*Zlata TOSIC, Sonja KRASIC*

# COMPARED ANALYSIS OF STANDARD AND PARAMETRIC MODELING ON THE STUDY CASE OF CATHEDRAL BRASILIA OF OSCAR NIEMEYER

***Abstract:*** *Conventional CAD software support, such as Auto Cad, is considered limited or rather complicated when it comes to freeform geometry design, because of their tools for modelling. Even though it cannot be said that in every case of complex forms they are unusable, they are limiting modelling conditions and quality of results in general. These statements are demonstrated with case study of modelling Cathedral Brasilia of architect Oscar Niemeyer in program Auto Cad and Rhinoceros. Comparative analysis will show that for every tested norm the software Rhinoceros was more efficient. Goal is also to encourage engineers to use contemporary programs while experimenting and designing complex forms because of the variety of different tools and methods that can be exploited and effective.*

***Key words:*** *CAD modelling, parametric design, case study, contemporary Architecture modelling, modelling complex geometry*

## 1. INTRODUCTION

The shape of the architecture derived the function (content) during the long historical period, which was the main parameter in the design process. We can see such architecture in one of the most famous schools of architecture "Bauhus", formed by Valter Gropius and Mies van der Rohe. The basic postulate of this school is that the form follows the function. The form in architecture changed and gave a certain context of thinking. Sometimes it is a message or motive that the designer wants to send to the world through the object model. In most cases they are objects of great importance that carry a dose of symbolism in themselves and give a certain attitude about a topic or event.

However, in contemporary architecture there are many examples where the function forms an object. Especially when it comes to representative public buildings, such as museums, operas, cathedrals, stadiums, exhibited halls, etc. More and more contemporary architects around the world are starting to design when designing, and then the function follows the form.

The form of an architectural object implies the entire physical structure of the building built by engineers. It begins as a need for a specific purpose of a building (buildings, schools, banks ...). Unlike other creations, it has its own sociological, utilitarian and ambient character. However, when it comes to perception, form is the factor that plays the greatest role [1].

Three dimensional images are two dimensional medium, which can provide precise information about special structure [2]. By developing new software and modelling methods, it is possible to create more innovative forms of objects faster and easier, which are attractive and demanding in terms of design, and execution. Standard or manual modelling in some case and software programs limits us to less formal forms, due to the type and number of options it possesses which is not difficult to define.

When precision is expected in cases of non-standard shapes, such programs do not produce good results. In other words, if the designer is not familiar with a certain type of surface from the very beginning of the design it will not be taken as a possible form of object, if there is not made option for it. In this paper the modeling of the Cathedral Brasilia, architect Oscar Niemeyer will be shown in the standard architectural software "Auto Cad" and the program adapted for the design of modern architectural forms "Rhinoceros".

The aim is to prove that the disadvantages that occur when modeling complex geometry surfaces in AutoCAD are much greater than the deficiencies in the use of Rhinoceros. The second goal of the project is to bring the designers closer to work in new programs, thus opening up opportunities for improvement of the process of designing architectural objects. The paper will analyze the speed, precision and a great number of possibilities in the modeling process in both programs.

## 2. CASE STUDY - THE MODELING PROCESS OF THE CATHEDRAL IN TWO PROGRAMS

The path to the reconstruction of an already existing object in a computer program may be different when it comes to drawing on paper. In order to avoid such parameters during the modelling of this example steps are predetermined and will be applied in the same way to both programs. The process is reduced to as few steps as possible that yield optimal results.

### 2.1 The first phase - drawing a basic hyperbole

The basic surface that makes the model of the Basel Cathedral of Niemeyer Oscars is a rotational hyperboloid of one sheet. It belongs to ruled double generating surface [3, 4]. The surface can be modelled in two ways:

1. By rotating one branch of the hyperbole around its imaginary axis (Fig. 1a), (in this case vertical),
2. By rotating one real straight line g around the other o, with which it is skew (Fig. 1b).

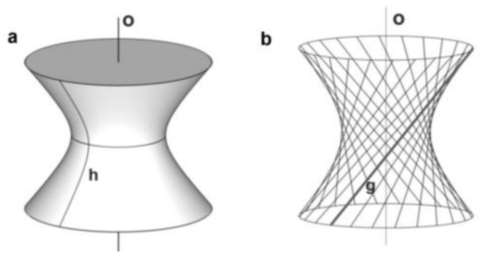


**Fig. 1** Modes of rotational hyperboloid of one sheet

From the previously explained procedure, it is necessary firstly to modify the basic hyperbola h. In this case, it is an asymmetric hyperbola so that it will not look like the hyperbola from figure 1.

*Rhinoceros* - drawing a basic hyperbola is very easy since this program itself has a ready option for this second-degree curve. There are four possibilities for its layout, from which one was selected through focus and center.

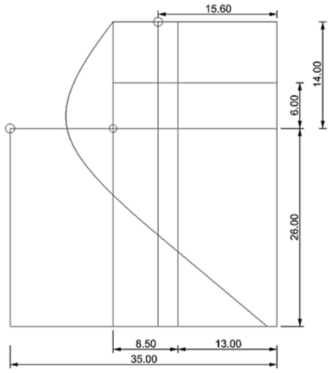


**Fig. 2** The drawing of a hyperbole in Rhinoceros

Some dimensions stem from constructive object data, while others are assumed by visual analysis and are proportional to dimensions. The hyperbolic is drawn in the Front view so that its branch is vertical (Fig. 2).

*Auto Cad* – this program does not have a made option to draw a basic hyperbole. Therefore, it is necessary to explore geometric modelling. By definition, the hyperbole is obtained from the cross-section of two cones, which have a common apex, with one plane that does not pass through the common apex and in this case is vertical. Cone bases are circles located in parallel vertical planes. The section gives two parts of the cone, which are then separated by the explode option on a hyperbola with two branches (Fig. 3).

From the image of the object it can be seen that the basic hyperbole should have a distance from the bottom point to the axis of rotation 35m. It is therefore necessary to guess the height and the radius of the cone, as well as the position of the vertical plane in order to obtain a hyperbole with these characteristics.

This part of the modelling takes up extra time that should be taken into account. If this part cannot be done precisely, the “move” option needs to modify the hyperbole points to get to the desired shape (Fig. 4).

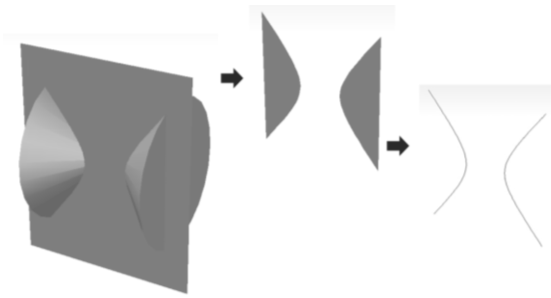

**Fig. 3** The cross-section of two cones in the Front view and perspective

**Fig. 4** Hyperbole display from AutoCAD

## 2.2 The second phase - the modelling of a hyperboloid of one sheet (HOS)

*Rhinoceros* - HOS is obtained, as the name of the surface suggests, when one branch of hyperbole is rotated for 360 ° around its imaginary axis. In this case, the axis is vertical. The distance of the imaginary axis from the hyperbola is given by the option of drawing a hyperbole (passing through the centre of hyperbole, point A). The diameter of the largest circle should be 70m, as given in the data of the object. When the axis is defined, the Surface model is obtained with the Revolve option (Fig. 5).

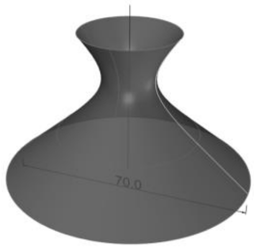


**Fig. 5** The model of a hyperboloid in Rhinoceros

**Fig. 6** The model of a hyperboloid in AutoCAD

*Auto CAD* - modelling in this program takes the same step in the same way. One branch of the hyperbole is rotated by the same option of the Revolve for 360 °, around the axis whose position must be defined, which is the extra work, and then the model of the surface is constructed (Fig. 6).

Difference in this case when modelling was that the axis of rotation had to be drawn to be precise when modelling in AutoCAD, while in the Rhinoceros program the position of the axis was defined.

### 2.3 The third phase - the modelling of concrete beams

During the analysis of the object it was defined that there are 16 concrete supports in the form of hyperboloid surfaces, which are placed in a circle and form the main construction of the object. They are non-standard, and the model itself is a challenge. Given the type of surfaces and the fact that the carriers are tilted to the hyperboloid with their wide side of the cross-section, one part of carrier consist of two different hyperbole having a common highest and lowest point and the other is symmetrical. By analysing the object, it was concluded that the carriers are touching at the throat circle. Each of the carriers has two contact points. This means that the position of the vertices on hyperbola (shown in a full red line) is obtained, the throat circle should be divided into 32 parts (Fig. 7).


**Fig. 7** Carrier analysis on the object [5]

The end points of both hyperbole are located on the upper and lower circles of hyperboloids and are already defined by the initial position of the primary hyperbole. It is envisaged to model only one carrier, and then by its simultaneous rotation and copying, a whole load-bearing structure would be obtained.

*Rhinoceros* – it is necessary firstly to find the throat circle at HOS. The Cutting Plane option selects the height of the hyperbolic edge through which the horizontal plane passes, whereby it cuts the entire surface. With the Intersection option, the grinding circle is obtained, which represents an intersection of the horizontal plane and HOS (Fig. 8a).

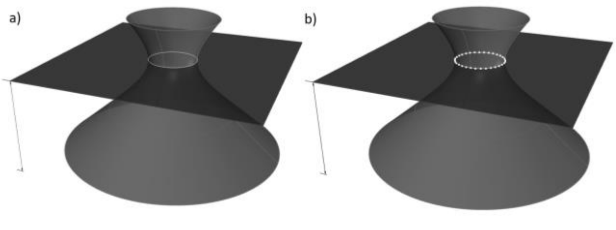


**Fig. 8** Display of the cross-section through the throat circle and its division into Rhino

Then it is necessary to divide the circle into 32 parts in order to find the position of the peak of the hyperbole that is touching and forming the parts of the carrier (Fig. 8b).

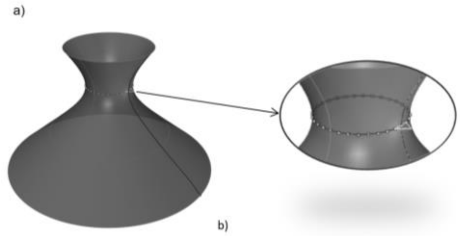


**Fig. 9** Drawing the widest part of the cross-section of the carrier

After that, Sweep 1 Rail (which means that the cross section moves along only one defined path) requires the surface area shown in Fig. 8b and the path is hyperbolic (Fig. 9a). In order to get the final carrier model, the final and transition points of the surface obtained (Fig. 10a) will be modified by turning points and move, so that the cross section of the carrier ends at one point from the top and bottom (Fig. 10b).

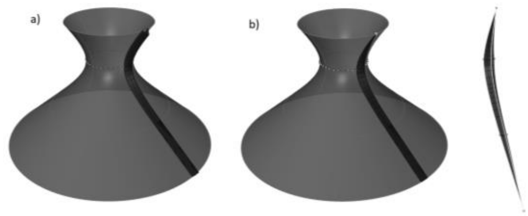


**Fig. 10** Modelling the carrier in Rhino with the final model of the carrier

Next it is necessary to rotate and copy the carrier at the same time with the option Array Polar in relation to the HOS rotation axis. In this way, complete models of all supports were obtained (Fig. 11).

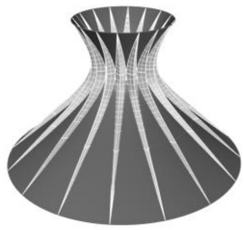

**Fig. 11** Model of all supports with hyperboloid

*Auto Cad* - Following the same process of finding the throat circle and dividing it into 32 parts. The process is a bit different because the cut off plane cannot be set directly to the desired height. Firstly it is necessary to draw the plane with the option Plane, then move it to the height of the pane. To get the circle we use the same Intersection option. Keep in mind that this option gets a circle, but the rest of the surface disappears, so all the surfaces we use in the option should be copied before using them. There is no direct option to split the curve into parts, and this is achieved by rotating and copying the radius of the circle 32 times (Fig. 12).

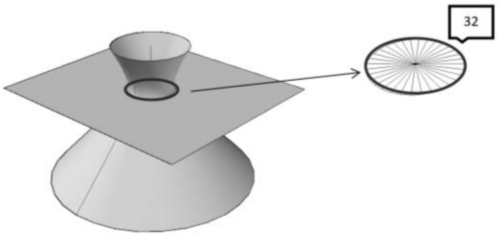


**Fig. 12** Finding a throat circle and dividing it

It then sets the vertical plane of the basic hyperbole. The idea is that, with the Transform / 3D Rotate option, the plane rotates in relation to the axis with endpoints of the hyperbole (Fig. 13a), where the shorter angles of rotation involve the point of the basic hyperbola and the first adjacent point on the throat circle (left or right obtained by division to 32 segments) (Fig. 13b).

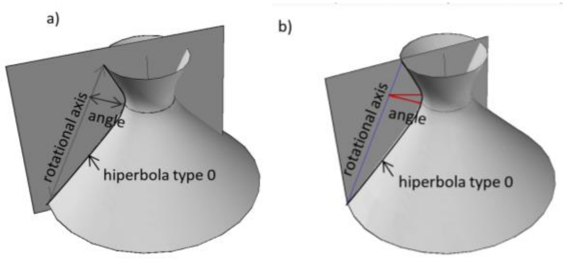


**Fig. 13** Rotating the vertical plane through the basic hyperbole

The problem occurs while rotating, because it is impossible to choose the axis of rotation in an arbitrary position. Rotation in 3D is only possible via the Global or Local Coordinate System. The first step was to rotate the local coordinate system around the "Y" axis by 25°, which is the angle at which the rotation arm is located (Fig 14a). After that, it is possible to rotate around "Z" axes for ≈ 11.25° to pass through the first adjacent point on the throat circle (Fig. 14b). A cross-sectional view of HOS and a hyperbole of type 1 were obtained (Fig. 14a)). We achieve this by the aforementioned Intersection. After the previous procedure, it is necessary to modify the basic hyperbole, so that the darkness is slightly ejected from the bottom of the throat circle, but to remain in the same horizontal plane. Moving the vertex of the hyperbole is 1m away from the surface, in order to get the carrier looks like on the object (Fig. 14 b)).

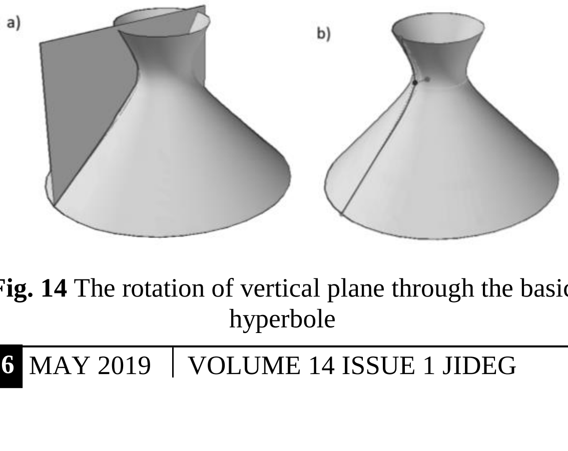


**Fig. 14** The rotation of vertical plane through the basic hyperbole

The next step would be to merge these two types of hyperbola, with the Loft option, to get half of the object carrier (Fig. 15a). Then the Mirror option is modelled on the other part of the carrier in relation to the vertical plane. It should be noted that this option should be known in relation to which plane an element is viewed, since it is necessary to select 3 points of this level for its activation.

When the entire carrier is obtained, in the same way as in the previous program, by simultaneously rotating and copying the Array Polar 16 elements option, all supports are positioned (Fig. 15b).

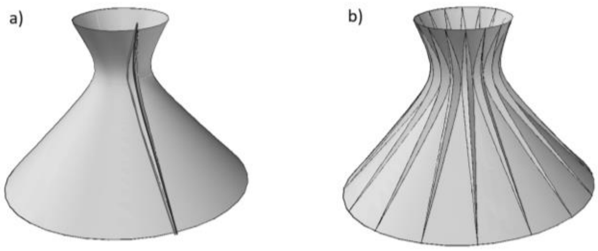


**Fig. 15** Joining hyperbolas, forming a carrier and copying it into AutoCAD

### 2.4 Fourth phase - modelling of the upper part of the building

*Rhinoceros*- the hyperboloid is a part of the object that has a lower height than the carrier. The Cutting Plane option sets a horizontal plane at a height of 32m. This size is also estimated by the proportions of the built object. After placing the level, the upper part of surface is removed with the Trim option (Fig. 16a). The top and bottom part of surface is closed with the Cap option and the thickness is 60 cm with the Extrude Surface option. Then the cross on the top should be modelled. It consists of two larger carriers with a further 4 smaller ones that are cut at an angle of 30° in one plane (in the form of the letter "x"). It was assumed that their cross sections are rectangular, according to the appearance of the object (Fig. 16b). The options that are used are: Box, Rotate and Move.

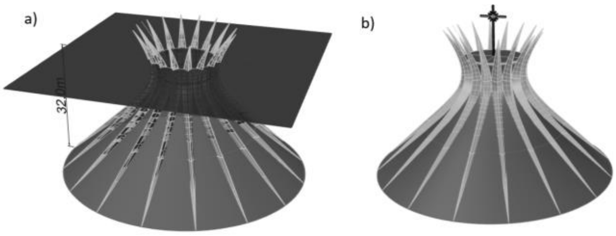


**Fig. 16** The removed part of the surface in Rhino

*Auto Cad* - When removing the upper part of hyperboloid, and here the horizontal plane is moved to a height of 32m with the option Plane and 3DMove. The upper part is removed by “SurfTrim” and cutting surface horizontally (Fig. 17a). It is necessary to copy the entire object after this option, because if the horizontal plane is deleted (which is no longer needed), cut surface will return to the original state (with the upper part above the plane).

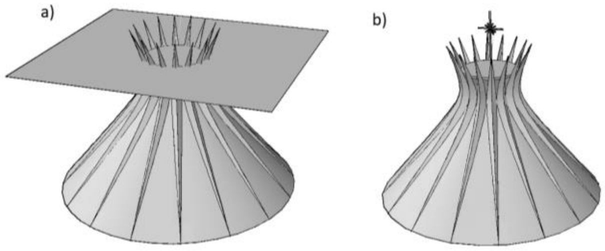


**Fig. 17** The removed part of the surface and the cross pattern in AutoCAD

With the Patch option, the top and bottom openings of hyperboloid are closed, then the Extrude option gives the upper part 60 cm thickness. If the Extrude option does not raise the surface itself, but only the lines that are the boundary of the surface, it is necessary to close the upper part of the hyperboloid again in order to get a piece of the pattern again (Fig. 18b). A cross with diagonals are also modeled using Box, Move and 2D and 3D Rotate.

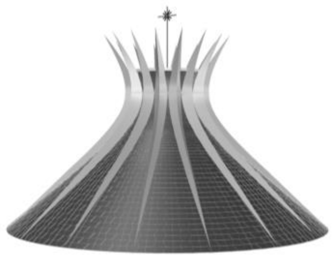

**Fig. 18** The finished model in Rhino

## 2.5 Fifth phase - division of surface into sections of stained glass

The optimal way of doing this division is by parametric modeling. Parametric design is a good pattern used in the design process where the link between the elements is used to manipulate the form with the complexity of geometry and shape. The term parametrically derives from mathematics (parametric equation) and refers to the use of certain parameters or variables that can be changed by manipulating or altering the result of an equation or system. Today, this term is most often used in the context of computer modeling [6].

In this particular case, the Grasshopper program served to divide the surface of the cathedral into segments that are not standard. Modeling the very surfaces of our hyperboloid could be achieved with the options in Grasshopper, but the Rhinoceros model will be used here. Grasshopper gives a wide choice of options, making its use more complex. For this case, the use of a smaller number of options was selected to show the efficiency and universality of the program. The first step is to split the surface into smaller parts. When it comes to surfaces consisting of points, divisions are done in two directions u and v. These are the direction in the general case of division for all surfaces. They do not have to be at right angles and depend on the surface geometry. There are several options for dividing the surfaces, but the one that is needed in this case should split the surface into smaller segments. Each of the options can be found by typing its name "Divide Domain", or in the Toolbar. This option is one of the most useful, because in different combinations with other modifiers, it offers a wide range of segment manipulation, which is always important when it comes to surfaces. Then we select two "Number Slider" components, which determine the number of divisions in both directions in particular. They allow you to use the slider to change the size and number of segments on the surface until the desired solution is reached. When there are splits on the surface, they will not be visible on the screen, because the Divide Domain option serves to split but not to display it. In order to split the viewer, the option in the Transform / Morph / Surface Box tab has three inputs. The first one searches for the surface to be divided (Surface), the second division (Domain), and the third thickness of those segments to have (Height of the Box). As a result, each segment gets separately, with which we can manipulate further. The last transformation option used is on the same tab and is called Box Morph. It serves to provide the desired geometric shape to each segment obtained by dividing the surface (Fig 19).

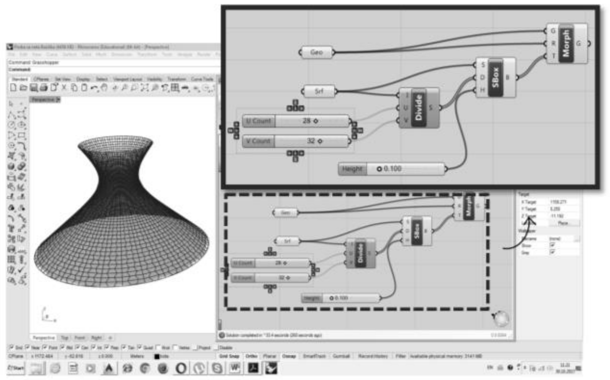


**Fig. 19** Segregation to segments, with number of segments 28x32

## 3. EVALUATION OF BOTH PROGRAMS

In order to see the difference and define the advantages and disadvantages of both programs, we will evaluate their level of fulfilment of certain criteria. The results will be presented in a table by category of criteria. They are in groups according to the need to use the program as well as the different requirements when it comes to transparency when drawing and compatibility with other programs. Most of the criteria was taken from a scientific paper that also deals with a comparative analysis of Auto Cad and Rhinoceros (without Grasshopper) by a case study method in order to compare the results [6]. According to the Table 1, it is clear that the Auto Cad has its good sides in precision, 2D modelling, compatibility with other programs for further modelling and the ability to export drawings for further processing. However, when we are talking about 3D models or more complex geometric surfaces and curves, it does not show good results. In addition to the lack of number of options as well as the ability to manipulate and transform the surface, it does not provide the transparency needed to make the modeling process easier. All these drawbacks are necessary for a better knowledge of geometry and more separated to achieve a solution for this type of objects. Modelling possibilities in the Rhinoceros program are high in all categories of criteria. It is not necessary to analyse and research geometric surfaces in order to model. The transparency of the program is very good, the possibility of making drawings, sketches and schemes. Compatibility with other programs and the possibility of further development and presentation of the project is a wide assortment (pdf., jpg. formats). It should be noted that similar results occurred in the above mentioned scientific work which deals with the modelling of the object formed by the geometric surfaces, the torus.

*Table 1*

**Evaluation of both programs based on the defined criteria**

| | Categories | Options | Auto Cad | Rhinoceros |
|---|---|---|---|---|
| **1.** | **Drawing lines** | **Drawing lines** | ✓ | ✓ |
| **2.** | | **Line manipulation** | ✓ | ✓ |
| **3.** | | **Curve types** | **X** | ✓ |
| **4.** | | **Precision in 2D** | ✓ | ✓ |
| **5.** | | **Precision in 3D** | ✓ | ✓ |
| **6.** | **Drawing planes** | **Drawing basic planes** | ✓ | ✓ |
| **7.** | | **Number of options** | **X** | ✓ |
| **8.** | | **Plane modification** | **X** | ✓ |
| **9.** | | **3D Rotation** | **X** | ✓ |
| **10.** | **Drawing surfaces** | **Basic surfaces** | ✓ | ✓ |
| **11.** | | **Complex surfaces** | **X** | ✓ |
| **12.** | | **Modification of surfaces** | **X** | ✓ |
| **13.** | | **Plane intersection** | **X** | ✓ |
| **14.** | | **Surface intersection** | **X** | ✓ |
| **15.** | **Visualization** | **Precision** | ✓ | ✓ |
| **16.** | | **Multiple views simultaneously** | **X** | ✓ |
| **17.** | | **Drawing dimension lines in 3D** | **X** | ✓ |
| **18.** | | **Layers** | ✓ | ✓ |
| **19.** | | **Speed of modeling** | **x** | ✓ |

## 4. CONCLUSION

The form plays one of the key roles when designing architectural objects, especially in representative objects. The aesthetic factor, which is extremely important in architecture, is represented in all historical periods, especially the XX and XXI centuries.

Designing this type of modern objects of a complex form is not easy and requires deeper analysis and knowledge of geometric shapes. Their modelling is a complex problem that can be solved if it is done in more advanced programs. There are many types of surfaces and their combinations in order to arrive at the final model when designing an object. The case study in this paper has shown, on the example of the Cathedral of Brazil, that the Rhinoceros software is a better and easier solution for modelling a complex type of object than AutoCAD software. By using this and similar software, ideas can be defined and designing better solutions.

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**Authors:**

**Zlata TOSIC**, PhD student of Architecture, Faculty of Civil Engineering and Architecture, University of Nis, Serbia, E-mail: zlata10@live.com

**Sonja KRASIC**, associate professor, Faculty of Civil Engineering and Architecture, University of Nis, E-mail: krasic.sonja@gmail.com,