

# Ractal structures in architectural design

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**Abstract.** The high rate of urbanization in the modern world requires a conscious approach to architectural design. A person needs an environment that fills him with new strength and does not drown out his creative potential with monotonous routine. Due to its natural feature, fractal architecture meets these requirements. The article examines the signs of fractal systems in relation to architecture, highlights the concept - "the principle of fragmentation of a fractal", the term "self-similarity" is broader. In addition, the existing experience of fractal architecture has been analyzed, and the relationship between fractality and the success of the project has been revealed using the example of existing objects. The materials of this article can serve for the further development of the theory of creating fractal architecture. Keywords: architectural design, fractal architecture, fractal structures, fractal.

## 1 Introduction

Our world is a higher system, where there are many interconnections and processes. Each of the subsystems of the higher system is coherent with respect to others. Accordingly, a change or a policy of focusing one element in a direct impact on another.

Man and his environment are one and interdependent [1]. The transformations of the environment cannot but affect a person. Architecture is a powerful tool for creating artificial habitats. And as in any "healthy system", the agreement of its elements is necessary, so there must be harmony between the natural and artificial environment. According to [2], a reasonable dynamic balance of nature and society will give its results: harmony of the intellectual, emotional and volitional spheres of a person's personality.

A person as a biological individual unconsciously always strives for nature, for an environment that fills him with new strength. The connection of people with certain natural fractal patterns has a positive effect on human nervous activity and the mechanisms of the parasympathetic system, this and many other conclusions in favor of the beneficial effects of nature on humans are presented in the study [3] on biophilia (love of life and all living things). In the article [4], using the empirical literature as an example, it is proved that people demonstrate a positive emotional connection with a certain set of natural elements and conditions, namely with vegetation (trees, plants, flowers) and savannas. Environmental psychology researcher M. Heidmetz [2] describes that the increase in artificial objects of a structured urban environment requires greater variety and specialization of design to create a favorable range of comfort for such an environment. If a

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person cannot always have enough imagination, then, as Benoit B. Mandelbrot writes about this in his book [5] "The Fractal Geometry of Nature", "nature has never suffered from such a deficiency».

By the way, it was this book that became the author's bestseller in the 1970s and fundamentally changed his worldview in relation to nature, opening up a great prospect for research in various scientific fields, where architecture was no exception. This is how the direction of "fractal architecture" was formed, which at the heart of its philosophy satisfies the need for harmony with nature.

The objective of the current study was to analyze the application of fractal systems in architecture, to reveal the principles and terms of fractal architecture more broadly, to reveal the relationship between fractality and the success of the project, to contribute to the creation of the basis of the theory of fractal architecture.

## 2 Materials and Methods

In order to achieve the set goals, within the framework of this study, the analytical method, the method of mathematical modeling and the method of synthesizing various fields of knowledge were applied.

Benoit B. Mandelbrot in 1975 coined the term "fractal", corresponding to the verb *frangere* (to break, to break). A fractal is a complex structure, the spatial shape of which is fractured and irregular or regular; chaotic or ordered and repeats itself on any scale [5]. The fractal structure has strong connections and its features are:

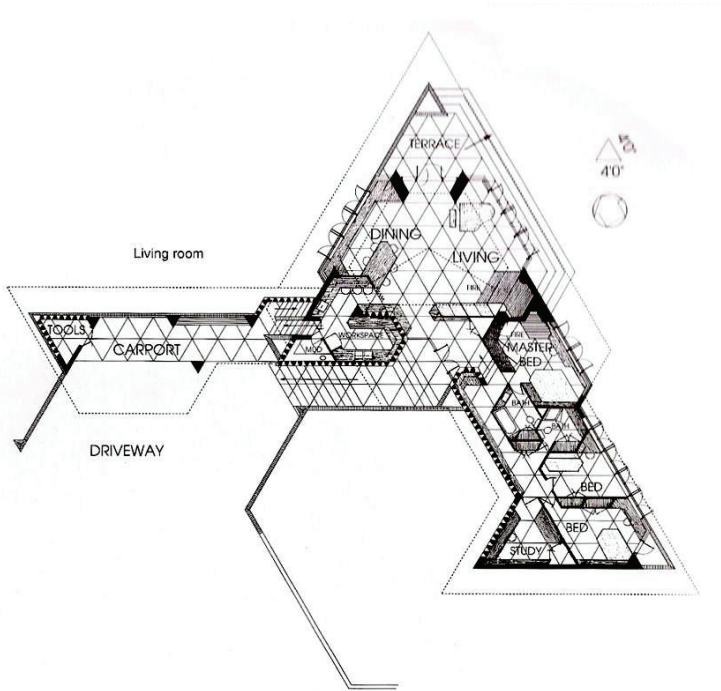
- self-similarity (hierarchical principle of organization);
- the ability to develop (the principle of the continuity of shaping);
- fractional metric dimension (principle of singularity of measure);
- blurring, indistinctness of the contours (the principle of uncertainty of boundaries);
- geometric representation of chaotic dynamics (the principle of dynamic chaos) [6].

A fractal in architecture is a geometrically self-similar object [7]. Despite the physical impossibility of endless splitting and unification in already real objects, this feature still finds its meaning in fractal architecture. First, a fractal structure can have a subsequent development in the peripheral direction instead of development inside. Secondly, if we consider an architectural object as a result of the project, and the project can later be modernized and erected at another location, then the project itself acquires the sign of infinity.

In architecture, natural and artificial fractal architecture are classified [8]. Natural created by nature, in particular natural landscape, flora and fauna. Artificial - erected by man. In turn, the artificial is divided into intuitive and consciously created. The latter presupposes the conscious use of fractals in design. However, studying many masterpieces of architecture, one can notice the existence of a clear fractal structure in them, despite the fact that the theory of fractality has not yet existed - this is intuitive fractal architecture. Often it is the intuition of a truly talented architect and the natural spiritual nature of a person that prompts him in the right direction.

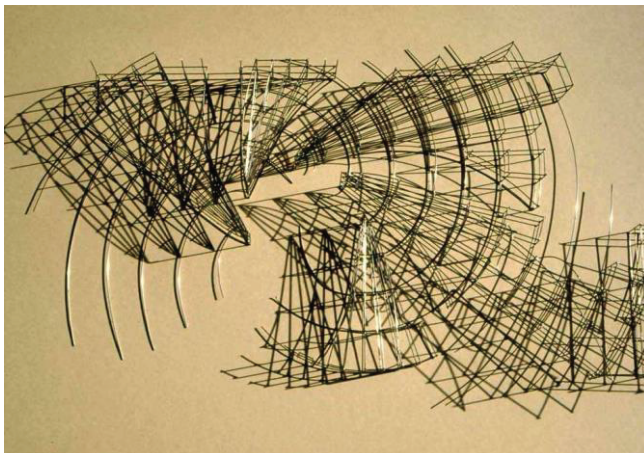
It should be noted that fractal structures in architectural design are used in both two-dimensional and three-dimensional systems.

In the works of the founder of "organic architecture" Frank Lloyd Wright, whose idea is integrity and unity with nature, one can trace the skillful use of fractals. Figure 1 shows the plan of Palmer House, the fractal unit in this work is an equilateral triangle, which is repeated in the plan in at least 7 different scales.

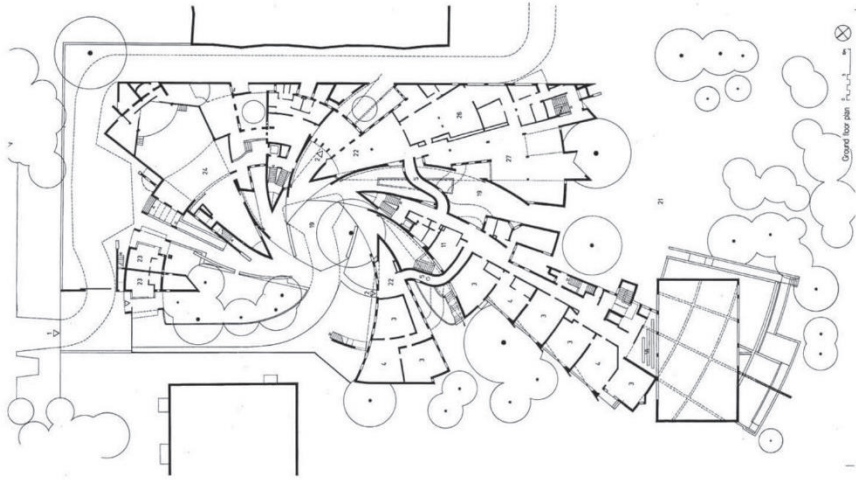


**Fig. 1.** Palmer House plan [9].

The works of another architect are impressive in their fractality. Zvi Hecker is an Israeli architect. In one of his interviews [10] he admits that he likes the architecture of Frank Lloyd Wright. But it would be inappropriate to compare Zvi Hecker with someone, since his works are unique. Figures 2, 3 and 4 show one of his outstanding projects - the Heinz Galinsky School in Berlin (1995). The original concept of the architect was the rays of the sun and the sunflower, which by its nature is one of the representatives of fractals. During the construction of the school, passing into a three-dimensional system from the plan views, the building suddenly began to acquire a new form - a book, the open pages of which bear the load of the building. As a result, according to the source [11], it was recognized that the sunflower transplanted from the Holy Land to Berlin naturally turned into a book.



**Fig. 2.** Sketch of the Heinz Galinsky School in Berlin [11].



**Fig. 3.** Plan of the Heinz Galinsky School in Berlin [11].

In this example, fractal architecture demonstrated its characteristic features of the continuity of shaping and the geometric representation of chaotic dynamics even at the construction stage, which did not prevent, but, on the contrary, contributed to the success of this project.

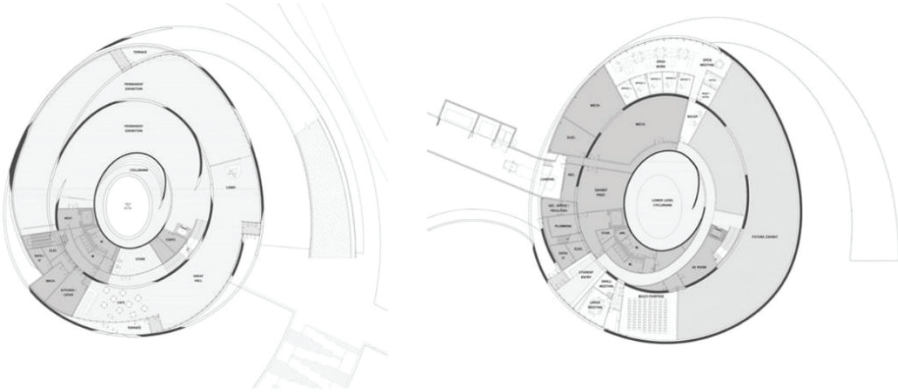


**Fig. 4.** School named after Heinz Galinsky, top view.

Studying fractal architecture, such a principle as fractal fragmentation is involuntarily highlighted. In fractal architecture it is not necessary to use a “pure” fractal with an infinite structure due to the physical limitations of the architecture; it is possible to use fragments of the fractal structure in architectural design. Fragmentation allows you to preserve the motives of the fractal structure, its naturalness and originality, while simultaneously introducing such an architecture into the framework of reality.

The next principle that should be clarified in fractal architecture is self-similarity. Benoit B. Mandelbrot did not just choose this term to explain the systemic nature of fractal structure. Self-similarity is not always an exact copy or a proportionally scaled copy. The self-similarity of a fractal can be expressed not only in the strict invariance of the spatial form, but also in the conditional self-similarity with a touch of randomness and naturalness.

In 2018, the construction of the Veterans Memorial and Museum was completed in the USA according to the project of the architectural firm Allied Works Architecture. This complex, while still at the project stage, received international recognition for its innovative design and was named one of the most anticipated buildings of 2018 by Architectural Digest [12]. The architecture of the complex is presented in the form of smoothly curved arcs, twisted around its axis, in addition, the idea of a spiral tending to the sky continues in the formation of the interior design. If you look at the plan of the memorial complex (fig. 5), you can see the stylization of the lines of the curled fingerprint, where a figure that is different from the Euclidean geometry is taken as a basis. This work clearly demonstrates the application of the principle of fragmentation of a fractal in architecture, and its integration into the existing landscape (fig. 6, 7).



**Fig. 5.** Memorial plans Veterans Memorial and Museum [13].



**Fig. 6.** Photo of the memorial complex Veterans Memorial and Museum.



**Fig. 7.** Photo of the memorial complex Veterans Memorial and Museum, top view.

Another important concept in fractal systems is dimension. Fractal dimension is a statistic that shows how completely the fractal fills the space when approaching smaller scales [14]. When analyzing fractal architecture, the most commonly used method is the box counting fractal dimension method (DB), which consists in sequentially overlaying a grid, zooming out and counting the number of cells. The calculation is expressed in the formula:

$$DB(1-2) = [\log N(s_2) - \log N(s_1)] / [\log 1/s_2 - \log 1/s_1] \text{ or}$$

$$DB(1-2) = [\log N(s_2) - \log N(s_1)] / [\log s_1/s_2], \quad (1)$$

where  $S$  – mesh size,  $N$  – the number of cells covering the details of the image [15].

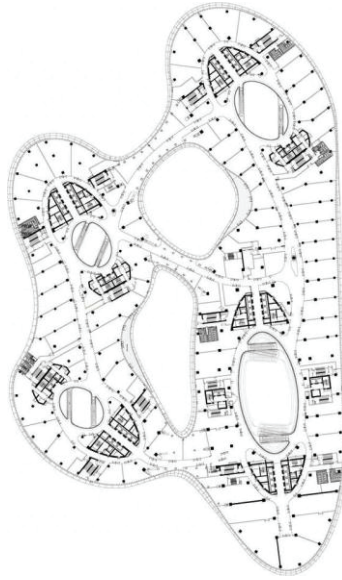
According to the source [16], the level of fractality is considered high if  $D$  is greater than 1.

Fractal architecture demonstrates good practice. Let us be convinced of this using the example of the Galaxy SOHO complex built in Beijing according to the project of Zaha Hadid (fig. 8).



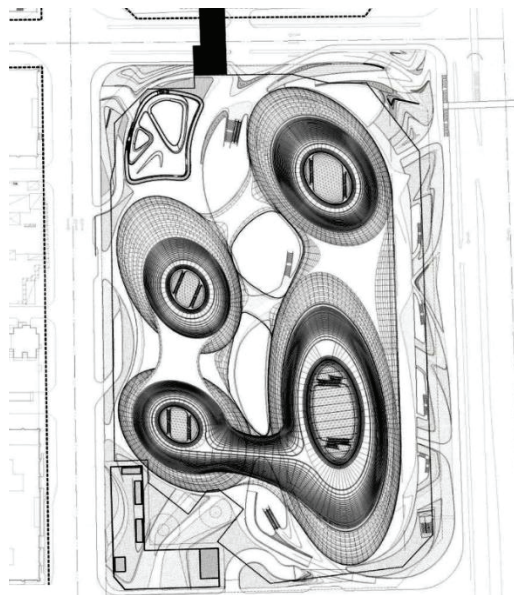
**Fig. 8.** Galaxy SOHO – photo [17].

The building received an international award from the Royal Institute of British Architects (RIBA), in addition, it was shortlisted for another award given by RIBA - the Berthold Lubetkin Prize and is one of the best projects of the renowned architect. Let's take a closer look at the configuration of the building in the plan. (fig. 9).



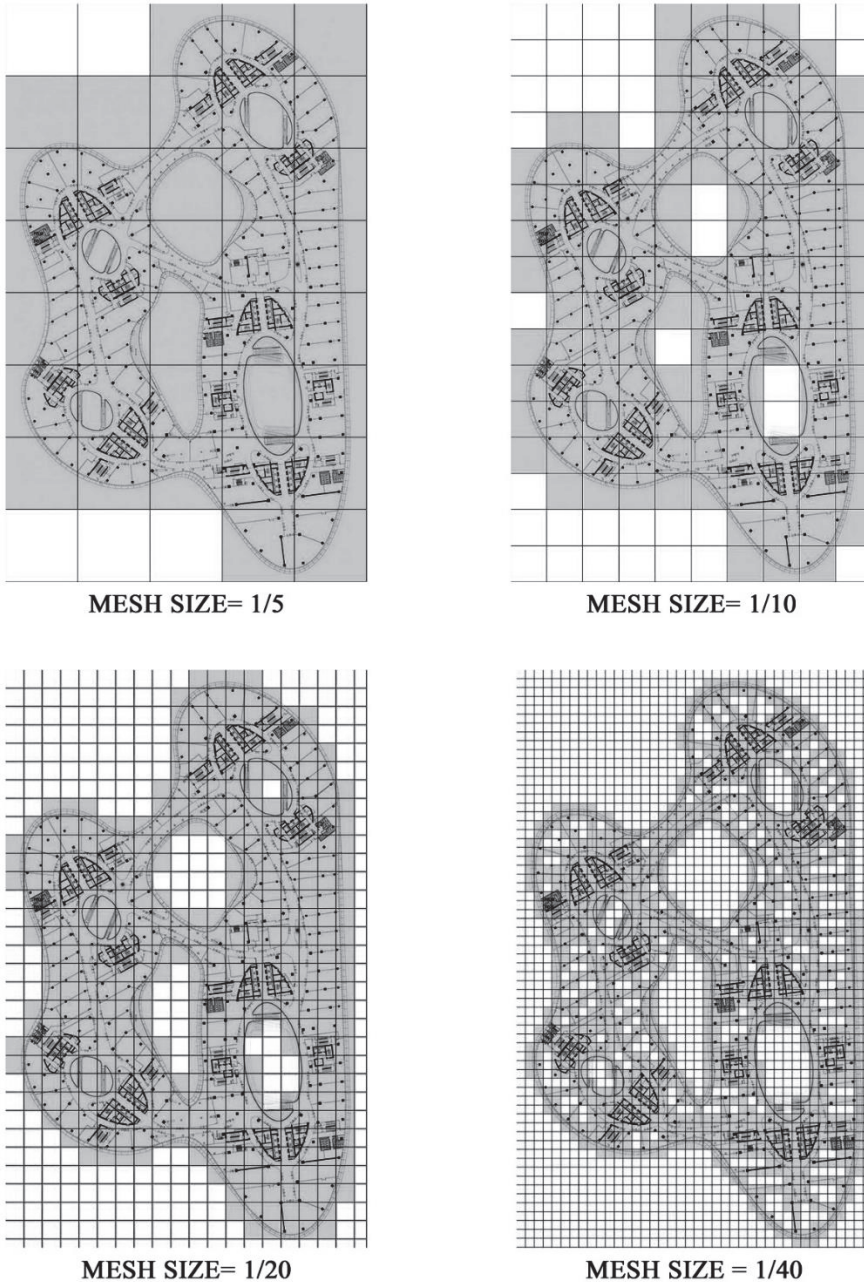
**Fig. 9.** Galaxy SOHO – plan [17].

The complex consists of domed volumetric elements, smoothly connected to each other at different levels. A feeling of continuous movement, transformation, transition from one state to another is created. If we look at the buildings from above, we will notice that they form a curved structure of self-similar oval elements (fig. 10). Fractality is observed both in the plans of the complex and in the sections of buildings.



**Fig. 10.** Galaxy SOHO – top view [17].

Let us investigate the relationship between the success of the Galaxy SOHO complex and the fractal dimension. Let's calculate the fractal dimension of his plan using the cellular calculation method. To do this, we will successively apply grids of different dimensions ( $1/5$ ,  $1/10$ ,  $1/20$ ,  $1/40$ ) to the plan (fig. 11) and, having counted the number of cells, we will perform calculations according to the formula 1.



**Fig. 11.** Calculating the degree of fractality of the Galaxy SOHO plan.



### 3 Results

In the course of the calculation, close numerical indicators were obtained:

1.  $D(5-10) = 1.691$ ;
2.  $D(10-20) = 1.824$ ;
3.  $D(20-40) = 1.668$ .

The consistency of the obtained fractal dimension between the studied scales confirms the harmony of the fractal characteristics of the plan elements.

The average fractal dimension of the plan of the complex ( $D$ ) = 1.728, which is more than 1, respectively, according to the method, the level of fractality is considered high. This result confirms the direct relationship between the success of the project and the fractal dimension.

### 4 Discussion

Fractal architecture is like a "diamond" that opened up new facets of the application of fractal systems in architecture and their advantages in the course of exciting analysis every time.

Typically, an architect's project starts with inspiration. What inspired the artist to create, inspiring him to pick up a brush or pencil in order to capture his admiration on a piece of paper at all times? - Nature. So why does she serve as limitless inspiration? Because she is an example of harmony and beauty. People are associated with her closely. The human body rests and is filled with new forces in the natural environment, this has a beneficial effect on health. Natural motives never get bored. So why don't get tired of it? Because nature is incredibly diverse. An artist may not always have enough imagination, he often reproduces what he sees only slightly modernizing and optimizing. Therefore, it is nature, saturated with fractal structures, that serves as an unlimited resource of inspiration and ideas for an architect.

In addition, such ideas are in harmony with the very natural essence of man remarkably, have a beneficial effect on his health and development. And this is exactly what is sorely lacking in the modern architectural environment.

After analyzing examples of fractal architecture in this study, we are convinced of its beneficial application. Frank Lloyd Wright, Zvi Hecker, architects of Allied Works Architecture and Zaha Hadid used natural fractals as the main idea of their projects, and these ideas have been justified always.

Studying examples of fractal architecture, we discovered its terms and principles deeper. As it turned out, the signs of fractal structure do not lose their essence in relation to architecture, too. For example, in the project of the Heinz Galinsky School in Berlin, signs of the continuity of shaping and the geometric representation of chaotic dynamics appeared, which contributed to the success of this project.

Studying the dependence of fractal dimension in architectural projects and their success, we again got a positive result.

Using method is the box counting fractal dimension method (DB), which consists in sequentially overlaying a grid, zooming out and counting the number of cells, we calculated the fractal dimension of the plan of the Galaxy SOHO complex. The results were clear. With a high fractality of the complex plan ( $D = 1.728$ ), we have a high success of this project. Obviously, the results is positive and justified.

Expanding their knowledge of the use of fractal structures in architectural design, the basis of the theory of fractal architecture is being formed. By applying which, architects will be able to create a better environment for humans in the conditions of a high rate of urbanization in the modern world.

## 5 Conclusions

Fractal architecture has great development prospects. Its relevance is primarily due to the favorable impact on a person, the creation of a comfortable environment for personal development, which is incredibly important in the current situation caused by the rapid pace of urbanization. Fractals, due to their natural originality, can serve as an endless source of inspiration for architects.

The article highlights a new concept - the principle of fractal fragmentation in architecture, which makes it possible to introduce fractal structures into the framework of the reality of architectural design without losing the advantages of such structures. In addition, the term self-similarity of fractals in relation to architecture is more broadly disclosed.

On the example of a successful project with the use of fractal structures in architectural design using the method of cellular calculation of fractal dimension, a direct relationship between the degree of fractality and the success of the project has been revealed.

The material of this article can be developed and applied for the theory of creating fractal architecture in view of the understanding that the use of fractal structures in architectural design is a promising direction of architecture.

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