Complex model of fractal architecture building

G M Kravchenko*, L I Pudanova
Don State Technical University, 1 Gagarin sq., Rostov-on-Don, 344000, Russia

E-mail: galina.907@mail.ru

Abstract. The fractal structures paradigm is applicable for creating the complex architectural objects. Using special programs, it is possible to implement a comprehensive model of the fractal architecture building as a structure consisting of an endostructure and an exostructure. During the study, the first two iterations of the endostructure on the possibility of using such structures’ element as a supporting skeleton of a fractal architecture building were considered. The endostructure elements of the first iteration strengthen the exobase and the lower surface of the f-quarks of the exostructure. The endostructure of the second iteration is much more complex and voluminous than the structure of the first iteration and strengthens the upper part of the exostructure. To ensure the stability of the fractal architecture building, the framework is formed by connecting the elements of the endostructures of the first and second iteration. Based on the fractal structures’ formation analysis results, the unique building stiffness cores formed from the f-quarks exobase have been developed. The strength and rigidity of the building is ensured by the combined action of the endostructure’s elements, the exostructure’s elements and the developed stiffness cores. Comprehensive building model was implemented in ANSYS PC. According to the numerical experiments’ results, the maximum displacements, shapes and frequencies of the fractal architecture object’s natural vibrations are determined. The proposed design solutions for a complex model of a building based on a fractal structure are unique and require the use of innovative technologies and materials.

Introduction
In accordance with the fractal structures’ paradigm, it is possible to use the theory of fractals to create the real objects, and to build the independent elements of the frame or the entire structure of the building [1-4]. It is possible to use the Mandelbulb 3D fractal (Mandelbulb) to create a complex artificial object, which is an ensemble of endless chaos and mathematics.

The authors have developed the innovative programs and special terminology for applying the fractal theory to create the objects of fractal architecture [5-7].

The developed algorithms make it possible to determine the points of exostructure and endostructure to create a finite element fractal model.

The external surface of the structure is approximated by iso-parametric triangular finite elements, and the internal structure by the rod finite elements. Various models with a fixed number of starting points on the outer surface of the first iteration of fractal structures with a variation in the power index have been developed.

Fractal power or quasi-volume is represented as an analogue of the fractal set local dimension concept.
Exostructure – is an external structure of a three-dimensional set. The exostructure consists of exobase, the surface of f-quarks and the corona [7].

Endostructure – is an internal structure of a three-dimensional set. The endostructure includes many nonlinear elements that create a unique three-dimensional fractal structure and serve as the supporting skeleton of the building.

The exostructure of the 3D fractal is formed during the iterative process. The shape and complexity of the endostructure depends on the power of the corresponding exostructure.

Methods
A comprehensive model of exostructure and endostructure is implemented using the algorithm for connecting nodes in a specially developed program “Finite-element modeling of fractal structure” [6].

An iterative process is a process of the internal structure development, as a result of which the endostructure forms a rigid framework inside the exostructure, strengthening the building’s shell.

The algorithm for constructing the endostructure is based on isolating a set of specific points that develop depending on each other from a fractal. The program provides the input data to specify the step of calculating points in spherical coordinates, the fractal power and the number of iterations.

A complex fractal structure is formed in the horizontal and vertical planes. Horizontal levels are formed by forming the points of a fractal set in separate groups. The fractal structure is complemented by the curvilinear elements in vertical planes, where many points are iterated and, accordingly, the number of times specified by the source data is grouped with rotation by a certain angle. The simulation result are the sets of finite elements that form the endostructure. Many internal structures are limited by exostructure. The development of the endostructure is shown in Figure 1.

Figure 1. Endostructure of the eighth power fractal: a) first iteration; b) second iteration

The development of the internal fractal structure occurs smoothly, forming a three-dimensional network of vertical and horizontal curves. At high-order iterations, space is filled with a dense structure, over-filling the fractal volume. A decision was made when modeling the object of fractal architecture to consider the first few iterations, which allows us to develop the constructive solutions for the building frame.

The horizontal levels of the structure’s first iteration are pronounced and form the distinct layers (Figure 1a). In this case, the structure of the first iteration develops in such a way that its elements are located in the lower part of the fractal and well strengthen the exobase and the lower part of the surface of f-quarks. In this case, the internal structure corona formation is practically considered not to be traced.
The structure of the second iteration is fundamentally different from the structure of the first iteration. This is reflected not only in the volume of the endostructure, but also in the complexity of its structure (Figure 1b).

A feature of the iterative process is the exponential increase in the number of elements at each step of the iteration. When creating a complex model, it is necessary to reduce the number of elements at each subsequent iteration by changing the initial data in the “Fractal FE modeling” program. It is necessary to control the approximation degree to obtain a rational structure.

The second iteration is actively developing in the middle and upper parts of the fractal; however, its elements are also present in the lower part.

In the iterative process, each step involves intersections and connections with the elements of the previous step, which ensures the object’s integrity. In contrast to the structural elements of the first iteration, the elements of the second iteration have a complex spatial shape, and only a small part of it is formed into groups of elements lying in the same plane, vertical or horizontal. This feature of the second iteration of the endostructure provides reinforcement of the first iteration and connection with it in a variety of compounds and intersections. The fractal structure of the second iteration of the endostructure provides the corona support.

In the complex model, a rigid fractal structure, which serves as a building or structure skeleton, is formed.

Results
Complex modeling of fractal endostructure and exostructure represents a new stage in the fractal architecture objects’ parametric design development. The proposed object of fractal architecture is not only based on a fractal form, but also repeats the natural algorithms.

The fractal architecture shaping is based on the 3D fractal growth principle in accordance with a certain law and involves changing the object’s structure, taking into account the analysis of the results obtained at each iteration [4].

The task of developing constructive solutions for the fractal architecture object is complex. The fractal object has unique levels, complex endostructure and exostructure, which dictate the methodology for the fractal principles’ implementation in the design process.

To create a complex building model in ANSYS, a volumetric diagram of the fractal structure was developed, which is exported from SCAD. The 3D structure of the Mandelbrot fractal and the complex model of the building are shown in Figure 2.

![Figure 2](image_url)

**Figure 2.** a) the structure of the 3D Mandelbrot fractal; b) complex building model
Based on the fractal structures’ formation process analysis [7], vertical connections in the building are developed taking into account the location of f-quarks in the exobase. This decision is based on the adaptation of the initial fractal forms in order to ensure rigidity and stability of the building as a whole. The artificially formed stiffness nuclei are connected with the elements of the endostructure.

The combined action of the endostructure elements of the first and second iterations, developed stiffness nuclei and endostructure allows us to talk about the stiffness and strength of the building.

A potential box-type foundation model with a system of radial and transverse stiffness diaphragms has been developed. In the context of the fractal structures paradigm, the box-like foundation consists of the cells combined in the underground part of the building into a separate fractal spatial structure. This new type of foundation makes it possible to evenly distribute the load on the soil base.

The fractal architecture object model is implemented in ANSYS PC and includes many complex and unique elements. Due to the large dimension of the problem, it was decided to perform the calculation of the building in parts. At the first stage, the stress-strain state of the endostructure with the developed levels is investigated. At the second stage - the study of a complex building model, which includes an exostructure, a system of stiffness nuclei and the levels which stiffness characteristics are equivalent to the joint work of the endostructure and levels (Figure 3). This assumption allows us to analyze the stress-strain state of the entire building.

![Figure 3. The finite element model of a fractal architecture building](image)

To study the maximum displacements, the design scheme takes into account constant, long, short-term payloads, snow and wind loads. Figure 4 presents the displacements’ model iso field of an object of fractal architecture. The maximum displacement is 34.4 mm, which corresponds to the permissible values for the unique buildings.
Figure 4. The fractal architecture object model’s displacements iso field

Modal analysis of the fractal architecture object makes it possible to set the resonant frequencies corresponding to the most dangerous bending-torsional forms of natural vibrations. Table 1 summarizes the spectra of frequencies and forms of the object’s natural vibrations. It should be noted that the first two forms of vibration are translational, the third form is torsional.

Table 1. Natural frequencies

| The form, № | Frequency, Hz | The form, № | Frequency, Hz |
|-------------|---------------|-------------|---------------|
| 1           | 0.88994       | 8           | 2.8994        |
| 2           | 0.89013       | 9           | 2.8995        |
| 3           | 2.0467        | 10          | 3.651         |
| 4           | 2.8132        | 11          | 3.657         |
| 5           | 2.8134        | 12          | 3.7093        |
| 6           | 2.8913        | 13          | 3.7105        |
| 7           | 2.8914        | 14          | 3.7729        |

Discussion

Structural solutions of high-rise and large-span buildings include the elements with a large dead weight, which is up to 60% of the calculated loads. The problem of developing the new types of structures based on the shaping and evolution of fractal structure is relevant [7-8].

The object of fractal architecture can be considered as a unique fractal beam developed by a group of researchers, including D. Reynaud-Kirkhor, J. Mao and R. Farr, which at the third iteration was 500 times lighter than a continuous beam [9].

In the article “Evolution of fractal structure”, the authors developed the flat fractal structures of different generations [10]. The obtained self-similar structures of a high generation are lace and delicate, but capable of bearing a significant load, many times exceeding the capabilities of the original structure. To implement such light structures, it is necessary to study the innovative materials with certain properties, in synthesis with modern technologies.
Taking the implementation of fractal principles into consideration, not only in the construction of one type of elements, but also in the design of the entire building, it is possible to get a unique building, characterized by high strength, functionality and aesthetics.

The design solutions proposed in this article for a complex model of a fractal architecture object are non-standard and unique. A stable building based on the fractal structure’s natural development algorithms is obtained.

A fractal, as an object of unusual complex geometry, is most rationally performed using the 3D printing technology. To implement the proposed complex model of a unique building, it is necessary to develop and study the innovative materials.

Summary
The developed complex model of the fractal architecture object allows us to analyze a new structural scheme of the building. The principle of fractal shaping is used to implement a rational building framework taking into account the resulting fractal structure’s adaptation.

In the process of studying the complex model, a numerical experiment of the spatial fractal structure and its elements was performed. Dynamic calculation of the fractal architecture object made it possible to obtain a spectrum of fourteen frequencies and forms of natural vibrations. The analysis of the endostructure effect on the overall stability of the building is carried out.

The opening of a new section in the unusual forms’ architecture is promising, competing with the usual objects of deconstructivism. It is intended to use such objects in the form of an enclosing framework for protecting a complex of buildings and structures from harmful influences.

The results obtained in this study expand the possibilities of studying the three-dimensional Mandelbrot fractal as well as its application in the fractal architecture buildings and structures’ design.

References
[1] Mandelbrot B B 1982 The Fractal Geometry of Nature (San Francisco).
[2] Peitgen H-O, Richter P H 1986 The beauty of fractals (Springer-Verlag, Heidelberg).
[3] Frame M L, & Mandelbrot B B 2002 Fractals, Graphics and Mathematical Education (Washington DC: Mathematical Association of America & Cambridge UK, The University Press).
[4] Jencks Ch. 2002 The New Paradigm in Architecture (seventh edition of The Language of Post-Modern Architecture) (Yale University Press, London, New Haven).
[5] Kravchenko G M, Vasil'ev S E, Pudanova L I 2017 3D modeling of fractal: the certificate of state registration of computer programs, №2017610058, 09.01.2017.
[6] Kravchenko G M, Vasil'ev S E, Pudanova L I 2017 The finite element simulation of a fractal structure. The state registration patent for ECM № 2017664255, 19.12.2017
[7] Kravchenko G M, Pudanova L I 2018 The fractal Mandelbrot set and the shaping of the 3D fractal Inženernyj vestnik Dona 4.
[8] Kravchenko G M 2017 Modeling the External Structure of a Fractals IOP Conference Series: Earth and Environmental Science 90 012100.
[9] Rayneau-Kirkhope D, Mao Y and Farr R 2012 Ultralight fractal structures from hollow tubes Phys. Rev. Lett. 109 204301.
[10] Kravchenko G M, Pudanova L I 2019 IOP Conf. Ser.: Mater. Sci. Eng. 698 022017.