TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue Special I, January, 2021

# DIGITAL PARAMETRIC DESIGN OF FRACTAL GEOMETRIC KOCH SNOWFLAKE PATTERNS

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***Abstract:*** *In this study, digital Koch snowflake models are developed in a variable mathematical order using the open source Blender 3D software and the specialized Snowflake Generator Add-on application. The three-dimensional geometry of the models is mainly made by applying parametric values, with conventional operations being applied in the final modeling phase. The purpose of the study is to illustrate the process of building fractal models from the nature and to find a way to properly construct the digital geometry of the models.*
***Key words:*** *3D, Blender, digitization, fractal, parametric.*

## 1. INTRODUCTION

Before embarking on the actual computer-aided design of Koch Snowflakes digital models, it is necessary to give a detailed description of what fractals themselves are, where they exist in space, and how and where they are used in modern science and practice. The essence of fractals is geometric shapes that are repeated many times based on mathematical principles [11]. A lot has been written about fractals, often giving different definitions of the term [1]. The term fractal (derived from the Latin fractus - broken, crushed) is thought to have been introduced in the 70s by Benoit Mandelbrot [2]. Benoit B. Mandelbrot is a mathematician born in Poland but works mainly in France and USA.

The fractals have a great impact on various sciences [3, 4], such as mathematics [5 - 8], biology and medicine [9 - 15], physics [16, 17], art [18-20], architecture [21-23], ecology [24], Virtual Reality and Programming [25] and others. Typical for fractals is their self-similarity: the geometric structure remains approximately the same on any scale of view [26 - 28]. Of the well-known fractals is the Koch Curve (named after the Swedish mathematician Helge von Koch, early 20th century). This curve is generated by infinite iterations of straight-line replacement [29 - 31]. Iteration (from the Latin iterare "repeat") is the repetition of a process. In programming, iterations most often mean "cycle" (returning to a condition until it becomes true and the program continues) [32 - 34]. The Koch curve is drawn by successive drawing - first a straight line, which is divided into three equal parts, (Figure 1) [35].

Subsequently, the middle part of the segment is replaced by two segments (in the form of a triangle) of length 1/3. A broken curve of 4/3 is obtained.

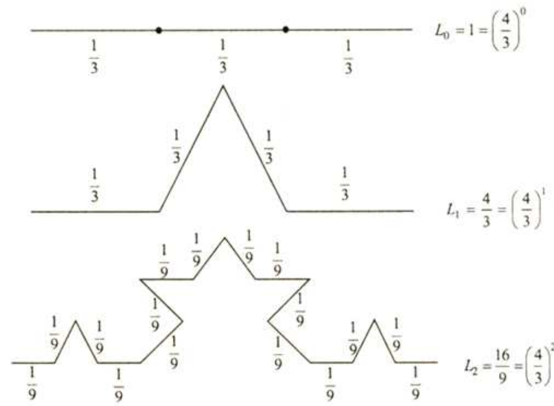


**Fig. 1.** The Koch curve [35].

The following iteration divides each of the 4 obtained segments into three equal parts, replacing each of the middle segments with sections with 1/9 length, respectively. A new 16/9 broken line is obtained, each of its four parts being like the curve obtained after the first step. The Koch Curve describes an object obtained after this process continues indefinitely or the length of the curve obtained after each step is equal to the length of the previous one multiplied by 4/3. Thus, after the n iterative step of constructing the Koch curve its length will be (Equation 1), [35]:

$$\left(\frac{4}{3}\right)^n = 1{,}3333^n \qquad (1)$$

The Koch Curve can be presented in tabular forms as shown in Table 1.

*Table 1*

**The Koch Curve [29]**

| Phase | Number of segments | Length of each segment | Sum of segments' lengths |
|---|---|---|---|
| 0 | 1 | 1 | 1 |
| 1 | 4 | $\frac{1}{3}$ | $4\times\frac{1}{3}=\left(\frac{4}{3}\right)$ |
| 2 | $4^2$ | $\frac{1}{3^2}$ | $4^2\times\frac{1}{3^2}=\left(\frac{4}{3}\right)^2$ |
| 3 | $4^3$ | $\frac{1}{3^3}$ | $4^3\times\frac{1}{3^3}=\left(\frac{4}{3}\right)^3$ |
| 4 | $4^4$ | $\frac{1}{3^4}$ | $4^4\times\frac{1}{3^4}=\left(\frac{4}{3}\right)^4$ |
| $n$ | $4^n$ | $\frac{1}{3^n}$ | $4^n\times\frac{1}{3^n}=\left(\frac{4}{3}\right)^n$ |

*Table 2*

**The Koch Snowflake [29]**

| Phase | Length of the side of each added triangle | Area of each added triangle | Number of added triangles | Sum of the areas of the added triangles |
|---|---|---|---|---|
| 1 | $\frac{1}{3}$ | $\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3}\right)^2$ | 3 | $3\cdot\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3}\right)^2$ |
| 2 | $\frac{1}{3^2}$ | $\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^2}\right)^2$ | $3\cdot4^1$ | $3\cdot4^1\cdot\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^2}\right)^2$ |
| 3 | $\frac{1}{3^3}$ | $\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^3}\right)^2$ | $3\cdot4^2$ | $3\cdot4^2\cdot\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^3}\right)^2$ |
| 4 | $\frac{1}{3^4}$ | $\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^4}\right)^2$ | $3\cdot4^3$ | $3\cdot4^3\cdot\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^4}\right)^2$ |
| $n$ | $\frac{1}{3^n}$ | $\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^n}\right)^2$ | $3\cdot4^{n-1}$ | $3\cdot4^{n-1}\cdot\frac{\sqrt{3}}{4}\cdot\left(\frac{1}{3^n}\right)^2$ |

Replacement iterations are used to create the Koch Snowflake fractal using a basis and a pattern [36].

The fractal Koch snowflake is obtained by successively applying the pattern (broken curve) to the triangle (basis), replacing each side. In this way a figure is obtained like The Star of David [37]. By applying the following replacement iteration, all 12 sections are replaced with the pattern, thus obtaining the fractal Koch Snowflake. Following this principle, many additional iterations can be added to multiply the pattern indefinitely. This would lead to the emergence of many new and new identical details that will increase in an otherwise limited area. The subject of a mathematical study of how this works in practice is well represented in the scientific study of Yaroslav D. Sergeyev ∗ *The exact (up to infinitesimals) infinite perimeter of the Koch snowflake and its finite area* [38]. Table 2 shows the calculations related to the area of the Koch snowflake, with the area of an equilateral triangle in phase 0 being $\frac{\sqrt{3}}{4}$ square units [29].

Koch curve has relationship with Thue-Morse sequences. The Thue–Morse sequence (or Prouhet–Thue–Morse sequence), is an infinite binary sequence obtained by starting with 0 and successively appending the Boolean complement of the sequence obtained thus far (Figure 2) [39]. Starting with 0, the bitwise negation of 0 is 1; combining these, the first 2 elements are 01; the bitwise negation of 01 is 10; combining these, the first 4 elements are 0110; the bitwise negation of 0110 is 1001; combining these, the first 8 elements are 01101001 and so on.

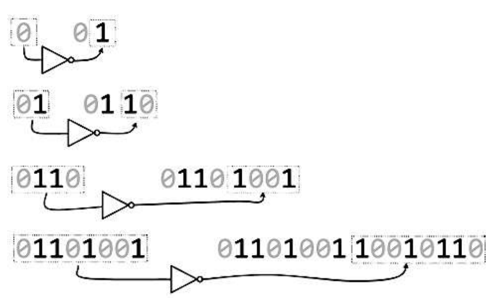


**Fig. 2.** Relationship between Koch curve and Thue-Morse sequences. [39].

Fractals provide an opportunity to generate interesting shapes and compositions and are the subject of presentation in the educational process. Two sizes of Koch snowflakes in area 1: 3 form a dense complementary composition [40]. The need for interactive presentation through visual images based on precise and clear parameters enhances the impact on learners. This may include different processes for the technical implementation of the reference models, containing complete concepts or individual stages depending on the set goals. [41-45]. This contributes to the overall quality of the educational process, especially when it comes to complex models that are invisible to the human eye (ie with minimal geometric dimensions). In this case we can focus on fractals, where Koch snowflake is of interest with its mathematical proportions, they are directly present in our environment and nature. In this context, one of the goals of this work is to optimize the capabilities of computer-aided parametric modeling of digital snowflake models, similar to real nature samples. This is in accordance with the fractal structure of the studied models, with reference to the specific Koch Snowflake fractal. Real examples of snowflakes like Koch Snowflake are shown in Figure 3 [46].

For the needs of the industrial practice, the application of the geometry of Koch fractals is of great importance for electronics. Fabrication of Koch fractal dipole antenna is shown on Figure 4.

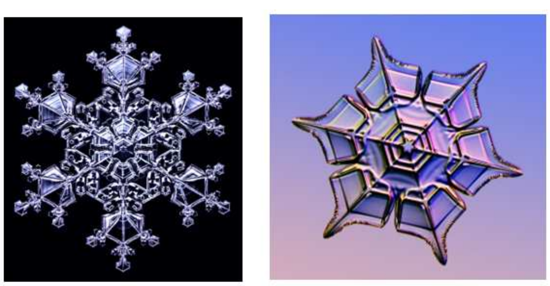

**Fig. 3.** Photos of real snowflakes like Koch Snowflake under microscope [46], where the left image source is http://www.snowcrystals.com/designer/IMG_7261-64-A1a.jpg and the right image source is http://www.snowcrystals.com/designer/IMG_1364-B1.jpg [47].

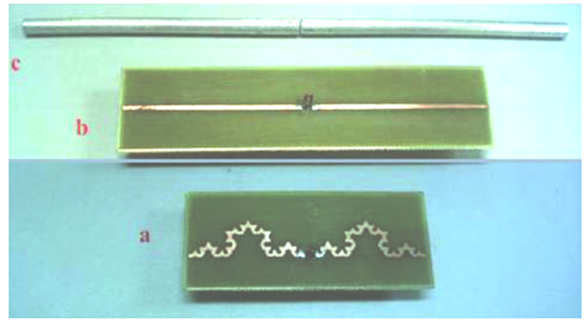


**Fig. 4.** Fabricated Koch fractal dipole antenna (a) compared to micro-strip dipole (b) and conventional dipole antenna (c) [47].

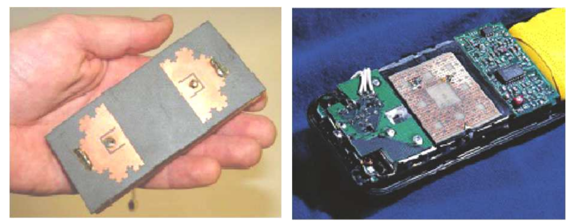

**Fig. 5.** Photos of the microstrip patches. Left photo: Koch fractal double-PIFA antenna. Two identical PIFA antennas, in the form of Koch are placed in smartphone sizes (100 · 45 mm 2) have been applied for Multiple Input Multiple Output system. Right photo: Sierpinski carpet used by the Spanish company FRACTUS, to build the build-in antenna of a mobile cellular system GSM 900/1800 handset [48].

A very useful application of Koch fractal is the microstrip patch antenna with same Koch shape edges, (Figure 5), [48]. Designed for handset terminals, smartphones, cooperating with several mobile communication systems: GSM1800, UMTS and HiperLAN2. Application of PIFA antenna in conjunction with the fractal geometry reduces antenna size by 62% compared to the conventional PIFA.

In accordance with the present work, the following goals and objectives are set:

- Finding an approach for parametric digital modeling of Koch snowflake fractals;
- Providing students with appropriate software resources, open source 3D programs, and further enhancing work applications add-ons;
- Visualization of Koch snowflake fractal digitization processes;
- Public presentation of the developed fractals to illustrate the learning content.

## 2. METHODOLOGY AND TECHNICAL REALIZATION

Given the complex geometry of the models and applying the mathematical features, the creation of computer models "Koch Snowflakes" is better to be accomplished by parametric generation of digital geometry. Blender 3D software [49, 50] (Blender is released under the GNU General Public License (GPL) [51]) and the specialized Addon - Snowflake Generator (Generator Add-on in Blender 3D software environment (File > User Preferences (Ctrl + Alt + U) > Add-ons > Install Add-on from File > snowflake_generator.py), [52]. After activating Snowflake Generator - Addon in Object Mode, it switches to creating digital geometry. For adding Snowflake object run Object Mode > Add > Mesh > Snowflake.

There can be specified the following parameters in it: Radius, Number of Slides, Iterations. Figures 6 and 7 show, in sequence, images of sequentially creating a future three-dimensional digital geometry of Snowflake with parameters: radius 1.00; number of slides: 3; iterations from 0 to 2. After creating the two-dimensional geometry, it goes into Edit Mode, selects all elements through the Select All operation, and closes the model's face. The resulting shape is extruded according to the Z dimension (Figures 8 and 9).

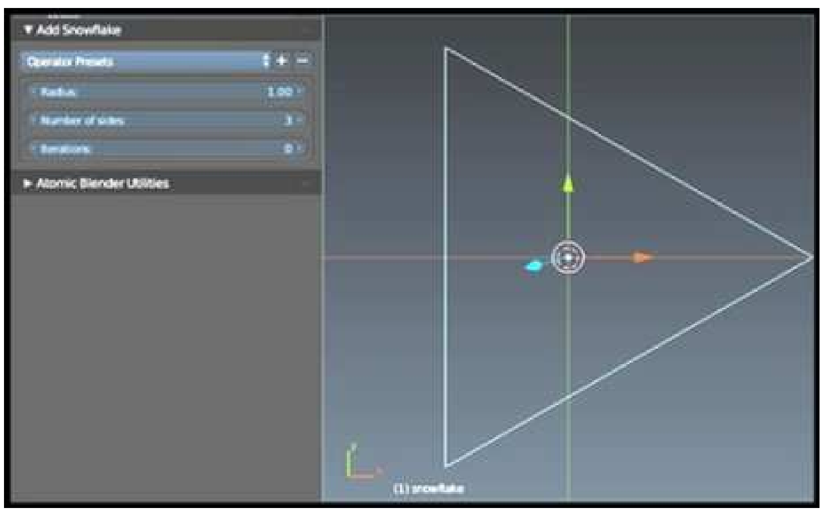


**Fig. 6.** Creating a fractal Koch snowflake shape model in sequence in an environment of Blender 3D software + Snowflake Generator Add-on . Parameters: Radius: 1, Number of sides: 3, Iterations: 0.

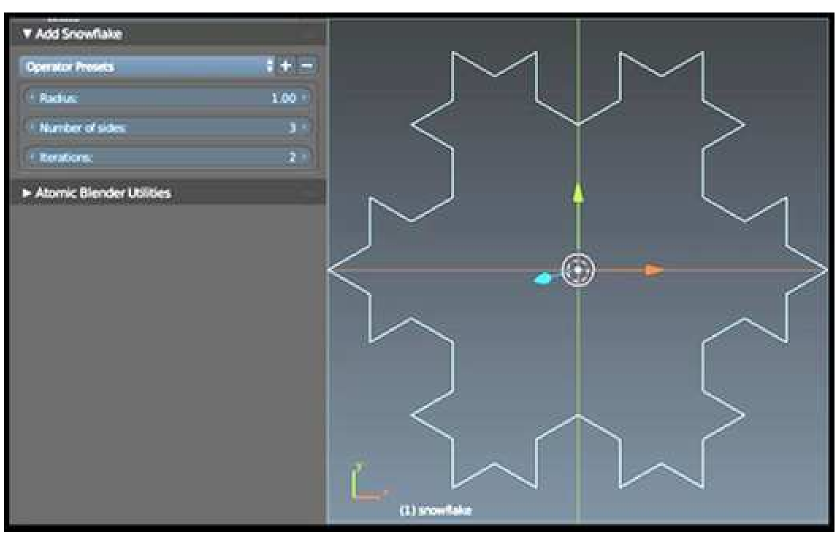


**Fig. 7.** Creating a fractal Koch snowflake shape model in sequence in an environment of Blender 3D software + Snowflake Generator Add-on . Parameters: Radius: 1, Number of sides: 3, Iterations: 2.

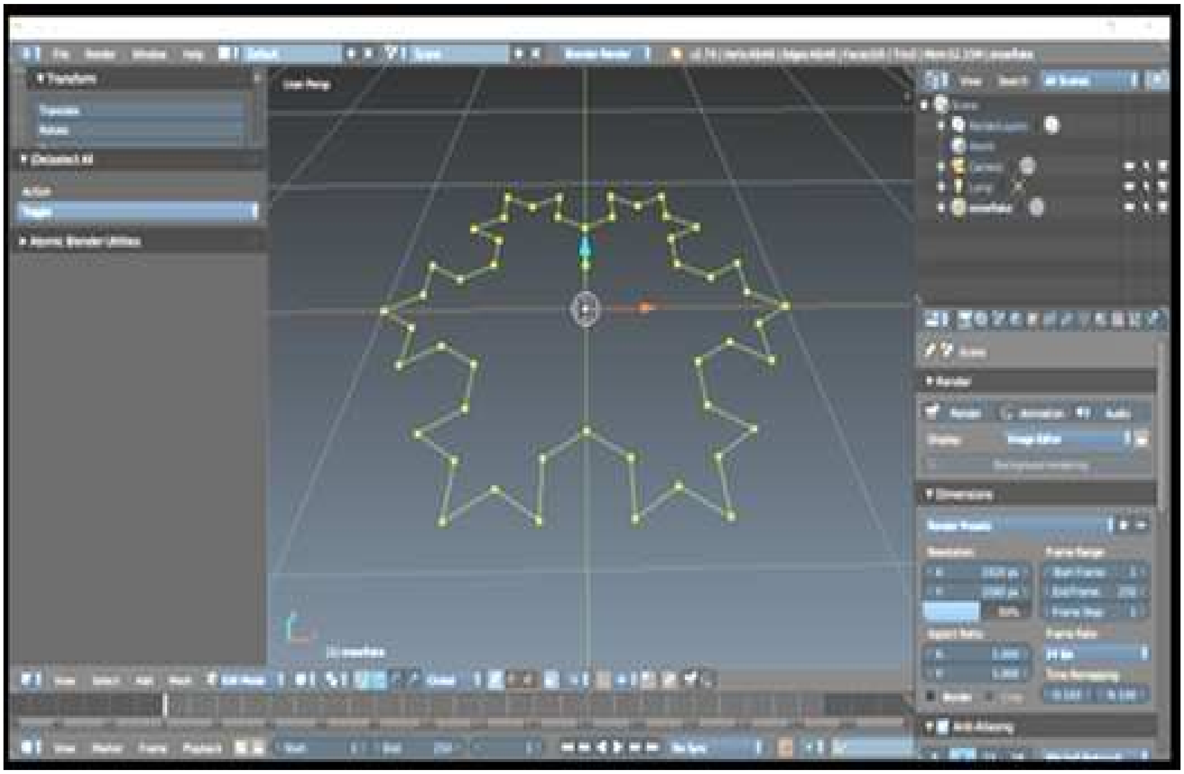

**Fig. 8.** Conventional design work. The defined fractal shape mesh geometry (Edit Mode).

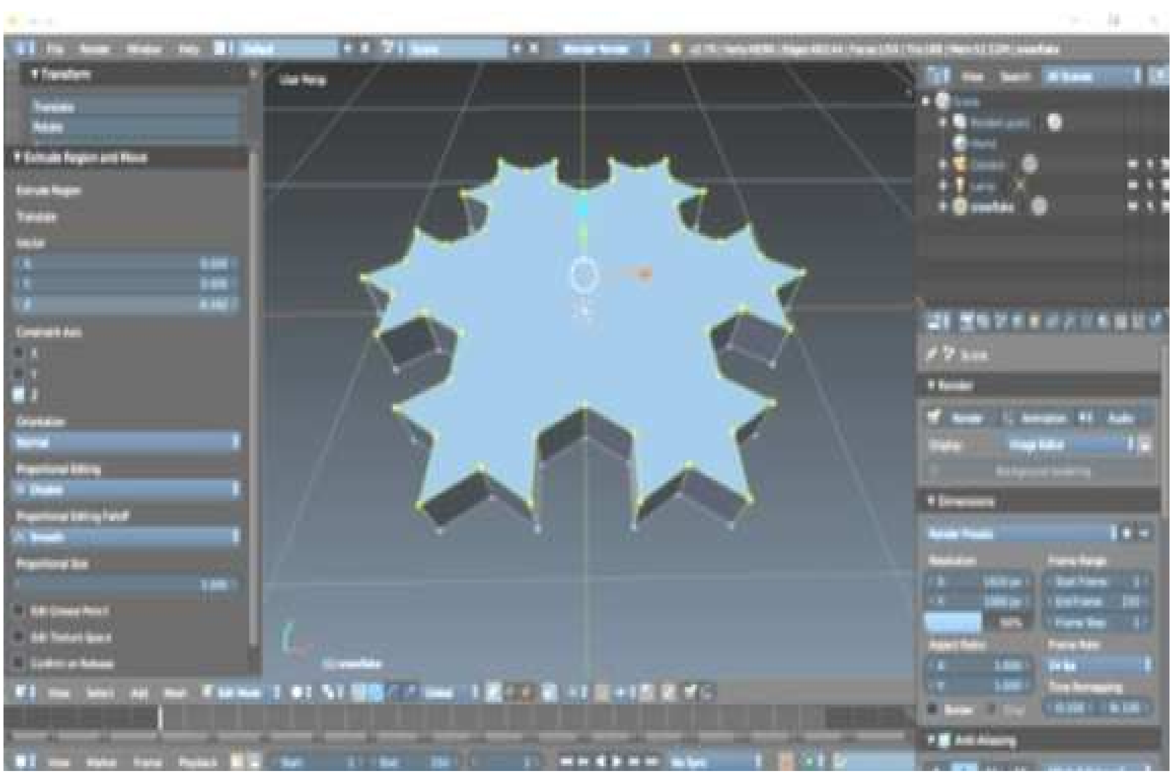

**Fig. 9.** The finished (extruded) 3D model has good mesh geometry and is applicable for future 3D printing.

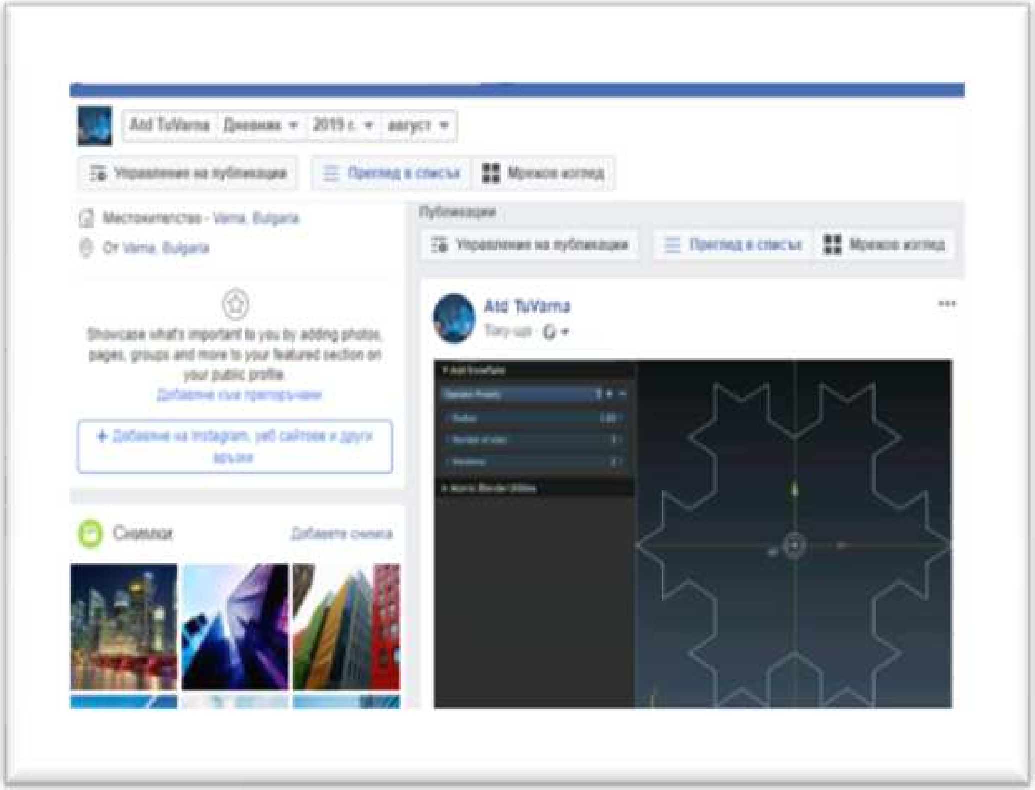


**Fig. 10.** Public presentation of parametrically created digital animated (GIF file) model of Koch Snowflake on the social network Facebook for accessibility to illustrate educational content (https://www.facebook.com/atd.tuvarna/videos/160921868364706/?t=0).

To illustrate the course content, iterations to create the Snowflake Koch model are animated in *.GIF format and publicly presented on the Facebook social network for accessibility, quick sharing, and introduction to the peculiarities of creating Koch Snowflake parametric models. (Figure 10). The animated GIF file is created using the free software GIF Animator [53].

Final fractal models of Koch's snowflake are printed in three dimensions, using additional free resources: MeshMixer and the specialized software XYZware. A video presentation of the real-time printing process is shown at the title/link: Design and 3D printing of Koch's snowflake fractal (as seen on: https://www.youtube.com/watch?v=-MtGpnZ5HE4).

## 3. RESULTS AND DISCUSSIONS

In the present work, digital models of fractal Koch snowflakes are created. For the accuracy of the generated shapes and three-dimensional geometry, the possibilities of open source parametric application are applied, which facilitates the process of constructing the main line of the models, which are conventionally completed in three dimensions. The 3D models are fully constructed and presented in public to illustrate the learning content of models invisible to the human eye. This report shares information knowledge and experience and contributes in the manner listed as follows:

- A thorough analysis of the application of fractals and Koch snowflake is made;
- The mathematical basis of fractals is synthesized in a single material to facilitate the educational process;
- The natural diversity is presented in an appropriate form, emphasizing the complexity of the mathematical connections and regularities that make up our world;
- 3D models of Koch snowflake fractals are developed, and the principle of operation is

presented in detail and shared for use with students and colleagues working with this type of fractals;

- Students are provided with access to free and open source resources for creating quality digital geometry in 3D environment, as well as subsequent digital visualization.

## 4. CONCLUSION

In this study, digital three-dimensional fractal Koch Snowflake models are developed. The Blender 3D software is accompanied by a specialized Add-on Snowflake Generator application. Through parameterization, the development of basic geometry of the models is facilitated to the maximum.

In the paper context there are given details provided and the stages of digital design described, which would be useful for scientists, users, and learners in the areas of fractal science. The obtained results are intended to illustrate the educational content of micro models borrowed from nature. Different variants of visualization of the obtained geometry of the developed models are presented, which contributes to a better understanding of the geometric features of the Koch Snowflake fractal.

A very important result of the present study is the optimized design of Koch Fractals with absolute accuracy. This allows the use of different parameters when creating applications for industrial practice. For this purpose, it is necessary to apply the selected material to the three-dimensional model and the appropriate technique for actual production.

At the same time, experience, and real technological resources with free access for the needs of the design engineers are shared, which significantly facilitates the work of building two-dimensional and three-dimensional geometry as intended.

## 5. ACKNOWLEDGMENT

This paper (result) is (partially) supported by the National Scientific Program "Information and Communication Technologies for a Single Digital Market in Science, Education and Security (ICTinSES)" (grant agreement DO1-205/23.11.18), financed by the Ministry of Education and Science.

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**Proiectare digitală parametrică a geometriei fractale a modelelor de fulgi de zăpadă Koch**

**Rezumat:** În acest studiu, modelele digitale ale fulgilor de zăpadă Koch sunt dezvoltate într-o ordine matematică variabilă, folosind aplicația software deschisă Blender 3D (open source) și aplicația specializată Snowflake Generator. Geometria tridimensională a modelelor este realizată în principal prin aplicarea valorilor parametrice, operațiile convenționale fiind aplicate în faza finală de modelare. Scopul studiului este de a ilustra un demers de construire a modelelor fractale din natură și de a identifica o modalitate de a construi corect geometria digitală a modelelor.

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