Creating unique objects of architecture and environmental design with the use of additive technologies

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Abstract. The article considers the possibility of implementing bionic forms in architecture using additive technologies. Parametric buildings and design products interact with the surrounding space, political context, social norms, and cultural traditions. Additive technologies, as a way to implement the spatial structure in architecture and design, have allowed us to open new horizons of shaping in the design of spatial structures that are inaccessible to conventional production methods, or too time-consuming for them. With the use of additive manufacturing, you can develop a unique interior design or small architectural forms for the improvement of the urban environment. Students of the Sochi State University are working in this direction.

1 Introduction

Additive technologies continue to develop at a very rapid pace, and their capabilities open up new opportunities in architecture and design.

A number of brilliant webinars prepared within the framework of the only Russian exhibition of forming equipment Rosmould attracted the attention of a large audience.

Dmitry Shelamov, head of Rosmould and Rosplast exhibitions, answered questions about what the year 2021 promises.

This year, the exhibition has gained the support of global, including foreign associations:
• The exhibition "3D-Tech-Additive technologies and 3D printing" is supported by the brand Formnext and the German association "VDMA" - "Working Group " Additive Manufacturing".
• Rosmould exhibition has gained support Ministry of Industry and Trade of Russia in the direction of "Additive technologies".
• With the support of the Federal Ministry of Economy and Energy, an official pavilion of German manufacturers is being formed.

In addition to the exhibition, we traditionally prepare a rich business and educational program.

This year will be held:
— forum of additive technologies;

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Additive technologies are becoming increasingly widespread in many areas of human activity today. According to Wohlers Associates, the world market for additive technologies will quadruple (up to $21 billion) over the next few years. In industries such as medicine, mechanical engineering, consumer goods, manufacturing, 3D printing is used very widely, when, in architecture and design, it is just beginning to develop.

Manufacturing processes using additive technologies have fundamentally changed the generative methods of shaping the spatial structure. They have transformed the manufacturing process into continuous product technology, where additive technologies are divided into three categories: 3D printers, mobile robots, and a manipulator [2].

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2 Materials and Methods

To create a complex architectural and design object, it is necessary to study nature, and study its laws, which is reflected in the architecture of the world. For example, the interior of the luxury plumbing salon in London, created by Zaha Hadid based on the study of nature, is water drops (Rosa London Gallery). The water element flows through the entire space, and of course connects the interior with the exterior. "Giant drops" of water unite the zones of this large territory (Fig. 1).
As well as the building-skyscraper "Cucumber", the project of which was created by the famous architect Norman Foster. The "Rotating Torso" building, designed by architect Santiago Calatrava, is a skyscraper based on the study of the male torso and many other architectural objects of the world. Students of the Sochi State University tested this method (Fig. 2).

![Fig. 2. Stylization and transformation of bioform (mussel). The work of a SSU student.](image)

The study of natural forms gradually covers all the complex problems that arise when creating an architectural and design object. SSU students conduct research on the external and internal environment with a gradual complication of professional issues (Fig. 3) [5].

![Fig. 3. Small architectural forms (mussel). The work of a SSU student.](image)

To create complex small architectural forms based on a bioform, a parametric design method is used, which includes the main stages of the computational design process, using the example of tools such as Rhinoceros 3D + Grasshopper.

- Shaping
- Form Processing
- Analytics
- Optimization
- Fabrication
- Assembly.
2.1 Shaping

Nurbs-surfaces. Nurbs modeling allows you to create arbitrary biomorphic geometry using nurbs curves, which are very easy to work with in Rhinoceros, unlike many 3D modeling packages. Also, to create such a geometry, the Autodesk Maya program is used (mainly for sketching).

Fields. Using the Grasshopper + plugin Flowl it is possible to distribute the geometry according to the principle of magnetic fields, which makes it possible to generate complex specific geometry.

Metaspheres (metaballs). The effect of splitting spheres that can smoothly merge into each other can be achieved with a special script for Grasshopper [3].

The minimum surface is the surface of zero mean curvature. Such surfaces, in addition to solving the problem of saving material, can form very complex bionic structures. It was actively used in the research of the German architect Frye Otto, who later founded the Institute of Light Structures in Stuttgart. Among his works is the roof of the Olympic Stadium in Munich, 1972 [2].

The Catenary Surface is based on the principle of the chain line, which can be obtained by fixing the two ends of the chain. The sagging chain is in balance and only one force acts on it – stretching. If we reverse such a construction while maintaining the shape of a chain line, then the forces acting on each node will remain the same in modulus, but their directions will turn in the opposite direction. This means that the system will be in equilibrium, but now each node will be affected by one force-compression, there will be no effort to break or shift. Therefore, chain lines are of great constructive value when creating arches, domes and vaulted structures.

Moreover, as Timur Arslanov writes in his article "Chain Surfaces "[4], people like aesthetically chain forms in architecture because of our intuitive understanding of physics. We can predict the behavior of physical systems at an unconscious level, such as how hard a ball needs to be thrown to hit a target. We also know how the force of gravity, on the basis of which the chain surfaces work, works, so it seems to us that gravity acts in the opposite direction, that is, upwards. A person gets the impression that the chain structure (dome or arch) has a negative weight, and does not stand on the supports, but rather holds on to them so as not to fly away. This technique of visual relief of overhanging structures could not fail to interest architects. The first conscious example of the use of chain surfaces in architecture is St. Paul's Cathedral in London. But the most famous works of Antonio Gaudi (Sograda Familia, the project of the hotel "Attraction", etc.)

Multi-agent systems. Agents are smart objects that move in the virtual space according to the specified rules. As Tim Cherkasov says in order to understand this more deeply, let's imagine a swarm of bees, depending on
the trajectory of movement, the location of the bees relative to each other, it can take completely different, bizarre forms [5]. At the same time, each bee has a so-called "set of rules" by which it moves in space. For example, it should not collide with other bees, it flies in a certain direction, or attracted by a certain goal. Adding all these elements in the form of bees, we get a single organism that lives according to certain rules. We can work with a set of rules using the information of each element.

Simulating the complex behavior of agents allows us to obtain a complex object geometry. You can also use agents in the opposite direction—set a simple basic shape and direct the agents to destroy it, simulating natural processes such as leaching or weathering.

Quelea is a plugin that allows you to simulate agent systems in Grasshopper. Before that, all agent-based modeling was created only in Processing.

3 Experimental results

Bionics is a science located on the border between biology and technology, one of the important problems of engineering based on a detailed analysis of the structural systems of living organisms, applying the principle of saving material, energy, and ensuring reliability.

In art, this trend originally emerged as a stylistic imitation of natural forms. This phenomenon in architectural practice, which originated in the early twentieth century, received the term "organic architecture".

One of the brightest representatives of organic architecture is considered to be Antonio Gaudi. His buildings—the House of Mila, Sagrada Familia, etc.—are the apogee of the bionic architecture of that time.

The organics of this time are represented by individual projects, and the international style is becoming widespread. Here it is worth noting the "Style" group of Le Corbusier, all the directors of the Bauhaus - Gropius, Hannes Mayer, Mies Van der Rohe, who just focused on the engineering approach to architecture. At this time, under the influence of the prevailing functional paradigm, organic architecture developed in such directions as bio-tech, neo-organic, structuralism and deconstructivism. With the experience of searching for the economic efficiency of modernism, the architects of post-modernism are again beginning to experiment with non-linear forms.

One of the first major projects to use this method is the Guggenheim Museum in Bilbao, designed by Frank Garry. Of course, from the point of view of aesthetics, this is deconstructivism, in the sense that this project exists in non-orthogonal axes and has a dynamic composition. But from the point of view of methodology, it is absolutely computational. When designing the building, CATIA machine-building CAD (computer-aided design systems) was used. The facade of the building is lined with titanium sheets with a total area of 24 thousand m2. The building was started in 1991 and finished in 1997 and still brings huge profits to the city and its owners [6].

Thus, modern architecture is already at the stage when it overcame first excessive rationalism, then reactionary postmodernism with a constant search for a new aesthetic and is now ready to come to the synthesis of visual harmony and constructiveness. And the task of modern designers and architects is to make their aesthetics as effective as possible.

Here we come to the modern concept of bionics as a component of the computational paradigm, which overcomes the gap between organic forms and functionality that existed in
this direction before. A computational method, like any other, has its own features and design stages. Parametrism is often used for this purpose.

Parametrism-design using innovative computing technologies, applying digital modeling techniques that were borrowed from the automotive and aviation industries. They help you change project parameters in real time. (Parametricism as Style — Parametricist Manifesto)

Based on the "classical" typology, the origins of parametrism come from the works of the German engineer and architect Fried Otto, who was the first to apply the "shape search" method to the design of environmental objects by simulating physical processes.

Such design methods became widespread only in the 90s, when affordable computers and the first digital architects, such as Greg Lynn and Lars Spybrook, appeared. The further introduction of digital technologies and programming into architecture and design greatly influenced many avant-garde architects, who began to actively apply computational design methods in their work[7].

Today, the official birth of parametricism as a style can be considered 2008, when the "Parametric Manifesto" by the architect and theorist Patrick Schumacher was published. Parametricism, according to Schumacher, was the response of the post-industrial society to the almost century-old hegemony of "Fordist" modernism in architecture and design. Parametricism does not use identical repeating elements and regular geometric shapes. Therefore, now in architecture they actively use smooth flowing forms, interdependent elements and variations of self-similar forms.

**4 Discussion**

Parametrism in Russia today is embodied in small architectural forms, for example, in the design project of benches installed during the reconstruction of pedestrian zones in the city of Moscow, fragments — in the design projects of the interiors of office, residential premises and public cafes. Parametric methods are also used in a number of architectural workshops to optimize some parts of a design project.

A bright interior design of the cottage using a parameter that can be implemented using additive technologies was presented by students of the Sochi State University (Fig. 4-9).

![Fig. 4. Cottage facade.](image.png)

The design project of the one-storey cottage is designed on a complex terrain, the difference is 36 meters. The facade of the house is made with masonry, huge windows, solid wood and metal beams. The outdoor terrace is decorated with stoneware, imitating wood, which gives this area an incredible delight and comfort (Fig. 4).

For each interior of the cottage, an individual solution was offered: Living room, combined kitchen and dining room: It is a very large, airy room with high ceilings, facing the courtyard with a swimming pool.
The living room is the heart of the house, designed for the whole family, for a good time, here they receive dear friends and relatives (Fig. 5). The entire room is designed in a modern, parametric and loft style. It was decided to use parametric lines. Complex shapes flow smoothly from the ceiling to the walls. The molds are made of solid wood and plastic. The furniture has both modern and parametric forms. A number of decorative items are made of metal.

Traditionally, design and architecture break through the wall of proven recipes: they bring originality to decorative techniques, expand the range of modern products, in which metal and architecture play a refined game. Through the whole set of useful, intellectual and abstract metal crafts, a metaphorical theme suddenly breaks through. These products exist at the limit of the taut string of forms of the highest tension, knocking them out of the ordinary [10, p. 250].
The kitchen and dining room are made in the same style (Fig. 7).

Billiard room: A multifunctional room designed for a good rest and a pleasant pastime. The billiard room is not austere, but original designed in a parametric style with elements of masonry (Fig. 8). Located on the upper part of the cottage, the entrance from the terrace. In this room, materials such as solid wood and stone were used.
Home theater: This is no longer just a luxury and delight, it has become a truly integral part of our lives. The interior is dominated by unreal shapes, thanks to the soft transition of lines from the ceiling to the walls, completely made of solid wood (Fig. 9). Sound-absorbing panels and floor carpeting improves acoustics. Home theater management is automated, you can control the lighting, screen, sound, etc.

The coloristic solution of the interior is based on natural motifs - the territory on which the cottage is located. Color culture is multi-layered, carries semantic, emotional and aesthetic information, and is characterized by a system of well-established and associatively emerging semantic meanings of color.

The core of color culture is the color language, which expresses ideological and artistic ideas. The communicativeness of the form is not so much permeated by the unified specifics of the landscape color of the region, including the richest metaphorical imagery, but also by the semiotic content of plastic and graphic forms [8, p. 20]. The cognitive attitude to the natural environment forms the ability of a person to transform the world according to the laws of beauty, expediency and not to break away from the natural roots, to be sensitive to the environment, to be an integral part of it [9, p. 250].

5 Conclusion

Today, when using 3D printing, new opportunities are opening up in shaping for the implementation of spatial structures in design. They are unavailable for conventional production methods, or very laborious to execute. Digital production shrinks the production chain, eliminates intermediaries between the architect and the final object of architectural creativity. And therefore, the use of additive technologies makes it possible to move to an innovative level of architecture, which blurs the boundaries between the information model and the real environmental object.

Architecture and design products in the style of parametrism using additive technologies interact with the subject-spatial environment, political context, social norms, and cultural traditions.

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