

# Geometrical Possibilities of the Modern Architectural Morphogenesis\*

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**Abstract**—Innovative architectural forms arise and develop at the intersection of science and art, architecture and engineering. Architecture and design have become the areas of practical application of mathematical concepts of spatial fragmentation. The approaches used in the classical geometry and “new” non-Euclidean geometries can be applied to a certain extent to the development of the spatial potential of architecture and urban planning. This particular work is related to various scientific areas, including geoinformatics, biology, crystallography, engineering geometry and computer modeling. The interdisciplinary approach allows us to reveal the spectrum of new geometric shapes, as well as patterns for space-filling and fragmentation of a two-dimensional surface and three-dimensional space. The study is of a theoretical nature, although the results can be applied in educational practice and experimental design.

**Keywords**—*morphogenesis and architectural geometry; architectural and landscape urbanism; morphogenesis of nature; innovative and virtual architecture; computer modeling; spatial fragmentation*

## I. INTRODUCTION

Globalization, digital revolution, a change in aesthetic perceptions within the framework of the ecological paradigm inevitably has an impact on the architectural morphogenesis. Architecture today develops in conjunction with exact and natural sciences; the introduction of the achievements of these sciences to architectural theory and practice can contribute to qualitative changes in architectural morphogenesis and performance. Modern ecological thinking approaches the terrestrial biosphere as an integrated whole, a single network of organisms and man-made objects interacting with each other and the inanimate nature. There has been a major advance made in understanding of the need for preserving the natural and cultural heritage and creating an eco-friendly landscape and architectural environment. Studies of transformations of the architectural and landscape environment are becoming more and more relevant, as well

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as the inquiry of "palimpsest" manifestations in architecture and urban planning, and changes of geometry and topology. The current urban environment provides numerous examples of successful integration and revalorization of historical and innovative structures. The implementation of informational and morphological interrelations of local and global mechanisms of architectural and town-planning morphogenesis, along with the thorough record of their subsequent interworking can generate an adaptive, conformal architecture, organically integrated into the existing environment.

An interdisciplinary approach pushes the scope of scientific research, helping to identify parallelism and commonality of natural and architectural morphogenesis. Architecture and design are the areas of practical application of mathematical concepts of spatial fragmentation. The present study is connected with other scientific fields and specializations, among which we can mention geoinformatics, biology, crystallography, engineering geometry and computer modeling. The question of architectural variability incorporates the landscape as an integral part of the complex architectural composition.

## II. HISTORICAL BACKGROUND

Examination of the geometrical laws of the forms' organization allows clarifying many issues of architectural morphogenesis. It is important to note the achievements of a numerous researchers of the architectural forms and space - it is enough to recall the engineering art connoisseurs - V.G. Shukhov, G. Eiffel and R.B. Fuller. The analysis of architectural morphogenesis is a part of the issue of studying morphogenesis in such different realms as inanimate and living nature and man-made forms. At the turn of the XIX and XX centuries technologies already allowed creating the new types of buildings that were inspired by the new technological order - commercial and industrial exhibitions, markets, train stations, various kinds of large-scale industrial structures and other buildings, such as the Crystal Palace, Eiffel Tower, buildings for the World Exhibition in Paris, or the structures for the 1896 fair in Nizhny Novgorod. Later on new technological innovations came into existence, new forms appeared, for example, the domes and space structures designed by R.B. Fuller. It is important to note that many of

those works represent a fusion of engineering, architecture and design in a broad sense.

A laboratory group on architectural bionics has been working at the Scientific Research Institute of Theory of Architecture and Urban Planning (NIITIAG) since the 1970s. Few enthusiasts in the world and in Russia are actively developing various trends in architectural and artistic form-working, creating unique objects based on the latest achievements of modern fundamental and applied science. It is the principles of morphogenesis that change the usual understanding about the architectonics of the created objects. This kind of researches, projects and models often has exceptionally artistic value, although in general, they broaden and deepen our understanding of the geometric and topological possibilities of exploring the space of the world around us. It is quite evident that with the interest of potential investors in the emergence of exclusive objects of architecture, such studies can create a whole range of new architectural forms, implemented both in small and large urban scales.

The fundamentals of studying the geometry of space were laid as far back as the Paleolithic time, and the most active development it received in the times of ancient Greece. Platonic solids underlie the modeling of a multitude of spatial forms in nature and architecture. Despite the sufficient knowledge of the Archimedean and Catalan solids, their use in architecture is quite limited and sometimes somewhat grotesque. However, it should be noted that with the development of computer technology, a number of innovative, in terms of architectural morphogenesis, projects have emerged. The principles of bionics and biomimetics still remain relevant to architecture. Although, a synthesis of various technologies of nature - both living and non-living - seems to be more promising [1].

Mathematicians G.F. Voronoy (1868-1908) and B.N. Delaunay (1890-1980) created new mathematical methods of fragmentation of surfaces that resemble some "chaotic" natural structures. Such structures were not used in architecture and were known only to a narrow circle of mathematicians before the beginning of the XIX century. In many projects of the early 2000s there was a gradual departure from the regular and symmetric splitting of the surface and space to the biomorphic one based on the Voronoy-Dirichlet algorithm [2]. At that, chaotically or pseudo-chaotically located units were arranged in a natural pattern, similar to the structures of living cells. It is appropriate to talk here about the development of the entirely new direction in the field of design and architectural morphogenesis, which can be very auspicious in both small and large scale forms in architecture and urban-planning.

### III. GEOMETRY OF THE ARCHITECTURAL FORM IN THE CONTEXT OF MODERN TECHNOLOGY

In modern architecture the form itself is generated simultaneously by new technologies and new ideology. It is quite difficult to call it architecture, design or art, and it refers to some sort of a fusion embodying and implementing interdisciplinary approaches. Projects and built structures are

able to simulate and generate the movement in static materials, embodying outstanding scientific achievements and design methods. Changes in the architectural paradigm and continuously developing technological capabilities make it possible to get more and more interesting results in architectural creative work every year. Such approaches actually and virtually change the geometry of the existing architecture and make it able to respond to human influence.

Currently there are more than five hundred geometric surfaces of nearly forty groups that are applicable in the architectural and construction fields: linear (of zero, positive and negative curvature), rotation surfaces of various types, spiral, umbrella-shaped, saddle-shaped, kinematic, algebraic surfaces of several tiers, quasi-polyhedra, etc. Folded systems, hyperboloid, geodesic, dome and vaulted forms are worth mentioning as well. Few abovementioned forms have found their place in architecture. To a large extent, this state of affairs is due to the designers' lack of knowledge of the possibilities of morphogenesis, which can be explained by the lack of attention to the relevant disciplines in training and not due to the technical complexity of realization. It is worth recalling the era of the Soviet architectural avant-garde, when the interest in such constructive solutions often outpaced technological capabilities.

There is entire world of various polyhedra discovered by the present time; it included irregular and non-convex polyhedrons, polyhedrons with holes, topologically deformed polyhedra, hypercubes, and complex combinations of different forms. Visualization of the abstract mathematical concept of hyperspace has already served as a metaphor for humanitarian ideas. The uniform laws of the topological organization of our world can concisely and correctly be formulated mathematically. When building three-dimensional models, these principles are visualized quite clearly; and the volumetric physical models obtained as a result of using three-dimensional printers could become the visual aids for demonstration during presentations or in educational process.

The absence of fivefold symmetry in inorganic matter was known as a crystallographic constraint. At the same time, quasicrystals are characterized by five-ray symmetry, "forbidden" in canonical crystallography, but widespread in the world of plants and animals. In addition to the five-ray symmetry, crystallographers' studies of quasicrystals revealed other seemingly impossible patterns with axial symmetry of the 7th, 8th, 10th, 12th, and even higher tiers, "forbidden" for ideal crystals [3]. The authors of this discovery were awarded the Nobel Prize, and their work has its roots not only in crystal chemistry, but in the study of the previously unknown and denied principles of geometry. A similar discovery was made by K. Novoselov and A. Geim [4], who received the Nobel Prize as well for the research on graphene.

Gradual fragmentation of polygons of the polyhedron, projected onto the sphere described around it, makes it possible to create domed and vaulted structures of high strength that do not require internal supports. Such structures are not a simple grid construction, but a complex system,

execution of which needs rod elements and connections of various types.

The topology of the organization of the physical space around us explains the manifestation of the laws and principles of morphogenesis common for the non-living, living and anthropogenic man-made world. The task of dividing a three-dimensional space into equal polyhedra solved by a mathematician William Thomson, 1st Baron Kelvin (1824-1907), leads to a 14-hedron. It is worth emphasizing here that this mathematical problem was solved by him more than a century ago, but, unfortunately, it did not attract the particular attention of architects, despite the widest technological possibilities that have opened up in recent decades. Even though further research in the development of such ideas has been also conducted [5].

The fundamental method of self-organization, called "tensegrity" — this term is composed of two truncated words: tension and integrity — was formulated by R.B. Fuller [6]. Rigid structures create a stressed whole (tensegrity) function in both anthropogenic and natural complexes, for example, body systems, tissues, and cells. When calculating the strength of various structures from a physical and engineering point of view, the structural rigidity of polyhedra and other structures constructed of strained rods is of interest.

In addition to the standard geodesic layouts of the Fuller-type spherical surfaces, new versions began to appear, including rotary symmetry. They are created on the basis of so-called "snub" shapes with offset, twisted or skewed symmetry [7]. The twist can be clockwise or counterclockwise, thereby constituting right or left side symmetry. Many constructions in nature are built in the same way.

Fractal geometry [8], topology and modern computer technologies provide the potential for correct description and modeling of morphogenesis, including architectural one. Fractal algorithms can include compression, rotation, nonlinear transformations of the original form. Fractal modeling, rendering and visualization of developing fractal structures became possible only because of the computer technologies. Evolution of the ecological consciousness in modern society and the desire to create ecological architecture that blends perfectly into the landscape makes this kind of modeling of current importance [9]. It is quite evident that with such development of the technologies, large-scale and bright examples of architectural or geo-architectural design with their subsequent implementation are to appear.

#### IV. PROSPECTS FOR INTERDISCIPLINARY RESEARCH ON MORPHOGENESIS AND HABITAT DEVELOPMENT

Over the past 20 years several Nobel Prizes in Chemistry and Physics have been received for the work in the field of crystallography (in a way, geometry) [10], [11]. We only have to wait for this trend to receive sufficient awareness and advancement in modern architecture of the world, and to be distinguished with the Pritzker awards.

It is already quite possible to make a standard "box" or a shell structure with a pseudo-bionic surface system based on one or another mathematical algorithm. However, interior spaces are usually simpler to create in the traditional orthogonal coordinate system; at least this was a case before the appearance of connection between the designer's computer and the machines producing construction details at the factories. The morphology of the new architecture is formed by external factors in combination with the internal organizational logic. In fact, a new morphotectonic typology of buildings has emerged based on mathematical pseudo-biomorphic principles. The implementation of informational and morphological interconnections among local, regional and global mechanisms and the calculation of their subsequent interactions can generate an adaptive, conformal architecture that is organically integrated into the existing environment.

Often projects tend to use symmetric fragmentation and spatial frame grid. The examination of minimal surfaces leads to the study of the caused by surface tension geometric properties of liquids in natural systems, e.g. the structure of foam. Mathematically, such structures are modeled using dense packing of balls with conglomerates in the form of twisted polyhedra connected with each other by means of the minimum contact area [12]. Dense packs change the nature of the interaction of structures: if there are six contiguities in a cubic system, there are more than 20 contiguities for one polyhedron.

Analyzing the data obtained from the study of natural physical phenomena, we can distinguish mathematical algorithms that accurately simulate natural principles and lead to the creation of ordered structures while minimizing the amount of materials used. New town planning formations are generated parametrically, optimizing the flows of people and the interaction of various systems. The volumes are increased according to the principles comparable to the growth of coral reefs, druse and crystal splices with a dynamic change in local and global morphogenesis and partial fusion of systems.

Avoiding symmetry becomes rational, reasonable and technologically accessible. In architectural projects, complex curvilinear bioforms, biomimetics and biomimicry as imitations of biological structures appear more frequently; the ideas of emergence (the emergence of new properties of complex systems generated by the interaction of their components) and "tensegrity" are used. The term "tensegrity" was also applied to the explanation of the properties of a stable, mechanically tense, integrated living cell cytoskeleton [13], [14]. Visual images, models and metaphors of the modern science concepts can be applied not only in architectural theory, but also in the field of architectural practice as a medium for the search of architecture that is adequate to the natural and historical context [15]. The problem of engineering and architectural diversity as a kind of biodiversity includes the consideration of the landscape as an integral part of the architectural composition; as well as the creation of structures designed for long-term service with the possibility of transformation and adaptation to changing conditions. Psychogeography



explores the impact of the environment on the psychology and behavior of a person; the environment can cause the most diverse range of emotions, both positive and negative. This question requires further investigation, and some works deserving attention have already been made [16].

Incorporating architecture into the existing environment becomes extremely important, as sometimes does the opposite tendency of separation, isolation, elevation of architectural structures above the landscape; the latter often makes a somewhat an “alienated” implant out of the building in modern architecture. The geometric potential of architectural means is far from being exhausted; nontrivial landmorphic solutions are possible; geo-landscape structures allow forms similar to the natural. In that context, one recent and quite interesting architectural and landscape experiment in the historical center of Moscow comes to mind. Landscape Park had been created by the winners of the international competition, American bureau Diller Scofidio + Renfro, in September of 2017 in the downtown Moscow. Artificial terrain has been executed in the park, into which a number of buildings of various purposes have been integrated; numerous new unexpected view points and visual perspectives have appeared on the site. The artificially created amphitheater is crowned by a “glass hood” - a curved spatial coating formed with glass triangles enclosed in a metal frame. Such roofing systems seem very promising from both constructive and architectural-artistic point of view; they allow creative architectural designs for the regions with mountainous and rugged landscapes. The techniques of this kind expand the range of architectural and spatial forms and solutions for large-scale design of a wide variety of structures [17].

Thus, the new technological approach with its exponential development and the results of the studies on the parallelism of architectural and natural morphogenesis can find application both in the practice of architecture and design, and in teaching theory and history of architecture. The use of such tools and methods contributes to obtaining qualitatively new illustrative and analytical materials. A modern scientific approach can be successfully applied to the search for an architecture that is suitable to the natural and historical context.

## V. CONCLUSION

Avoiding traditional orthogonal thinking is the realm of innovators from architecture and engineering. Their approaches generate perspectives in the form-shaping of public buildings and technical structures, allowing them to be more artistically meaningful. For a clearer understanding of morphogenesis, it is necessary to go beyond the narrow specialization into a practically limitless sphere of research of natural structures and processes, a single interdisciplinary field. Approaching nature in terms of morphogenesis and ideology, architecture today still remains inanimate, only imitating wildlife. Though this is quite understandable, since architecture by definition is an anthropogenic environment, and self-developing “architecture” is closer to the ideology of transhumanism. However, it is possible that at some stage of their development technologies will allow some structures,

for example, the ones undergoing a process of biomineralization, to be used in the construction of future buildings. The achievements of scientific and technological progress and new discoveries in various fields provide us with new opportunities for improving the habitat of mankind in the third millennium, as well as the advancement in history and theory of architecture.

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