MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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OF ECONOMICS

3D Graphics

Guidelines for self-study

**for Master's (second) degree higher education students
of specialty 186 "Publishing and Printing"
of the study program "Technologies
of Electronic Multimedia Publications"**

Kharkiv
S. Kuznets KhNUE
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T49 **3D Graphics** [Electronic resource] : guidelines for self-study for Master's (second) degree higher education students of specialty 186 "Publishing and Printing" of the study program "Technologies of Electronic Multimedia Publications" / compiled by I. Kobzev. – Kharkiv : S. Kuznets KhNUE, 2025. – 30 p. (English)

The main provisions regarding the organization and performance of self-study are presented. The general provisions and the program of the implementation of self-study on the academic discipline are included. A detailed description of the tasks for self-study and a list of literature necessary for completing the tasks are provided.

For Master's (second) degree higher education students of specialty 186 "Publishing and Printing" of the study program "Technologies of Electronic Multimedia Publications".

UDC 004.92(072.034)

Introduction

The purpose of the work program is to maximize the implementation of personal qualities and integrated competences of Master's degree students in the academic discipline, developed on the basis of educational standards using a competency-based approach to learning outcomes.

The main goal is achieved by systematizing, deepening and generalizing the knowledge that forms the theoretical and practical basis of the academic discipline for the program "Publishing and Printing".

3D graphics has a wide range of applications in all types of design activities (interior design, creation of virtual museum spaces, animation) and in the visualization of various technological processes (animation of the movement of mechanisms, the internal structure of various structures, etc.).

The academic discipline plays a major role in the Master's degree program "Publishing and Printing".

The aims and objectives of the academic discipline are determined by the scientific and professional aspects of training qualified specialists and consist in shaping the minds of students on the basis of mastering the laws of information processes in an inseparable connection with the methods and ways of visualizing and modeling three-dimensional objects.

The objectives of the academic discipline are as follows:

- gaining a systematic understanding of the peculiarities of three-dimensional modeling;
- acquiring knowledge in the field of description, presentation and formalization of various capabilities of a 3D graphic editor;
- gaining skills in using three-dimensional modeling for solving various applied problems;
- acquaintance with the methods of creating virtual spaces.

The academic discipline is studied in the 1st semester and is a binder in relation to related disciplines.

The academic discipline belongs to the cycle of professionally oriented disciplines in the speciality "Publishing and Printing", specialization "Technology of Electronic Multimedia Publications".

To study the academic discipline, you need to know the basics of the following disciplines: Higher Mathematics, Applied Mathematics, Engineering and Computer Graphics, Colour Theory, Computer Design Technologies, Computer Animation.

In studying the academic discipline, the main didactic condition for the development of graduate competences is observed, which is the optimal synthesis of contextual learning, modeling elements of the future work of a Master's degree student, and interdisciplinary integration.

Therefore, the main goal of extracurricular self-study on the academic discipline is to provide an opportunity to consolidate the competences of students of speciality 186 "Publishing and Printing".

Given the specified nature and specificity of extracurricular self-study (a type of activity that forms students' new knowledge without the direct participation of a teacher), these guidelines contain a program of self-study on the academic discipline that allows the learner to get a general idea of the content of self-study and plan the performance it the program in accordance with methodical requirements.

The competences of students and the content of self-study

The learning results and competences formed by the academic discipline are defined in Table 1.

Table 1

The outcomes and competences formed by the academic discipline

The outcomes	The competences that must be mastered by a student of higher education
LR1	GC2, GC3, SC5
LR2	GC1, GC3, SC5
LR3	GC2, SC5
LR4	GC1, GC3, SC6
LR5	SC4
LR6	SC5
LR7	GC1, SC5
LR8	SC5
LR9	GC2, GC3
LR10	GC2
LR11	GC2, SC11
LR12	GC2, GC1
LR13	GC2, GC3
LR14	SC9

Note.

GC1. The ability to apply knowledge to practical situations.

GC2. The ability to generate new ideas (creativity).

GC3. The ability to communicate in a foreign language.

SC4. The ability to organize the operation of technical and software means for publishing information and processing of materials, to analyze and evaluate the possibilities of adapting technological complexes for effective use during the preparation of all types of publishing and printing products in a specific production system.

SC5. The ability to develop and implement new technological processes, in particular resource- and energy-saving technologies, and types of products in the field of publishing and printing, to optimize production processes in accordance with the requirements.

SC6. The ability to manage complex activities in the field of publishing and printing, organize and improve the activities of publishing and printing industries, develop plans and measures for their implementation, ensure quality, and calculate the technical and economic efficiency of production.

SC9. The ability to conduct an analysis of modern digital media products as cultural forms of ways to increase the efficiency of the enterprise.

SC11. The ability to analyze the structure and content of interactive media projects.

LR1. The ability to be responsible for the development of professional knowledge and practices, evaluation of the team's strategic development, formation of an effective personnel policy.

LR2. The ability to assess prospects, create scientifically and technically based forecasts, research and carry out conceptual and substantive modeling of industry development trends.

LR3. The ability to make effective decisions on issues of publishing and printing, including difficult and unpredictable conditions; predict their development and market conditions; determine the factors affecting the achievement of set goals, in particular, consumer requirements; analyze and compare alternatives; assess risks and likely consequences of decisions.

LR4. The ability to communicate freely orally and in writing in Ukrainian and one of the foreign languages (English, German, Italian, French, Spanish) when discussing professional issues, research and innovations in the field of publishing and printing and related problems.

LR5. The ability to develop and execute projects of publishing and printing industries and systems of their engineering and technical support, taking into account engineering, legal, economic, ecological and social aspects, to carry out their informational and methodical support.

LR6. The ability to manage complex activities in the field of publishing and printing, organize and improve the activities of publishing and printing industries, develop plans and measures for their implementation, ensure quality, and calculate the technical and economic efficiency of production.

LR7. The ability to carry out computer design of individual components of the technological process.

LR8 The ability to develop and implement effective technologies, develop instructions and technological regulations for the production of publishing and printing products.

LR9. The ability to conduct research and/or innovative activities in order to obtain new knowledge and create new technologies and products in the field of publishing and printing and in wider multidisciplinary contexts.

LR10. The ability to build and research models of technological processes of publishing and printing, evaluate their adequacy, determine limits of applicability.

LR11. The ability to apply modern experimental and mathematical methods, information technologies and specialized software for research and development in the field of publishing and printing.

LR12. The ability to search for necessary data in scientific literature, databases and other sources, analyze and evaluate these data.

LR13. The ability to use knowledge of domestic and international legislation regarding the protection and preservation of copyrights in the production of printed and electronic publications, packaging, multimedia information products and other types of publishing and printing products in practical activities.

LR14. The ability to analyze, discuss and determine the most appropriate decision regarding the design and applied implementation of the process of development of printed and multimedia products.

The number of hours of lectures, practical (seminar) and/or laboratory classes and hours of independent work are given in the work plan (technological map) for the academic discipline.

Tasks for self-study of students are listed in Table 2.

Table 2

Tasks for students' self-study and forms of control

Topic name	Content of students' self-study	Forms of control	Recommended literature	The week during which the task is performed
Content module 1. Analytical 3D objects				
Topic 1. Analytical 3D graphics	Studying the lecture material, preparing for the laboratory session, reviewing the theoretical material	Express poll	[2; 4 – 8]	2 – 4
Topic 2. Fractal 3D graphics	Studying the lecture material, preparing for the laboratory session, reviewing the theoretical material	Express poll	[1 – 3; 5; 6; 8]	5 – 7
Content module 2. Polygonal 3D objects				
Topic 3. Polygonal 3D graphics	Studying the lecture material, preparing for the laboratory session, reviewing the theoretical material	Express poll	[3; 5; 17; 18]	8 – 11
Topic 4. Spline 3D graphics	Studying the lecture material, preparing for the laboratory session, reviewing the theoretical material	Express poll	[3; 5; 6]	12 – 14

Content module 1. Analytical 3D object

Topic 1. Analytical 3D graphics

Task 1. 3D graphics in Mathcad.

The goal of self-study is to acquire knowledge and skills in working with the elements of a modern interface in the system and work features, as well as adaptation of the workspace to the needs of the user.

The object of self-study is the Mathcad software product.

The subject is adaptation of the workspace to the needs of the user.

Methods used for self-study: analysis and synthesis, induction and deduction.

The expected result. A report with answers to questions for self-testing.

Study material

Analytical graphics. Classification of methods of constructing 3D graphs. A mathematical model of the surface. Description of analytical surfaces. Plane. Surfaces of the second order. Sphere. A two-cavity hyperboloid. Elliptical paraboloid. Hyperbolic paraboloid. Cylinder. Cone. Toroidal surface. Quadratic form. Matrix notation of the second-order surface equation. A characteristic square shape.

Surface graphs. Surface plots are used to visualize three-dimensional functions that depend on two variables. They show the surface defined by the function $z = f(x, y)$. Mesh plots are similar to surface plots, but the surface is presented as a grid without filling. This allows you to better see the structure of the function.

Contour plots show contour lines on a plane. In a three-dimensional form, they can be represented as colored bands on the surface.

Scatter plots are used to visualize data sets in three-dimensional space, where each point has (x, y, z) coordinates.

Line plots are used to visualize lines or curves in three-dimensional space. This can be useful for showing trajectories or connections between points.

Vector fields show the direction and magnitude of vectors in three-dimensional space. This is often used to visualize force or velocity fields.

Heatmaps show the value of a function or data in three-dimensional space using color to represent the value. In three-dimensional space, heat maps can be superimposed on a surface.

Isosurfaces are three-dimensional surfaces on which the function has a constant value. This is useful for visualizing 3D data such as concentrations or potentials.

Volume rendering is used to visualize three-dimensional data, such as medical scans or fluid simulations. This allows you to see the internal structure of the object.

Histograms (3D histograms) are used to visualize the frequency distribution of data in three-dimensional space. They show how the data is distributed along the three axes.

Three-dimensional graphics are one of the most attractive aspects of Mathcad. You can plot 3D graphs of the following types:

a surface plot [Ctrl] + 2 – a three-dimensional graph;

a contour plot [Ctrl] + 5 – a level line map;

a 3D scatter plot – an image of a collection of points in three-dimensional space;

a 3D bar plot – a three-dimensional histogram;

a vector field plot – a vector field.

You can choose the type of graph to be plotted in one of three ways:

a) from the Insert-Graph submenu;

b) through the toolbar by opening the graphic palette with the "Graph Toolbar" button and selecting the required type of graph from it;

c) through the keyboard:

[Ctrl] + 2 – to build a three-dimensional graph;

[Ctrl] + 5 – to build a level line map.

You can change the constructed schedule according to your wish:

1) move away or bring it closer;

2) change the scale;

3) return;

4) change the method of painting the surface;

5) hide the hidden lines or show them, etc.

Let's consider in more detail the process of building and editing various three-dimensional graphs.

1. Construction of a three-dimensional graph in rectangular coordinates.

You can plot a 3D graph on an array of data or on a given analytical expression – a function of two variables.

1.1. Construction of a three-dimensional graph from the array of data.

In order to build a surface based on the array of data, do the following:

1) set the dimension of the matrix, according to which the graph will be built;

2) enter the expressions by which x and y are calculated (and these expressions must include the previously specified indices);

3) give an analytical expression for a function of two variables x and y, and then define a matrix based on this function. The row number specifies the x value, the column number specifies the y value, and the matrix element specifies the z value, i. e. the height above the xy plane;

4) create a 3D plot field in one of three ways:

a) through the Insert-Graph-Surface Plot submenu;

b) through the toolbar – by opening the graphic palette with the "Graph Toolbar" button and selecting the "Surface Plot" graph type from it;

c) through the keyboard [Ctrl] + 2;

5) enter the name of the matrix containing the data set instead of the marker and click with the mouse outside the graph field. After that, a surface built by the array of data will appear on the screen (Fig. 1).

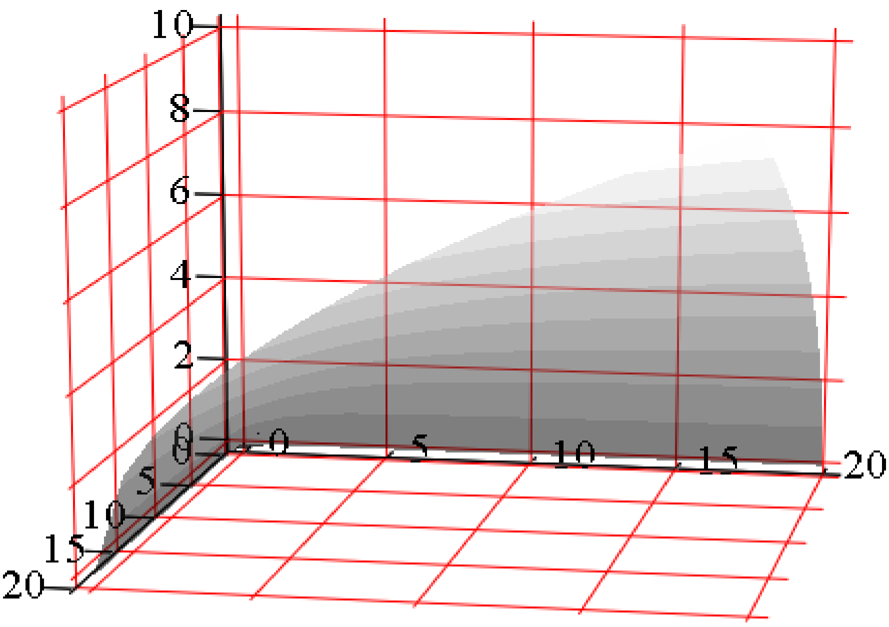


Fig. 1. **An example of building a data array surface**

Note. If you already have an array of data, enter it in the form of a matrix or import it from another program, and then follow step 4.

Consider an example of building a data array surface:

1. Index change range: J: = 0…N, N: = 20, i: = 0…N.

2. Let's set x and y:

$Y_{j:}$ = 0.5 j, x_i = 0.5 i.

3. Let's define f(x, y) and the matrix M:

$$f(x, y) := \sqrt{x \cdot y}$$

$M_{i,j} = f(x_i, y_j)$

Let's make a graph.

1.2. Construction of a three-dimensional graph based on a given analytical expression.

You can plot a 3D graph not only from a given array of data, but also from an analytical expression – a function of two variables. For this do the following:

1) write an expression that defines a function of two variables. It can be both scalar (example 2) and vector (example 3);

2) create a 3D plot field in one of three ways:

a) through the Insert-Graph-Surface Plot submenu;

b) through the toolbar by opening the graphic palette with the "Graph Toolbar" button and selecting the "Surface Plot" graph type from it;

c) through the keyboard – [Ctrl] + 2;

3) enter the name of the function instead of the input marker (arguments are not required) and click with the mouse outside the graph field. After that, a surface built according to the function you specified will appear on the screen (Fig. 2, 3).

Example 2

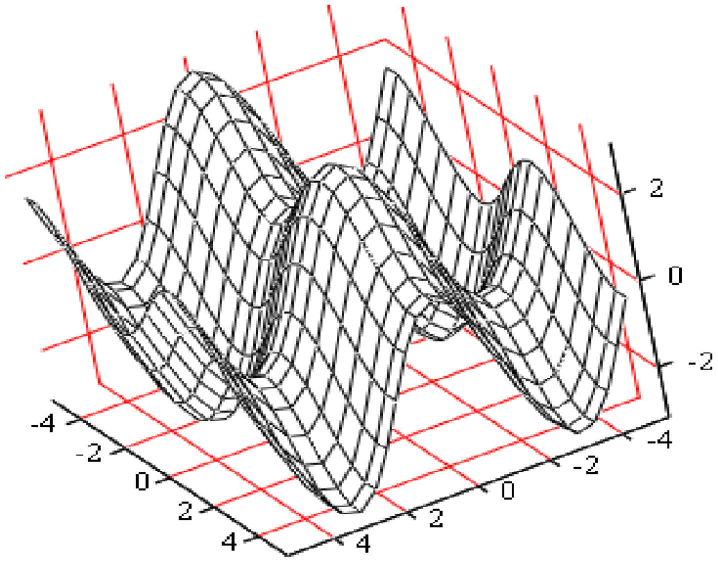


Fig. 2. **Construction of the surface according to the analytical expression in scalar form**

Example 2.
1. Define a function of two variables (scalar):
F(x, y): = sin(y) + 2cos(x).
2. Let's make a graph.

Example 3.
1. Let's define a function of two variables (vector):

$$G(\theta, \phi) := \begin{pmatrix} \cos(\phi) \\ \cos(\theta) \\ \sin(\theta) \end{pmatrix}$$

2. Let's make a graph.

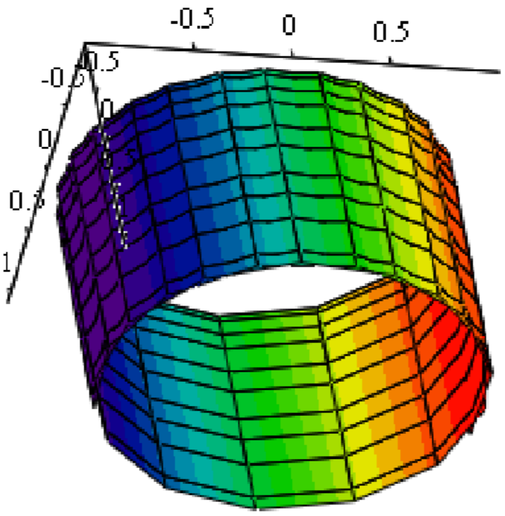
Example 3


Fig. 3. **Construction of the surface according to the analytical expression in vector form**

Before plotting the graph, Mathcad calculates the matrix of values of the given function. If the function is specified as a vector, its first element specifies the x value and the second element specifies the y value. Limits of change of independent variables during graph construction are from −5 to 5.

1.3. Building a level line map.

A three-dimensional object can be imagined in the form of a map of level lines – in this case, contours are drawn on the xy plane, all points of which have the same height (i. e. z value). These contours are also called level lines. Such a card can also be both colored and black and white. To build a map of level lines, you need to do the following:

1. Set up a matrix or function of two variables to be plotted. In the first case, do not forget that to build the map, the level lines x and y must change with a constant step.

2. Create a chart field in one of three ways:

a) through the Insert-Graph-Contour Plot submenu;

b) through the toolbar – by opening the graphic palette with the "Graph Toolbar" button and selecting the "Contour Plot" graph type from it;

c) through the keyboard – [Ctrl] + 5.

3. Enter the name of the function or matrix instead of the input marker and click with the mouse outside the graph. After that, a map of the level lines will appear on the screen, built according to the function you specified.

1.4. Construction of a three-dimensional bar chart.

A three-dimensional object can be imagined in the form of a surface (see Fig. 1 – 3), but also in the form of a three-dimensional bar chart. To build it, you need to perform the following actions:

1. Set up a matrix or function of two variables to be plotted.

2. Create a chart field in one of two ways:

a) through the Insert-Graph-3D Bar Plot submenu;

b) through the toolbar by opening the graphic palette with the "Graph Toolbar" button and selecting the "3D Bar Plot" graph type from it.

3. Enter the name of the function or matrix instead of the input marker and click with the mouse outside the graph. After that, a three-dimensional bar chart will appear on the screen, built according to the function you specified.

1.5. Construction of a collection of points in three-dimensional space.

If you want to represent an existing array of data as points in 3D space, rather than interpolating it to build a surface, do the following:

1) specify three vectors or matrices defining the x-, y-, and z-coordinates of the points, respectively. The number of elements in these vectors and matrices is equal to the number of points that will be displayed on the graph. You can also set three functions of one or two variables;

2) create a chart field in one of two ways:

a) through the Insert Graph 3D Scatter Plot submenu;

b) through the toolbar by opening the graphics palette with the "Graph Toolbar" button and selecting the "3D Scatter Plot" graph type from it.

3) enter the names of three vectors or matrices in round brackets instead of the input marker, separating them with commas and click outside the graph field. After that, a set of points in three-dimensional space will appear on the screen, built according to the vectors or matrices you specified.

1.6. Construction of several graphs in three-dimensional space.

You can plot a three-dimensional graph based not only on a given array of data, but also on an analytical expression – a function of two variables. For this, do the following:

1) specify two arrays of data or two functions of two variables to be plotted;

2) create a 3D plot field in one of three ways:

a) through the Insert-Graph-Surface Plot submenu;

b) through the toolbar by opening the graphic palette with the "Graph Toolbar" button and selecting the "Surface Plot" graph type from it;

c) through the keyboard [Ctrl] + 2;

3) instead of an input marker, enter (with a comma) the names of matrices or functions and click with the mouse outside the graph field. After that, two surfaces built according to the given functions or matrices will appear in the graphics field.

As a result of self-study, the student develops the following competencies: knowledge and understanding of the subject area, understanding of professional activity.

Tasks for self-study:

build a surface graph;

build a grid graph;

construct a contour graph;

build a dot graph;

create a three-dimensional rendering;

define a 3D data volume as a set of features;

use Mathcad to visualize this volume using color to display function values;

construct a 3D graph for the function from any of the previous tasks;

customize the graph to make it more informative.

Questions for self-testing

1. What is a 3D chart and what is it used for?
2. Describe what types of data or functions are typically visualized using 3D graphs?
3. What are the main types of 3D graphs available in Mathcad?

4. What are the steps to create a 3D graph in Mathcad?
5. What functions are used to define the range of variables in Mathcad?
6. What is the difference between a surface plot and a contour plot? Give an example.
7. How to create a 3D dot plot for a set of random points?
8. What is volumetric rendering and how is it used to visualize 3D data?
9. What are the advantages of using Mathcad to construct 3D graphs? What are the disadvantages?
10. Give examples where 3D graphics can be useful in real engineering problems.
11. Compare surface, grid, and contour plots. In what situations is each of them more suitable?

Topic 2. Fractal 3D graphics

Task 2. Fractal 3D graphics.

The goal of independent work is to acquire knowledge and skills in working with fractal 3D graphics.

The object of independent work is the Mandelbulb3D and Incendia programs.

The subject is the creation of fractal 3D graphics using appropriate software tools.

Methods used for independent work: analysis and synthesis, induction and deduction.

The expected result: A report with answers to questions for self-testing.

Study material

The concept of fractal. The history of fractals. Classification of fractals. Geometric fractals. Algebraic fractals. Stochastic fractals. Spatial fractals. Fields of application of fractals. Mathematical description of fractals. Programs for creating and editing fractals. The Mandelbulb3D 3D fractal editor. The generator of three-dimensional fractals Incendia. Incendia interface. Initial creation and editing of fractals in Incendia. Exporting 3D fractals from Incendia to 3ds max. Fractals in 3ds max.

A fractal is a complex geometric figure that has the property of self-similarity, that is, each part of it is similar to the whole figure as a whole, regardless of scale. They often have a fractional (fractal) dimension and can be determined by recursive processes. Fractals are often found in nature, such as coastlines, mountains, clouds, trees, and the vascular system.

Ideas resembling fractals appeared as early as the 19th century. For example, the Cantor set (Georg Cantor, 1883) and the Peano curves (Giuseppe Peano, 1890).

The very term "fractal" was proposed by Benoit Mandelbrot in 1975. He introduced this term in his work "The Fractal Geometry of Nature", where he explained phenomena and objects that cannot be described by traditional Euclidean geometry.

Fractals can be classified according to various criteria:

analysis and synthesis, induction and deduction;

according to the geometric structure:

curves: for example, the Koch curve, the Dragon curve, the Hilbert curve;

surfaces: for example, Julia Polynomials, Mandelbrot Surface;

volumetric fractals: for example, Menger's sponge, fractal mountains;

according to the generation method:

iterative fractals generated by repeating a certain process, for example, the Mandelbrot set;

linear recursive fractals generated by repeating linear transformations, for example, the Koch curve;

stochastic fractals generated using random processes, for example, fractal mountains and coastlines;

by nature of self-similarity:

strictly self-similar fractals having exact self-similarity on all scales, for example, the Serpinsky Triangle;

statistically self-similar fractals having self-similarity on average, but not on all scales, for example, fractals describing the structure of coastlines;

quasifractals having self-similarity properties only on a limited number of scales, for example, the structure of some plants;

by size:

one-dimensional fractals, for example, the Koch curve;

two-dimensional fractals, for example, the Mandelbrot set.

Incendia is a program for generating 3D fractals that allows you to create complex fractal structures with many possibilities for editing them. Here are the basic steps to get started with Incendia, creating and editing fractals.

Open Incendia after installation.

Incendia's main interface consists of a viewport, a toolbar, an options panel, and a menu.

Select a base fractal from the Fractals menu. Incendia offers several predefined fractals that you can use as a starting point.

Use the options panel to adjust the properties of the fractal. You can change various parameters such as iterations, scale, colors and other properties (Fig. 4).

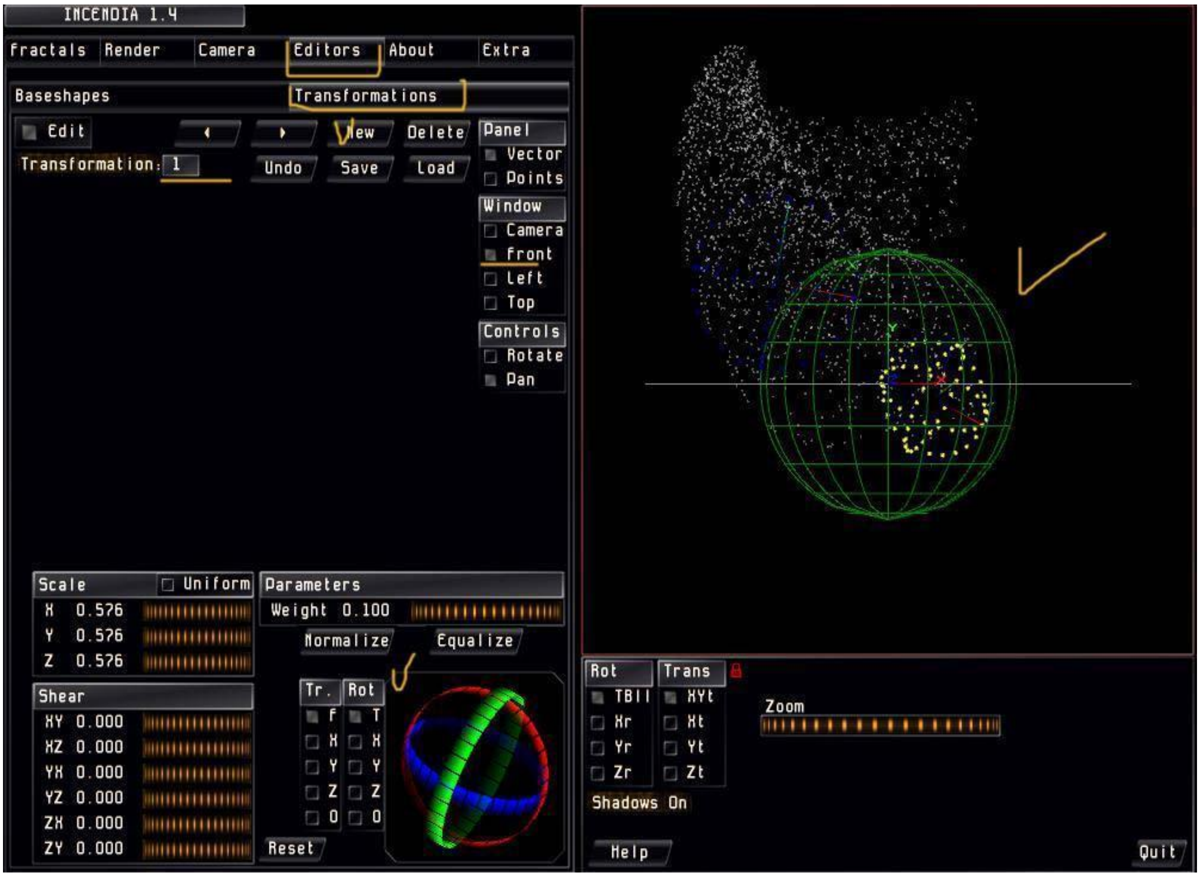


Fig. 4. **Incendia interface**

Click the Render button to see a preview of your fractal. You can change the parameters and render the fractal several times until you achieve the desired result.

Use the options panel to change the properties of the fractal. You can change the generation parameters, such as the number of iterations, the type of transformations, the lighting parameters and others.

Incendia supports modules to add new functionality. You can download and use various modules to extend the program's capabilities.

In the options panel, you can customize the colors, materials, and textures for your fractal, allowing you to create more realistic images.

After finishing editing, you can save your project or export the fractal image in various formats such as PNG, JPG or 3D models in OBJ or STL formats.

As a result of self-study, the student develops the following competences: knowledge and understanding of the subject area, understanding of professional activity.

Tasks for self-study:

create a basic fractal;

adjust basic fractal parameters such as iterations and scale;

render the fractal and save the image;

change the color of the fractal using the available options;

using the parameters panel, change the fractal generation parameters, such as the number of iterations and the type of transformations;

download and install any add-on for Incendia. Use this module to create a new fractal;

adjust the parameters and render the fractal using the new module;

adjust texture parameters such as scale and material type;

change the lighting parameters in your project;

create a fractal animation project;

render the animation and save it in video format;

configure options for fractal animation, such as changing colors or transformations during animation;

using all the available tools and options, create a unique fractal according to your design. Adjust colors, textures, lighting and other parameters to get the desired result.

Render and save the image of your fractal.

Questions for self-testing

1. What is a fractal?
2. What are the main types of fractals supported by Incendia?
3. What are the steps to create a basic fractal in Incendia?
4. How to change fractal colors in Incendia?
5. How to add textures to a fractal?
6. What parameters can be changed to adjust the lighting of the fractal?
7. What is an iteration function and how is it used to generate fractals?
8. What is self-similarity in the context of fractals?
9. What are the differences between strictly self-similar and statistically self-similar fractals?
10. How to export a fractal from Incendia to the 3D model format?
11. How to create a fractal animation in Incendia?
12. What features do modules in Incendia provide?

Content module 2. Polygonal 3D objects

Topic 3. Polygonal 3D graphics

Task 3. Polygonal 3D graphics.

The goal of self-study is to acquire knowledge and skills in working with polygonal 3D graphics.

The object of self-study is the 3ds Max program (Blender).

The subject is the creation of polygonal 3D graphics using appropriate software tools.

Methods used for self-study: analysis and synthesis, induction and deduction.

The expected result: A report with answers to questions for self-testing.

Study material

The task of representing 3D objects. The main types of 3D models. Ways of representing models of geometric objects. The structure of the geometric model of objects. Point and frame representation of the geometric model of objects. General view of the parametric surface. Surface task of three-dimensional objects. Polygonal model. Patch model. Volumetric task of three-dimensional objects. The concept of voxel. Parametric task of geometric objects. Types of parametric functions of two variables.

Types of editable surfaces: Editable Mesh, Editable Poly, Editable Patch, NURBS Surface. Converting 3ds Max objects into different types of surfaces. Editing mode settings. Vertex, Edge, Face, Polygon, and Element surface editing modes. Mesh modeling in 3ds Max. Modeling using polygons.

In general, the polygonal model in the 3ds Max program looks as follows (Fig. 5).

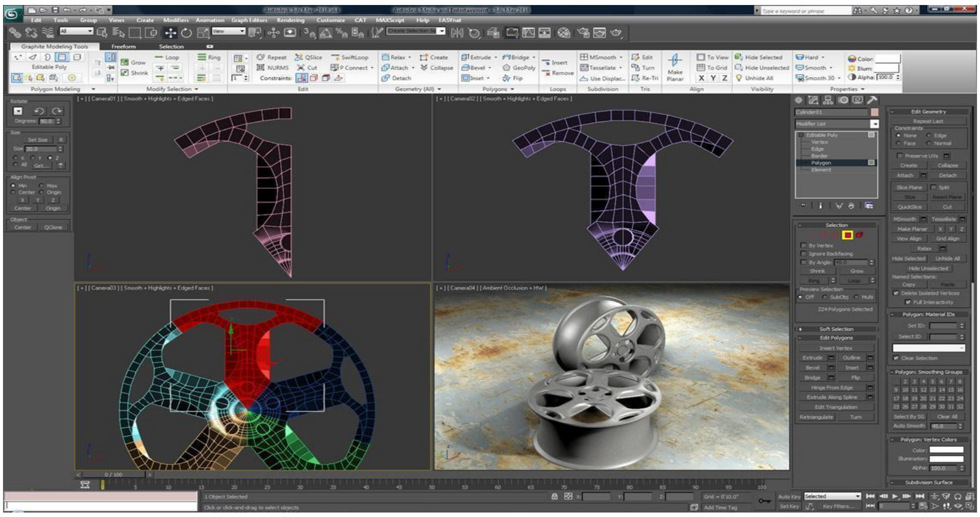


Fig. 5. **A polygonal model in the 3ds Max program**

In 3D modeling, there are several basic types of 3D models, each with its own characteristics and applications. The main types include:

- polygonal models. Models consist of polygons, usually triangles or quadrilaterals, which form a mesh. They are used in games, animation and rendering due to their flexibility and ease of processing. Examples of programs: Blender, 3ds Max, Maya;
- NURBS models (Non-Uniform Rational B-Splines). Curves and surfaces defined by mathematical functions (splines) are used. They provide high precision and smooth surfaces, making them ideal for industrial design and CAD. Examples of programs: Rhino, Alias, CATIA;
- voxel models, which are built from voxels (three-dimensional pixels), which form a three-dimensional structure. They are used in science, medicine and games for modeling voluminous data and complex structures. Examples of programs: MagicaVoxel, 3D-Coat;
- sculpting models. They are created using digital sculpting, which simulates working with clay. They are used to create detailed organic models such as characters or creatures. Examples of programs: ZBrush, Mudbox, Blender (Sculpt Mode);
- parametric models. They are determined using parametric relationships and dependencies. Models of this type are used in CAD to create accurate and variable models such as machine parts. Examples of programs: SolidWorks, Autodesk Inventor, Fusion 360.

There are several basic methods of representing geometric objects in three-dimensional modeling:

- mesh representation which uses polygons to create a grid that defines the shape of the object. This is the most common method in computer graphics and games;
- primitives. This method uses basic geometric shapes such as cubes, spheres, cylinders and cones and can be combined to create more complex objects;
- NURBS representation which uses NURBS curves and surfaces to create smooth and accurate models. It provides high accuracy and the ability to model complex curved surfaces;
- voxel representation that uses three-dimensional pixels (voxels) to define the volume of an object. It is suitable for modeling volumetric and detailed structures;

- CSG (Constructive Solid Geometry). This method uses Boolean operations (union, difference, intersection) to create complex objects from simple primitives. It is widely used in CAD systems for engineering design;
- iterative functional systems (IFS). Recursive functions are used to create complex fractal geometries. They are used to model natural phenomena, such as trees or landscapes;
- parametric representation which uses parametric dependencies to define object geometry. It allows you to easily change the shape of the object by changing the parameters;
- implicit surfaces which are defined as a set of points that satisfy a certain equation. They are used to create smooth and seamless surfaces.

Geometric models are used to represent three-dimensional objects in computer graphics, CAD systems, animation, and other fields. The structure of the geometric model determines the way in which the shapes and properties of the object are described. The main components of the geometric model structure include:

- vertices – points in three-dimensional space that define key positions on the object. Each vertex has coordinates (x, y, z);
- edges – line segments connecting pairs of vertices that determine the faces of the object and its shape;
- faces – flat surfaces bounded by edges. They are usually represented by triangles or quadrilaterals (polygons);
- normals – vectors perpendicular to the surface of the face. They are used to specify the direction of a surface for lighting and rendering;
- UV coordinates (Texture Coordinates) – coordinates for binding textures to the surface of the object. They determine how the texture will be projected onto the object;
- materials and textures. They determine the appearance of the surface of the object, including color, texture, reflections and other properties. Materials can include options for textures, reflectivity, transparency, and other visual effects;
- hierarchy and transformations – hierarchical structures that define relationships between different parts of the model (for example, bones for skeletal animation). Transformations (translation, scaling, rotation) are applied to individual parts of the object.

Tasks for self-study:

create a base object. Open Blender or any other 3D editor. Create a basic object (a cube, a sphere, a cylinder);

go to the editing mode. Add new vertices and edges to change the shape of the object;

go into the edit mode and create a UV sweep for the object. Edit the UV sweep to match the geometry of the object;

create or find a texture for your object. Apply a texture to the object using UV sweep;

rendering with normals. Adjust the lighting in your scene. Render the object, making sure that the normals affect the reflection of light and shadows;

skeletal animation settings. Add armature to your character. Connect the skeleton to the model by setting up weight maps (weight painting);

adjust keyframes to create character movement animations. Create simple animations, such as a character walking or a camera moving around an object. Render the animation and save it in the video format;

use tools to optimize the model, such as polygon reduction (decimation).

Questions for self-testing

1. What is a polygonal 3D model?
2. What are the main elements that make up a polygonal 3D model?
3. What are normals and what are they used for in polygonal graphics?
4. What types of polygons are most often used in polygonal models?
5. What is UV scanning and why is it needed?
6. What is the topology of a polygonal model?
7. What are the main tools used for polygon modeling in Blender (3ds Max)?
8. How are Boolean operations used in polygonal modeling?
9. What is retopology and why is it needed?
10. How to create a basic polygonal cube model in Blender (3ds Max)?
11. How to add a texture to a polygonal model?
12. How to configure lighting for rendering a polygonal model?
13. What are the advantages and disadvantages of polygon modeling compared to other methods?
14. What are subdivision surfaces and how are they used?
15. How does the number of polygons affect the performance and quality of the model?

Topic 4. Spline 3D graphics

Task 4. Spline 3D graphics.

The goal of self-study is to acquire knowledge and skills in working with polygonal 3D graphics.

The object of self-study is the 3ds Max program (Blender).

The subject is the creation of spline 3D graphics using appropriate software tools.

Methods used for self-study: analysis and synthesis, induction and deduction.

The expected result: A report with answers to questions for self-diagnosis.

Study material

The concept of spline. Spline interpolation. Types of splines. Cubic spline. B-spline. NURBS. Spline function. Conditions for the formation of the spline function. Spline in the Hermite form. Spline in the Bezier form. Polynomial spline interpolation. Construction of curved surfaces. Primitives of splines. Additional spline objects. Creation of complex geometric three-dimensional objects based on spline shapes. Surface, Lathe, Sweep, Extrude and BeveL, Loft modifiers. Creation of three-dimensional objects based on splines. Using NURBS to create three-dimensional objects. Two types of NURBS curves and surfaces: Point and CV. Floating NURBS panel. Basic techniques for working with NURBS curves and surfaces. The Sub-Object mode.

In general, the spline model in the 3ds Max program looks like follows (Fig. 6).

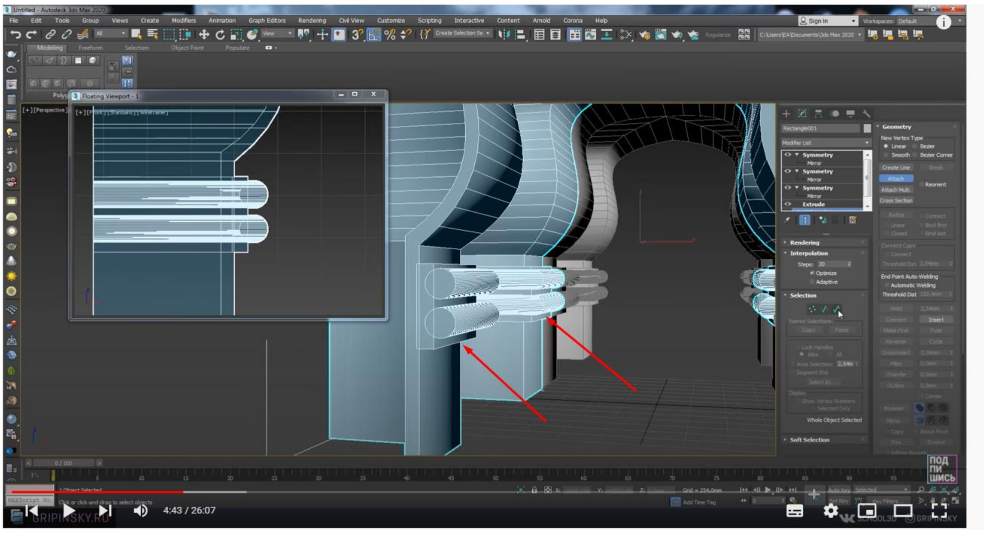


Fig. 6. **A spline model in 3ds Max**

A spline is a smooth curve that passes through or near given points (control points) and is used to model curved lines and surfaces in computer graphics, animation, and other fields. Splines can be represented as a set of polynomials that connect at control points, ensuring smoothness and continuity of the curve.

Spline interpolation is the process of constructing a spline curve that passes through all given control points. The goal of interpolation is to find a function that provides a smooth transition between points while maintaining a given shape.

Basic steps of spline interpolation:

1. Setting control points. Defining the set of points through which the curve should pass.

2. Breakdown of intervals. Distribution of intervals between control points.

3. Construction of polynomials. Construction of polynomials for each interval, which ensure the smoothness and continuity of the curve.

4. Definition of smoothness conditions. Application of smoothness conditions, such as continuity of first and second derivatives, to ensure a smooth transition between polynomials.

There are several main types of splines, each of which has its own characteristics and applications:

- a linear spline which uses linear polynomials to connect control points. It is simple to implement, but does not ensure the smoothness of the curve. It is used for fast approach;
- a quadratic spline. It uses quadratic polynomials to interpolate between points and ensures the continuity of the first derivative;
- a cubic spline which uses cubic polynomials for interpolation and ensures the continuity of the first and second derivatives. It is the most common type of spline due to its good balance between complexity and smoothness;
- a B-spline (Basis spline) which uses basis functions to construct a curve. It provides high flexibility and control over the shape of the curve and can be used to create NURBS (Non-Uniform Rational B-Splines);
- a NURBS (Non-Uniform Rational B-Splines) which is a generalization of B-splines that uses weighting factors to control the shape of the curve. It is widely used in computer graphics and CAD systems for modeling complex curves and surfaces;

- Bezier curves. Polynomials defined by control points are used. They are easy to implement and manipulate and are widely used in graphic design and animation. They ensure the smoothness of the curve, but control over the shape is limited by the number of control points.

Using splines, you can create complex 3D shapes and surfaces. Here are some basic techniques for creating 3D objects based on splines:

- revolution. This method creates a three-dimensional object by rotating a two-dimensional profile (spline curve) around an axis. It is used to create objects with rotational symmetry, such as vases, bowls, bottles;
- extrusion. The extrusion method creates a three-dimensional object by drawing a spline curve along a certain path. It is used to create pipes, rods and other objects with a constant cross-section;
- loafing creates a three-dimensional object by passing through several spline curves that define the shape at different intersections. It is used to create complex forms, such as the bodies of airplanes, boats, and cars;
- skinning is similar to loafing, but uses a set of spline curves to define the shape of the surface. It is used to create organic shapes such as characters, animals and plants;
- NURBS surfaces. NURBS surfaces use splines to define smooth, precise surfaces that can be used in CAD and computer graphics. They provide high accuracy and flexibility in modeling complex forms.

Tasks for self-study:

create a profile for rotation. Open Blender. Choose Add > Curve > > Bezier. Use control points to create a profile of an object, such as a vase or a glass;

select the created curve. Go to Object Data Properties. Under Geometry, find the Bevel option and set it to rotate the curve around an axis;

adjust the lighting and materials. Render an image of the object and save it;

draw a curve that defines the shape of the object (for example, the outline of a pipe or rod). Go to Object Data Properties. In the Geometry section, increase the Extrude value to extrude the curve into a 3D object;

create a UV sweep and apply a texture to the object. Adjust materials and textures for a more realistic look;

open Blender and create several spline curves at different heights (eg Add > Curve > Bezier). Use these curves to create a surface that passes through all intersections. Use the Surface Modifier or an appropriate tool in your 3D editor;

create a NURBS curve: open Blender and choose Add > Curve > > NURBS Curve. Use control points to create a smooth curve. Use multiple NURBS curves to define the surface. Use the NURBS surface tools to combine these curves into a smooth surface. Customize materials and textures. Apply materials and textures to a NURBS surface. Adjust lighting and rendering;

apply the skinning method. Combine these curves to create a smooth surface. Use the Skin modifier or a suitable tool to create a surface. Create a UV sweep and apply textures to the object. Adjust materials, lighting, and rendering.

Questions for self-testing

1. What is a spline and what are its main properties?
2. What types of splines do you know?
3. What is spline interpolation?
4. What is the revolution method and how is it used to create three-dimensional objects?
5. How does the extrusion method work?
6. What is the loafing method and what are its features?
7. How are NURBS surfaces used in three-dimensional modeling?
8. What is the method of skinning and for which objects is it used?
9. What steps must be taken to create a three-dimensional object using the rotation method in Blender (3ds Max)?
10. How to create a UV sweep for a three-dimensional object in Blender (3ds Max)?
11. What tools in Blender (3ds Max) are used to edit spline curves?
12. What are the advantages of NURBS surfaces compared to polygonal models?
13. How does the number of control points affect the shape of the spline curve?
14. What are the advantages and disadvantages of the skinning method?
15. Give examples of real projects where splines are used to create three-dimensional objects.

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другого (магістерського) рівня
(англ. мовою)

Самостійне електронне текстове мережеве видання

Укладач **Кобзев** Ігор Володимирович

Відповідальний за видання *О. І. Пушкар*

Редактор *З. В. Зобова*

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