic lines on the surface of zero curvature — on the plane. Henri Poincaré created hyperbolic geometry as the geometry of geodesic lines on the surface of constant negative curvature; all Euclidean axioms meet the requirements of this geometry, except the parallel postulate.

The abstract topological theory of morphogenesis was created by the outstanding mathematician Rene Thom, the creator of the catastrophe theory. According to Thom [1, 2], reality appears before us as phenomena of discrete forms, so any form and any morphogenesis is a distinct expression of the properties of our space. The stability of any organism and any structural form is based on its geometrical essence. The quantitative measure of an object as an information medium is the topological complexity of its form. The main problems of form building are topological because it is the topology that studies the most fundamental properties of spaces and allows us to move from local to global aspects of morphogenesis. R. Thom distinguishes between static and metabolic (dynamic) forms, calling a

jet of water, flame, atmospheric vortices, and living beings as examples of metabolic forms.

Traditional architectural forms are static. The gravitational vector inevitably leads to differences between the upper and lower parts of an architectural structure. The great variety of natural and anthropogenic forms is based on a limited number of basic structures and patterns, among which fractal (spiral, dendritic) structures are widespread. The spiral shape is often found in living beings. Symmetry is a way of repeating the structure in the process of its formation. The formation of structures similar to bee honeycombs is a rational way of compact placement of a number of identical, initially rounded parts.

Fractal geometry explores the transformations of the symmetry with changing its scale. Simple algorithms of fractal geometry can generate complex forms of nonlinear fractals of the Mandelbrot set [3, 4] and Julia sets. The formation of a snowflake is an example of natural morphogenesis, which represents both phase transition and symmetry breaking, as well as a cascade of bifurcations and fractal morphogenesis. The general laws repeating in various systems and numerical ratios are often considered as sacral, magic, attracting the attention of researchers and architects, as, for example, the golden section and the Fibonacci sequence associated with it. A number of mathematical formulas and theorems establish regularities of form building: for instance, L. Euler has shown that the number of sides of a polyhedron plus the number of vertices is always equal to the number of edges plus two.

Biological structures that are optimal in the context of natural selection are also optimal in terms of minimizing functional costs. With respect to architectural structures, R.B. Fuller formulated the Minimax principle, which takes into account the ratio of consumed materials to the strength of the structure, as well as the ratio of surface area to the volume of the dome [5]. In some constructions, the implementation of the "Tensegrity" scheme (from the combination of the words "tension" and "integrity"), where the system of rigid rods and stretched ropes interact, is effective. Rods work well under compression, while ropes compensate for stretching. As a result, the design becomes steady against mechanical influences; the creation of kinematic designs is also possible on the basis of this principle.

In living nature, branched fractal structures of organisms maximize the interface organism / environment while minimizing the total volume. Biological morphogenesis is characterized by the manifestations of physical optimization as the minimization of energetic "cost" of structural morpho-functional organization [6].

In architectural morphogenesis, manifestations of cost minimization are also inevitable. The requirements of economy, energy efficiency, reliability are well known to architects and builders, who usually try to realize the principle of minimization of costs in the design and construction of buildings for various purposes, although sacral, ideological buildings fall out of this rule — the function of such representative architecture is special, requiring maximum effect and allowing corresponding costs. For such objects, the use of noncanonical forms and nontrivial geometrical images in combination with large-span spatial coverings is characteristic.

III. MODELING NATURAL AND ARCHITECTURAL MORPHOGENESIS

The modern environmental paradigm does not separate people and the anthropogenic world from the natural environment, considering them as parts of a single ecosystem network. The modeling of the spatial organization of living organisms and objects of architecture with the use of fractal and topological models can be used for the analysis of morphogenesis. The concepts and methodology of interdisciplinary science — fractal geometry, in particular, are successfully applied in such areas as astronomy, physics, chemistry, economics. Fundamental scientific researches aimed at developing neuromorphic computer systems are relevant.

The modeling is one of the main methodological approaches to the study of the formation of natural structures. Alan Turing in 1952 theoretically established that in reaction-diffusion systems of chemical substances various ordered, dynamically transformed structural patterns can spontaneously arise. Later, a real chemical model capable of such spontaneous formation — the Belousov-Zhabotinsky's reaction was discovered. In the 1960s, John Conway created the "Life Game" — a cellular automaton, which included only black and white squares and only three simple rules, which enabled this system to form a variety of pulsating, symmetrical, and moving configurations.

Fractal geometry, topology, and modern computer technologies allow the potential possibility of correct and compact description and modeling of architectural morphogenesis. This will enable us to form a heuristic view of the object under study, for example, an urban cluster modeled as a chaotic fractal cluster, which has common features with similar clusters of living and non-living nature. The methodology of imitational computer modeling gives an opportunity for the experimental construction of virtual architectural objects and the search of new architectural design.

Fractal algorithms and logarithmic regularities are universal rules of morphogenesis both in nature and human creative activity. These algorithms provide an opportunity to construct photorealistic computer landscapes of the virtual world; at the same time, the similarity with reality is achieved by some structural irregularity. Nonlinear fractal algorithms of Julia and Mandelbrot sets encode virtual dynamics of the complex morphogenesis. For experimental construction of virtual structures, discrete models related to the class of cellular automata and diffusion-limited aggregation (DLA) were used, in particular. In such modeling, a very simple set of rules leads to the appearance of complex patterns. Cellular automata have been repeatedly used to model a wide range of physical and biological phenomena. The DLA model [7], developed initially for modeling the morphogenesis of physical fractal clusters, was used to simulate biological morphogenesis, including the morphology of neurons [8], [9]. Since many natural objects are fractals with heterogeneous distribution of the points of a set, or multifractals, to characterize their morphology, it is promising to use analysis with several algorithms successively changing each other [10], [11]. A city in the landscape is also a hierarchical multifractal system, including many scales and several fractal algorithms. DLA variants can simulate the vectorized growth of a cluster (e.g., the growth of a city along such natural limits as a seashore or river) or the interaction of chaotic fractal clusters creating a quasi-fractal network (e.g., a megapolis as an association of several cities). A fractal geomorphology and its influence on urban growth can be taken into account when analyzing and modelling city plans according to the natural landscape. The development of ecological consciousness in modern society and the desire to create humanistic architecture that fits organically into the landscape makes this kind of modeling very relevant.

The fractal dimension serves as an index and measure of filling with the fractal structure of the topological space in which the morphogenesis of this structure is carried out. As an additional characteristic of fractals, B. Mandelbrot [3, 4] introduced the concept of lacunarity as a measure of the heterogeneity of the fractal structure. The fractal dimension was used to estimate the spatial complexity of physical and biological objects; attempts were also made to apply the value of the fractal dimension to estimate the complexity of architectural objects quantitatively [12].

Repeatability and similarity elements are quite typical for architecture. Coherent fractals are suitable for modeling individual buildings and structures, while city plans can be represented by discrete fractals. For the modeling of architectural forms, two-dimensional geometrical fractals are applicable, in particular spiral and branching forms, as well as the graph of the Weierstrass function, but some three-dimensional

fractals are the most perspective. The orderliness of such structures is higher in architecture than in living nature. Unlike simple geometrical and computer fractals with infinite repetition of the same form, in architecture, the rules of construction with the use of the limited number of repetitions, the change of rules of their building, as well as the violation of the strict similarity by the introduction of a set of variations are applied.

The so-called "Menger sponge" may be the most common three-dimensional fractal model or the metaphor of a typical building. The rectangles of windows are similar to the outlines of the whole building, and cubes, or parallelepipeds of the interior spaces — to the entire "box" of the building. Of course, a multi-story building is not built according to the algorithm of the Menger sponge, but fractal algorithms can include compression, rotation, nonlinear transformations of the original form.

Computer modeling, aimed at finding algorithms of the architectural morphogenesis, allows getting the results of a wide range of research — both on the level of urban planning solutions, and the scale of individual buildings and structures. Nowadays, there comes a deeper awareness of the unity of natural and anthropogenic environments and the unity of the principles of formation in the "living" and "non-living" nature. Studies on the commonality and distinctions of the formation of architectural and natural objects should contribute to the solution of the problems of organic interaction between architecture and the natural environment, contribute to the humanization of architectural and landscape environment [13].

IV. ARCHITECTURAL FORM AND MODERN INFORMATION TECHNOLOGIES

It becomes possible to create architecture with the "intelligence" of its own, experimental, innovative projects with the incorporation of new technologies directly into the building envelope, its structures, and mechanisms. The introduction to the architectural practice of the achievements of other fields of knowledge — from molecular research in crystallography and biology to aircraft building technologies — can provide a qualitative leap not only in form-finding techniques but also in the functioning of the new architecture. Learning from nature, we can assume that the best way to interact with the environment is to create some kind of protective shell capable of providing an optimal response to external conditions, functional requirements, and building type.

From the ideas of the "smart house", innovative architectural and engineering projects are gradually developing in the direction of creating self-organizing cybernetic systems. This includes computer recognition

and synthesis of visual images and speech, as well as various areas of robotics, including drone control. Fundamental research should be aimed at the creation of universal artificial intelligence as a system imitating the cognitive functions of a human being. This task is related to the natural sciences, technical, and socio-humanitarian spheres; of course, ethical norms, safety, and protection of human rights and freedoms should be taken into account.

The successful imitations of biological distributed collective systems such as termite mounds, anthills, and swarms of bees look promising. Thus, detailed studies of the patterns of human movement have become possible with the advent of mobile communication devices. The results obtained could be useful for the rational distribution of human and transport flows. It is also essential for medicine, for example, to forecast the spread of epidemics.

Theoretical studies of morphogenetic processes in architecture and urban planning are inextricably linked with applied aspects of creating a psychologically comfortable living environment. Examples of such a solution are the Koch Biology Building and the Brain and Cognitive Sciences Complex of the Massachusetts Institute of Technology, USA, where an interactive space for successful research has been created, providing an opportunity for a spiritual rise, encouraging contacts and interactions between researchers, removing inter-laboratory barriers [14].

The promising direction for the development of architectural morphogenesis is also technologies of the three-dimensional printing of buildings and constructions, allowing to create complex forms and automate the process of the building construction.

Technologies, which create graphical representations of mathematical concepts, nonlinear dynamics, fractal geometry, and topology, make them visual for architects and give an opportunity to "translate" modern scientific terminology into the language of architectural theory and export concepts of interdisciplinary science not only in biology [15, 16], but also in architecture theory. New spatial forms of architecture, created by means of a computer, can be called the "virtual style" or "virtual architecture". Both virtual and real architecture exist simultaneously, interacting and complementing each other.

V. CONCLUSION

So, the analysis and study of natural and architectural objects, regularities and principles of their morphogenesis with the use of cognitive technologies and the construction of computer models lead to the identification of previously undiscovered aspects of form building. Concepts and methods of modern interdisciplinary science apply not only to the theory of

architecture but also can expand the capabilities of practical design. In experimental architectural design, it is possible to use algorithms, visual images, and metaphors of nonlinear interdisciplinary science. New concepts and a new language of architectural science give rise to a new understanding of the forms of universally recognized examples of world architecture, the principles of harmonic integrity of the architectural environment and contribute to the solution of a number of problems of architectural formation, which cannot be fully understood without going beyond a narrow professional approach. The study of the commonality and distinctions of architectural and natural objects should contribute to the solution of the problems of organic interaction between architecture and the natural environment, contribute to the creation of a comfortable and environmentally friendly architectural and landscape habitat.

Computer modeling and the use of artificial intelligence elements, aimed at finding the algorithms of architectural formation, will allow getting the results of a wide range of both at the level of urban planning decisions and on the scale of individual buildings and structures; creation of diverse conceptual projects is possible. It can become a new vector of innovative development of architectural science, besides theoretical and historical directions of researches.

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