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INTRODUCTION OF RHINOCEROS SOFTWARE FOR EXERCISES OF SUBJECT GEOMETRIC SURFACES IN ARCHITECTURE

Abstract: In contemporary architecture, free curved forms of objects, or parametrically modeled shapes, are in the expansion. The authors had an interest to upgrade student's knowledge with complex geometry design and contemporary software such as Rhinoceros. In that manner we made an exercise templates, that our students on Architecture used in elected subject „Geometric Surfaces in Architecture" where they learned about types, usage and design of geometric surfaces in architecture. By creating templates we reassure precise, faster and planed work with students as they obtain every possible explanation, for every exercise and homework that they have to master. Moreover this teaching method allows students not only to pass the course and learn new modeling and design techniques, but also keeping the prepared material as support for future architectural work.

Key words: Free curved forms, Rhinoceros Software, Exercise Templates, Geometric Surfaces in Architecture.

1. INTRODUCTION

Traditional orthogonal system is no longer dominant, but on the contrary, free, curved forms or parametrically designed shapes are going through an expansion in architectural and urban design [1]. To design the architecture under its various forms, a student in architecture needs to know the geometry of these forms [2]. Whereas the variety of shapes that could be treated by traditional geometric methods has been rather limited, modern computing technologies have led to a real geometry revolution [3].

The increasing use of free form in architecture has required the need to study curved shapes, complex geometries. Before they begin to use free forms for objects, students must learn how to model geometric surfaces, which are obtained by a certain rule. Therefore, at the Faculty of Civil Engineering and Architecture (in further text FCEA) University of Niš, in the 2009/10 academic year for students of architecture in the master study program was introduced the elected subject of Geometric Surfaces in Architecture, with a fund of lessons - lectures + exercises (1 + 1). Students were taught about all types and characteristics of geometric surfaces used in architecture in lectures, while at the exercises modelled those same surfaces in some CAD software, AutoCAD, Sketch Up and 3D Studio Max were used. In some of these software it was very complicated to model curved surfaces. In addition, students were of the opinion that the subject was very useful and attractive, but was late introduced into the curriculum, and the knowledge gained on it could only be used for master work.

2. INFORMATION

During the new accreditation, the subject is foreseen for the second year of integrated academic architecture studies. The fund of lessons remained the same (1 + 1), as well as the content of the subject, as in the previous period. The basic literature for the course are Presentations by units and the book "Geometric Surfaces in Architecture", which was published in a printed version in 2012 in Serbian, and available at the faculty library [4]. Changes were made during exercise classes. Rhinoceros software was introduced for students during exercises in which it was possible to easily model all the geometric surfaces taught in the lectures. Since students are not familiar with the work in this software, it was necessary to explain them to the basic commands first. Then, tasks were assigned to modelling architectural objects from geometric surfaces. Due to the small amount of exercise time, in order for students to learn to model a larger number of geometric surfaces that they acquire knowledge in lectures, it is envisaged that one surface from the same lecture be processed during the exercises classes and the other for a homework assignment. In order to make it easier for students to work in the Rhinoceros software, both at classes and at home, exercise templates are made [5]. It was a challenge for the author team to create exercise templates that were designed so that attractive objects could be selected for tasks, which can be modelled in steps, with as few options as possible. Textual explanations of the options in the steps are given and some drawings are shown, most often in the perspective view, with the basic dimensions. For each task for working on class and homework, the final model of the object and orthogonal projections with all the characteristic dimensions is given. Teaching methods applied to create an exercise templates helps students to master the course. At the same time all of prepared material is of great help for student's future work when creating their architectural projects.

3. CONTENT OF THE GSA COURSE

The GSA course at the FCEA, University of Niš is conducted in 12 Units, both in lectures and in exercises [6]. The units in the lectures follow the division of geometric surfaces with the introductory lecture, classification and historical overview of the application of these surfaces in architecture (Table 1). Lectures are prepared with PowerPoint presentations. At the

exercises, the first 3 units were introductory. From the fourth unit, the surfaces that are studied at the same lecture are modelled, one at the exercise class (EC), and one for the homework (HW) (Table 2). Exercises are prepared with templates [5].

Table 1

Content of lectures in course GSA on FCEA in Nis [6]

Unit	Title	Unit	Title
1	Introduction in course	7	Helicoids
2	Classification of the surfaces	8	Cylindroids, Conoids and Tetroids
3	Regular polyhedra, Platonic and Archimedean solids	9	Revolving, Elliptical hyperboloid of one sheet and Hyperbolic paraboloid
4	Pyramids, prisms and fold structures	10	Double curved surfaces - Sphere
5	Cones, cylinders and fold structures	11	Ellipsoid, Paraboloid and Hyperboloid of two sheets
6	Twisted surfaces	12	General surfaces of revolution, Torus and Sliding surfaces

Table 2

Content of exercises classes and homework in course GSA on FCEA in Nis [6]

Unit	Title	Unit	Title
1	Rhinoceros – basic commands, point and straight line	7	Oblique helical staircase (EC)– normal helical staircase (HW)
2	Rhinoceros – free form curves and conics	8	Conoidal canopy (EC)– cylindroid (HW)
3	Rhinoceros – surfaces and geometric solids	9	Hyperbolic paraboloid object (EC) – spherical canopy (HW)
4	Pentagonal dodecahedron (EC) - icosahedron (HW)	10	Revolving hyperboloid of one sheet object (EC) - spherical slice (HW)
5	Pyramidal folds (EC) - prism's folds (HW)	11	Triaxial ellipsoid object (EC) – paraboloid object (HW)
6	Conical folds (EC)– cylinder's object (HW)	12	Torus object (EC) - sliding surface (HW)

4. EXERCISE TEMPLATES

Exercises are performed using computers in the Rhinoceros 5 software. Templates are posted on the Internet network and are available to all students. The assistant works every step of the task to the final solution, on computer, and his/her work is projected on the screen, via video beam. The templates clearly indicate the views in which a step needs to be work, the command to be selected from the main menu or the mini-menu, whether it should be typed command on the command line and additional explanations are provided for the inclusion of Osnap options that give precise positioning of the points (End, Point, Mid, Cen, Int, Perp, Tan ...), or the Grid Snap, Ortho, Planar, Smart Track options that are included as needed (fig. 1).
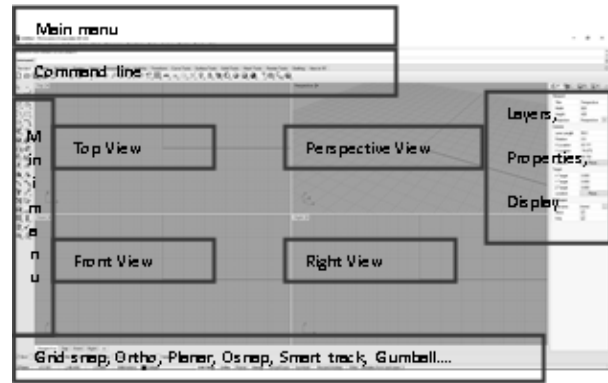

Fig. 1 Desktop in the Rhinoceros software.

4.1. Exercise template – Unit 1

Unit 1, the basic commands (options) explains:
Running the Rhinoceros software, a 4-window desktop, top, front, right and perspective (fig. 1), important commands that are often used from main and mini manu, layers, properties, display, commands for drawing points, lines, polylines, quadrilaterals, polygons, object disassembling the elements, connecting elements into a whole. It is also explained how the units in which it is modelled are adapted. Student's homework for Unit 1 is to enter 9 points, which are assigned with x, y, and z coordinates.

4.2. Exercise template – Unit 2

Unit 2 explains how to construct planar free curves and conics of II degree (circles, ellipses, parabolas, and hyperbolas). It is shown how to construct a helix and spiral from spatial curves. Moreover, how the curves can be divided into parts, cut, expand, how the solid contour can be found in a certain direction. Student's homework for Unit 2 is to replace straight lines with the curves, which construction they have learned, in given structure.

4.3. Exercise template – Unit 3

Unit 3 explains the surfaces and geometric solids constructions. It is explained how to construct a planes, and then surfaces with Loft, Sweep and Revolve commands, which are most commonly used. In further work it has been shown how the surface can be extended, rounded or cut off and offset an identical surface at a certain distance. The following are explanations of the construction of the geometric solids, Box, Sphere, Cylinder, Cone, Pyramid, Ellipsoid and Torus. Some operations with geometric solids have been shown. Surface visibility is also very important, so it is shown how it can be changed. Student's homework for Unit 3 is to draw the given meridian, which consists of straight and curved lines and with option **Surface/Revolve** to obtain surface of revolution.

4.4. Exercise template – Unit 4

Unit 4 demonstrated how to construct a pentagonal dodecahedron (fig. 2), in 9 steps. Solid dimensions are not defined. First it is needed to draw a regular pentagon,

than with **Transform/Mirror** option we mirror it in relation its two sides. Then draw two circles in vertical planes as in fig. 2 and search their intersection. With the **Transform/3d Rotate** option, the two pentagons move so that one vertex of each coincides the upper point of intersection of the circles. The remaining three inclined pentagon obtained by the **Transform /Rotate** command. In this way, the bottom half of the dodecahedron was obtained. The upper half gets the **Orijent3pt** option on the command line. The order of selection points for this command is shown in fig. 2.
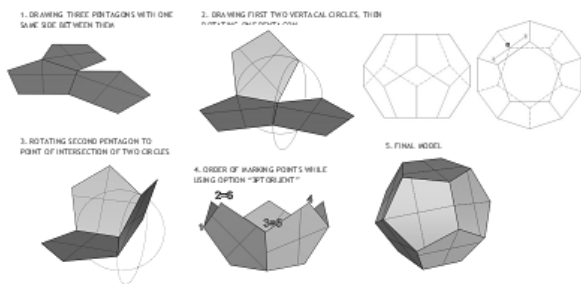
Fig. 2 Drawings in steps - Exercises for Unit 4

Students homework for Unit 4 is modelling icosahedron (fig. 3), using 8 steps, given dimensions. This solid consists of 2 pentagon pyramids, which are spaced apart for the height $H_2 = 0.85a$, where the edge of the icosahedrons is **a**, and the central part consists of equilateral triangles. With **Solid/Pyramid** option constructed the first pyramid, then reflected in relation to a basis and second pyramid lowered for height H_2.

In order for the interior of the solid to be empty, it is necessary to disassemble the pyramid with the **Explode** option and **Delete** the bases. The central part was obtained by using **Mini Manu/Surface from 3 or 4 other point's** option.
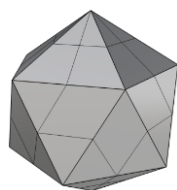

Fig. 3 Final model - Homework for Unit 4

4.5. Exercise template – Unit 5

Unit 5 demonstrated how to construct a pyramidal folds above the circular basis (fig. 4), in 10 steps.

Unit settings are in **m**. The options from the **Curve Manu**: **Circle, Divide Curve by Number of Segments** and the **Move** option are used to separate the circles where are the points forming the folds element. It was modelled using the **Surface of 3 or 4 Other Points**, **Mirror** and **Join** commands. Then, with the **Array/Polar** option, the folds element is radially copied 25 times.

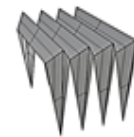| **Fig. 4** Final model – Exercises for Unit 5 | **Fig. 5** Final model – Homework for Unit 5 |

Student's homework for Unit 5 is modelling prismatic folds (fig. 5), in 8 steps. Units are **m**. The **Curve/ Rectangle** option was used to draw a rectangle and command **F10** to separate the rectangle points and move in two directions. Prismatic and single pyramidal fold are constructed by the **Surface from 3 or 4 other points** command, then reflected pyramidal fold. The **Join** option is integrated all elements into one whole, and then copied 3 more times.

4.6. Exercise template – Unit 6

Unit 6 demonstrated how to construct a cone folds over the circular basis (fig. 6), in 11 steps. Unit settings are in **m**. The **Solid/Cone** option was used for modelling the cone, which is the basic element of the fold. The cone is rotated so that the axis is oblique and by **Array/Polar** option, radially copied. Then the conical fold is cut by one horizontal and 6 vertical planes. The part of the folds below the horizontal plane was removed, and by the **Explode** option was disassembled folds on the parts. This makes it easier to remove all the parts of the cone inside the building and the basis. The object should be closed by a vertical cylinder, so the constructed circle is inscribed in the 12-angled basis, by **Curve/Circle** option, raised the wrapper with **Surface/Extrude Curve/Straight** option and removed the excess surface. The shell thickness was obtained using the **Solid/Offset** command.
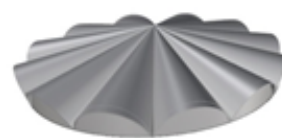

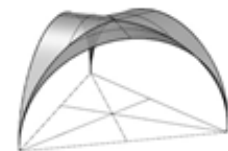| **Fig. 6** Final model – Exercises for Unit 6 | **Fig. 7** Final model – Homework for Unit 6 |

Student's homework for Unit 6 is modelling the vault, which was obtained by breakthrough of three cylinders over the equilateral triangle basis (fig. 7).

The task is solved in 8 steps. Units are **m**. The first is drawn an equilateral triangle with the **Curve/Polygon** option and its orthocentre is defined. Over one side of the triangle as a diameter, a horizontal cylinder is constructed with the **Solid/Cylinder** option, to the triangle orthocentre and cut by two vertical and one horizontal plane. Remove cylinder parts outside the triangle, then by the **Array/Polar** command radially copied the part that remained.

4.7. Exercise template – Unit 7

Unit 7 demonstrated how to construct a helical staircase (fig. 8). The stair plate is an oblique helicoid, whose directrices are two helix. The construction of the staircase with the fence was done in 19 steps. Unit settings is in **m**. The **Curve/Helix** option was used to draw two helix with different initial heights (fig. 8). With **Surface/2 Sweep Rail** option, is modelled an oblique helicoid (stair plate). To model a stair is required a circular surface (base) subdivided into 12 parts by **Array/Polar** option, then remove the 11 parts, and form the solid, from one stair's part with command **Extrude/Surfaces/Straight**. Quite simply, by the **Array/Along Curve/Method** option, copy all the stairs at a larger helix. For modelling the handrail fence, a larger helix is copied, raised to the appropriate height and formed surface by the **Surface/Sweep 1 Rail** option, and closes with the **Cup** option (fig. 8).
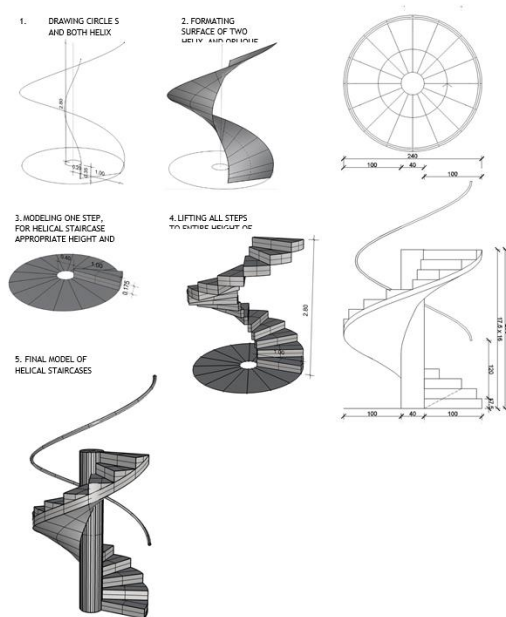

Fig. 8 Drawings in steps - Exercises for Unit 7

Student's homework for Unit 7 is modelling helical staircase with the same dimensions, but with a plate that is normal helicoid (fig. 9). That's why it copied everything that was done to the 13th step of the exercise. Only the plate formed from the same helix is changed, related to the exercise. The helix have the same initial height.
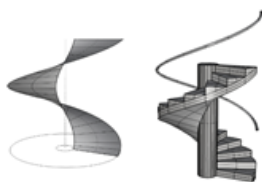

Fig. 9 Drawings in steps - Homework for Unit 7

4.8. Exercise template – Unit 8

Unit 8 demonstrated how to construct a conoidal canopy (fig. 10), in 10 steps. Unit settings are in **m**. Conoid construction is obtained using two directrices, one, semicircle and second, straight line over opposite sides of the square, by the **Surface/Loft** option. The base surface is cut with a vertical plane per square diagonal and the lower part removed. Mirror the slice, a quarter of the canopy is obtained, and by the **Array/Polar** option radially copied a quarter to get the entire canopy. With the **Solid/Box** option, one pillar bearing a canopy was obtained, and then copied 3 times. The thickness of the canopy is obtained by the **Solid/Offset** option.

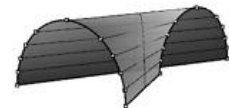**Fig. 10** Final model – Exercises for Unit 8

Fig. 11 Final model - Homework for Unit 8

Student's homework for Unit 8 is modelling cylindroid (fig. 11), in 7 steps. Units are **m**. Cylindroid directrices are two vertical semicircles that are in normal planes. With the **Surface/Loft** option, the surface was obtained, and then with the **Curve from Objects/Intersection** option it was shown that the straight lines are generatrices in a horizontal directrix planes.

4.9. Exercise template – Unit 9

Unit 9 demonstrated how to construct an object created by connecting 3 Hyperbolic paraboloids (**HP**). That is Chapel St. Vicente de Paul, Mexico City, arch. F. Candela (fig. 12), in 16 steps. Unit setting is in **cm**. First, the deltoid is constructed with the **Curve/Polyline** option, which is the basis of one **HP**, using the diagonals. Because it was necessary to find a spatial quadrangle, with which **HP** is obtained, the deltoid vertices is marked by **Mini Manu/Text** + **Object Point/Single Point** option. The deltoid is disassembled with the **Explode** option, because the vertices have different heights. Two opposite sides of the deltoid were used to get **HP** by **Surface/Loft/Style:** **Normal** option. By **Surface/Extrude Curve/Straight** option, vertical walls over longitudinal sides of the deltoid were obtained. To get the whole object, one HP with vertical walls is radially copied with the **Array/Polar** option. The shell thickness is obtained by the **Solid/Offset** option, and the lanterns are modelled by the **Surface/Corner Points** command.

Student's homework for Unit 9, is modelling an object obtained from two semi-spheres (fig. 13), in 7 steps. Units are **cm**. The **Solid/Sphere** option give one sphere to which the lower half was removed by the **Surface/Cutting plane** option. Then, once again a plane through the center, at an angle of 60^0 cut the sphere, the plane was moved from the center 500cm to the right and a smaller part of the sphere is removed by the **Trim**

option. Then the sphere is rotated, inclined plane move to the vertical position, and by the **Transform/Mirror** option gets the entire object.

Fig. 12 Final model – Exercises for Unit 9

Fig. 13 Final model - Homework for Unit 9

Exercise template – Unit 10

Unit 10 demonstrated how to construct an object from a rotational hyperboloid of one sheet (**HOS**), Cathedral, Brasilia, arch. O.Niemeyer (fig. 14), in 15 steps. Unit setting is in **cm**. First, a hyperbole in the vertical plane is drawn with a center and a focus that are indicated by the points of a polyline. Then, with the **Surface/Revolve** option where the axis of the surface passes through the center of the hyperbole, the basic rotational hyperboloid of one sheet is obtained. The surface was cut with a horizontal plane so as not to be symmetrical and a smaller part with the **Trim** option was removed. Found the throat circle through the vertex of hyperbole and divided into 32 parts by **Curve/Point Object/Divide Curve by Number** option. To get the carriers (pillars) on the object, the basic hyperbole is shortened and moved off the surface by option **F10** and **Move**. Another hyperbole was obtained by cross-section of the inclined plane passing through the points on the largest circles of the basic hyperbole and the first adjacent point on the throat circle obtained by dividing into 32 parts. For this reason, the vertical plane with the **Transform/3D Rotate** option is rotated and its cross-section with **HOS** is required. Half of the pillar surface was obtained with the **Surface/Loft** option, and then the surface was examined to get the entire carrier. The two surfaces are joined into one, which is radially copied with the **Array/Polar** option. It was necessary once again to cut the **HOS** with a lower horizontal plane, so that the carriers go out of the surface and close holes on both sides with the option **Cup**.
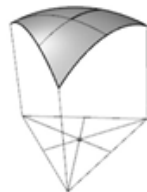

Fig. 14 Final model – Exercises for Unit 10

Fig. 15 Final model – Homework for Unit 10

Students homework for Unit 10 is modelling the sphere slice above the triangular basis (fig. 15), in 6 steps. Units are **cm**. It is necessary to construct the sphere by **Solid/Sphere/Center, Radius** option, with the center at the center of the equilateral triangle. Then, by the **Surface/Extrude Curve/Straight** option gets a vertical three-sided prism. The last step is to remove all

parts of the sphere outside the prism by using the **Trim** option, and then delete the prism wrapper.

4.10. Exercise template – Unit 11

Unit 11 demonstrated how to construct a cross-vault of a tri-axial ellipsoid (fig. 16), in 12 steps. Unit setting is in **m**. First, it is necessary to construct an ellipsoid, whose horizontal ellipse through the center is inscribed in the rectangle. Because the ellipsoid will be cut cross the sides of the rectangle, it is necessary to increase the ellipsoid with the **Transform/Scale** option, so that the horizontal ellipse describes the rectangle. Next, vertical cutting planes are placed through the rectangle sides and horizontal plane through the center of the ellipsoid and its lower and outer parts are removed by the **Trim** option. Vertical planes above the shorter sides of the rectangle are copied and rotated to get overhang in the vault. In order to obtained the entire vault, is using the **Transform/Rotate** option, and then to remove the inner parts of the vertical planes, first **Split** the planes from the surface and then delete. The shell thickness is obtained by the **Solid/Offset** option.
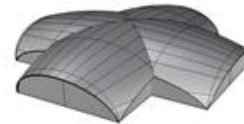

Fig. 16 Final model – Exercises for Unit 11

Fig. 17 Final model – Homework for Unit 11

Student's homework for Unit 11 is modelling the object from a rotating paraboloid, over a hexagonal basis (fig. 17), in 10 steps. Units are **m**. The parabola is drawn with the **Curve/Parabola/Vertex, Focus** option and rotates around the vertical axis by the **Surface/Revolve** command. The horizontal hexagon, whose center coincides with the center of the basic circle of the paraboloid, is inscribed. With the **Curve/Offset/Offset, Curve** option, the new hexagon is drawn inside the basic. With the **Surface/Extrude Curve/Straight** option, two hexagonal prisms with different heights are modelled. It is necessary to split the paraboloid with the vertical planes. Parts of paraboloid are removed from the larger hexagon. Then the upper part of the shell is raised by 2m, with the **Move** option. It is necessary to remove all parts of the vertical planes above the paraboloid and give the thickness of the shell.

4.11. Exercise template – Unit 12

Unit 12 demonstrated how to construct an object from torus (fig. 18 and 19), in 15 steps. Unit settings are in **m**. The upper half of the ring torus was selected, which is obtained by the **Solid/Torus, Radius 7m, second Radius 6.9m**, option whose center is coincided with the center of the square within the equatorial circle. Then the toroidal shell is divided into 12 equal parts by **Split** option, with vertical cutting planes through the center of the surface by **Surface/Cutting Plane** and **Array/Polar** options. To make it easier to manipulate, all the vertical planes and largest toroidal shells are hidden, as in fig. 18. The **Surface/Extrude/Curve/Straight** option was

assigned a third dimension to the square, and then the outer parts of the toroidal shell are removed. Different height to the visible parts of the toroidal shells are assigned. Then the hidden surfaces were returned. With the **Trim** option, all the inner parts of the vertical planes have been removed. The shell thickness is obtained by the **Solid/Offset** option.
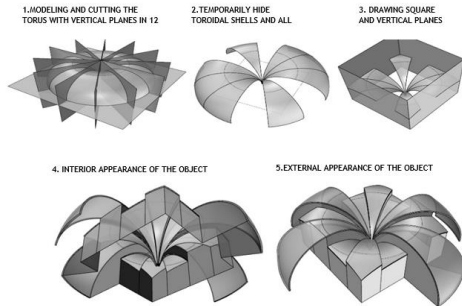

Fig. 18 Drawings in steps - Exercises for Unit 12

5. CONCLUSION

The Rhinoceros software was introduced in the teaching process at the Faculty of Civil Engineering and Architecture (FCEA) in Nis to improve teaching. Due to the increasing presence of curved shapes and geometric surfaces in architecture, it is necessary for students to be familiar with their modelling, types and characteristics, which is significantly facilitated in this software. Easy manipulation, a large number of ready-made options for modelling straight lines, polygons, planar and spatial curves, surfaces and solids are just some of the benefits of this software. The usage of different displaying of surfaces, at several levels and options of different materialization are some of the advantages of working in this software. Precise drawing and modelling that are characteristic of all CAD softwares is extremely high in Rhinoceros. All these advantages have been used to create the exercises templates on the subject Geometric Surfaces in Architecture. The didactic principle, gradual solving of tasks, which was used for the preparation of these materials, contributed to an excellent final result, mastering the course and a large number of excellent student projects. All explanations on the templates are of great benefit to students to work at classes and at home. Prepared materials for this course, serve students for the development of their architectural projects, during their studies, and later in their further work, which was the author's goal. Therefore, the authors recommend use of Rhinoceros software to other colleagues on courses where work in other CAD software is mastered.

Student's homework for Unit 12, is modelling a sliding surface (fig. 20), in 3 steps. With the **Curve/ Free-Form/Interpolate Points** option, two free form curves are drawn, according to the image, which have one point in common. The curves lie in the normal planes. The sliding surface modelling is obtained by the **Surface/Extrude Curve/Along Curve** option, where one curve is generatrix, and the other is the directrix.

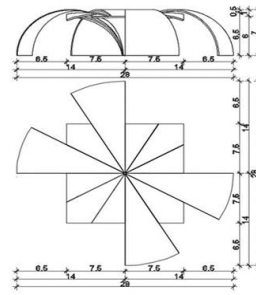The same surface is obtained if the curves replace the places.

Fig. 19 Drawings - Exercise for Unit 12

Fig. 20 Final model – Homework for Unit 12

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