

Utilization of Generative Design Tools in Designing Components Necessary for 3D Printing Done by a Robot

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Abstract – At present, one can encounter a large number of CAD systems in design practice. They are mostly CAD systems for creation and modification of a geometric model. Modelling new prototype components requires high flexibility. To achieve such flexibility, special tools and methods that are a part of generative design are used. Generative design is currently one of the new and rapidly evolving modelling technologies in computer aided design. The paper describes a new design approach and the software used for modelling components in a generative way of designing, with the possibility of interfacing it with software suitable for the creation of a robot control program for component production by additive technology.

Keywords – Generative design creation, Rhinoceros, Plug-in Grasshopper, Plug-in RoboDK, Additive technology.

1. Introduction

In recent years, CAD systems have been developed to provide a more user-friendly interface and make the work for the users easier. Simplification leads to greater efficiency in the use of CAD systems, providing the designer with the ability to create more complex models in less time.

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An example is the development of an automobile, which requires simultaneous designing of parts at several design workplaces. [1], [2] This is a very demanding activity because of the need to ensure congruence of cooperating workplaces and the project teams working on the same task in the design of parts. At the same time, the components so designed have to be quick and easy to modify. In order to further reduce the time required, various component design procedures are used [3]. The most widely used modelling approach so far (parametric modelling) has been gradually replaced by generative engineering (GEM) approaches. Unlike parametric modelling, GEM provides the ability to create surface-based components, such as car body parts and other free areas of complex shapes, which would be time consuming to model with conventional and hitherto used modelling tools. [4]

2. Generative Design

With the simultaneous production of increasingly complex components, the need for enormous flexibility in component production and the effort to minimize the cost of time spent in developing new models, a new method of designing, called Generative Design, has been created. This method ensures cutting production costs at the time interval of design creation and also allows dynamic optimization of the model created. [5], [6]

Generative design is a process that creates a design or model based on quantitative and qualitative parameters, or aesthetic adjustments, and uses human-entered algorithms to generate a variable set of final models as its output, while consistently maintaining bonds and not disrupting the hierarchical relations. Comprehensive CAD systems make it possible to use the generative design approach in the automotive industry (e.g. Catia, Rhinoceros and others). In these systems, the designing utilizes the so-called tree history, which facilitates the model design process, as it can be go back at any time by means of a specific command. It works with many subsystems into which the generative model is

divided, which are interconnected by geometric and functional links. [7] This section allows conversion or replacement of individual subsystems, with the remaining subsystems undergoing change directly in the model and adapting there automatically. Generative design offers the possibility of simplified and efficient time-saving optimization of the model created, but in some parts, it also requires the designer to possess specialized knowledge and to follow a demanding procedure during the design process itself. [8], [9], [10]

3. Currently Used Software in Generative Design Approach

3.1. Rhinoceros

Rhinoceros is a powerful 3D graphics and modelling software developed by McNeely & Associates. The program unilaterally specializes in NURBS (Non Uniform Rational B-Splines) modelling, which means modelling of free-form surfaces. This software enables the creation, analysis, editing and exporting NURBS curves. NURBS curves can be defined as the mathematical notation of the geometry of any 2D shapes (curves, lines, circles, arcs, etc.) up to complex 3D shapes and surfaces. Rhinoceros provides the means to accurately build the model being created and prepares it for animation calculation, drawing creation, image creation, rapid prototyping, analysis performance and, last but not least, production orientation. Another significant benefit of this program is that by defining surfaces using NURBS curves, the transferred area is defined mathematically, as opposed to polygonal modelling, where any curvature is made up of multiple polygons.

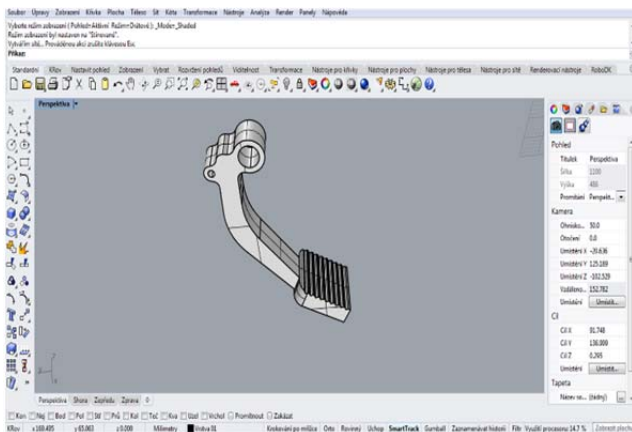


Figure 1. Component design by parametric design approach in the Rhinoceros environment

3.2. Grasshopper

The first name for this plug-in was Explicit History, and it was promoted under that name for

some time, until it was later renamed and became known by its current name. Grasshopper is interesting for users because it offers the possibility to create a complex algorithmic structure, and it also consists of a number of components designed to create 3D geometry. Its use is very intuitive and illustrative. The primary use of Grasshopper is to create generative parametric models. It is used in generative design, which is currently a developing field and is based on random codes and various algorithms. Parametric modelling tools are used in structural engineering, architecture and manufacturing. Other types of algorithms are also used, such as numerical, textual, even audio-visual ones.

4. Design of a Selected Component Structure Using the Tools of Generative Design

Rhinoceros 6 and Grasshopper work together on creating a component with generative design tools. When designing a car brake pedal component, it was first necessary to create two curves in the Rhinoceros program that would serve as the component's extreme edges. In Grasshopper, the *Curve* function was selected and inserted twice next to one another. The first *Curve* function was defined as the left curve and the second was defined as the right curve. Subsequently, a new *Divide Curve* was created. This function divides the curves into several parts and creates points at the site of division. A *Number Slider* function was inserted to the *Divide Curve* for linking. The value on this scale determines how many parts the curves are divided into. Values on the scale can be changed and adjusted as needed. In this design, a division into six parts will suffice. The *Explode Tree* function ensures that individual points can be edited separately. Adding the *Shift List* function allows shifting the links between the points on the first and second curve later on. The *Shift* parameters define how much the link should move. Positive values move links up and negative values move them down.

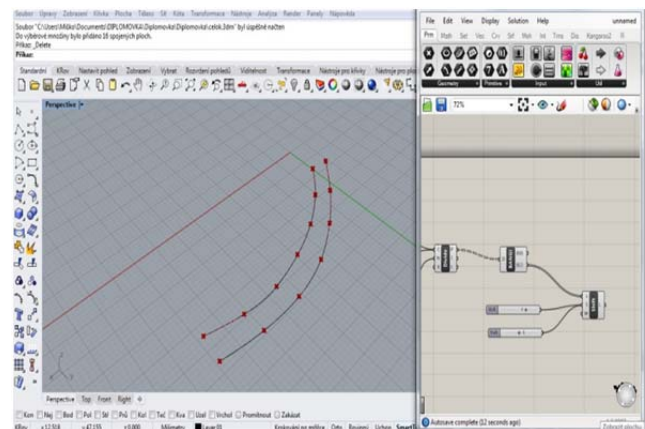


Figure 2. Initial design steps – creating curves

Thanks to the previous step, the *Line* function connects the points, creating the desired structure.

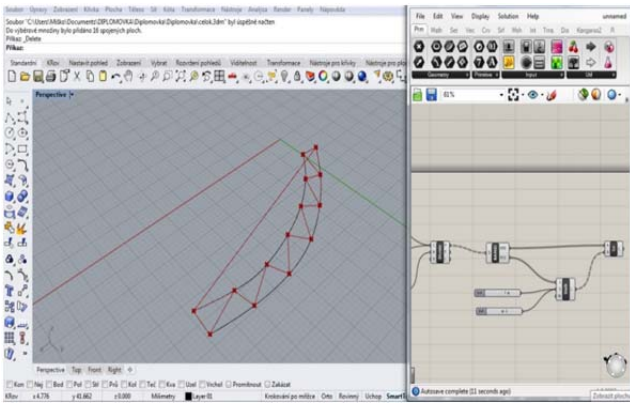


Figure 3. Linking the points with curves in the model draft

The *Pipe* component creates a tubular design from curves and links. The *Radius* value determines the pipe width and the *Caps* value determines the pipe termination options. A value of 0 means no termination, so the tubes will be open. A value of 1 terminates the pipe with a plane, and a value of 2, that was used for this model, has a rounded end. The final step is to select the *Bake* function, which is accessed by right-clicking on the *Pipe* function. The *Bake* function turns the Grasshopper model into a solid model ready to be further used in the Rhinoceros.

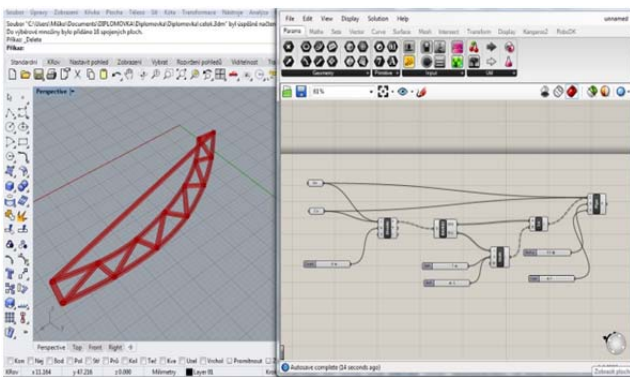


Figure 4. Final design of the model done through the *Bake* function

When one opens the Grasshopper, one can see what components and functions have resulted in the desired design.

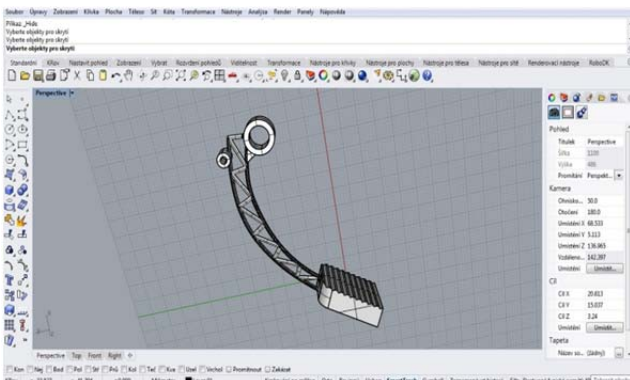


Figure 5. Final component designed through the generative design approach

5. RoboDK Software Plug-In for Rhinoceros and Grasshopper

This plug-in is installed as an add application to RoboDK software and offers the option of using a link to Rhinoceros software to create 3D model designs through a generative design approach. The work between the individual software consists in uploading the 3D model to the RoboDK software and subsequent processing of the control program with simulation of the robot's movement. In the offline simulation model of the RoboDK software created in this way, the correctness of all movements of the robot arm is verified. For the design of simulation models, it is possible to select several types of robots from different manufacturers, as well as to create and download new end tools for a specific type of robot. This plug-in allows programming more than thirty different types of robots from multiple manufacturers and three hundred robots from the Rhinoceros software environment directly. Control programs for robots can be created through created points, groups of curves or generated G-codes, similar to CAM programming or designing programs for additive manufacturing. The programs created in this way by automatic path generation are used to control robots with the possibility of their application to the production sphere, e.g. for the needs of multi-axis machining, 3D printing from various types of materials, hole drilling, welding, and other manufacturing applications. [11], [12]

By default, the RoboDK plug-in for Rhinoceros offers several creation options when connected to Rhinoceros software. One option is to create geometry using selected points and curves to define the 3D model, which are loaded from Rhinoceros software and then placed in RoboDK software as a 3D model (*Auto Setup* function). Another option is to upload the created 3D model in the Rhinoceros environment and then load it into the RoboDK software environment (*Load Part* function). It also allows us to select curves or points based on which RoboDK software can calculate areas using their normal vectors, which are necessary to correctly determine the approach axis of the robot arm to define targets path (*Load Curve* and *Load Point* function).

The RoboDK plug-in for Grasshopper consists of three components and a menu of options for initializing the robot for specific designs created by the selected component. The *Curve to Robot* component offers the ability to load a curve or multiple curves from the RoboDK environment for subsequent surface creation using the created normals of selected points on the curves. Another component *File to robot* allows us to upload a G-code or APT file, which is located on a computer for

the needs of multi-axis machining applications or also for the needs of creating a 3D printing program. The third component is the *Point to robot* component, which allows us to load a point or multiple points for the needs of working with a 3D model in the RoboDK environment, and it also allows the creation of normal vectors for selected points.

5.1. Using the RoboDK Software Plug-In for Rhinoceros to Design a Robot Arm Control Program

The paper also contains a design of the robot control program for the subsequent 3D printing by means of a selected print head attached to the flange of the robot arm. [13], [14], [15] The first design step is to transfer the generative model to the RoboDK software environment. After opening the generative model that has been created, the RoboDK box is selected in the plug-in menu. Subsequently, the user will see the functions of the selected plug-in that can be used in the design (the tools menu was described in the previous section of the paper). First of all, the *Settings* tool has to be used because of the need to set up the initial run of the RoboDK subroutine. The *Settings* tool offers multiple plug-in settings where *Load Project* has been selected. This function will open another RoboDK settings window. After this action, RoboDK opens with the setup default robot. In the Rhinoceros, the setup tools need to be used to mark the necessary surfaces, curves, and points that will then be transferred to RoboDK using *Auto Setup*.

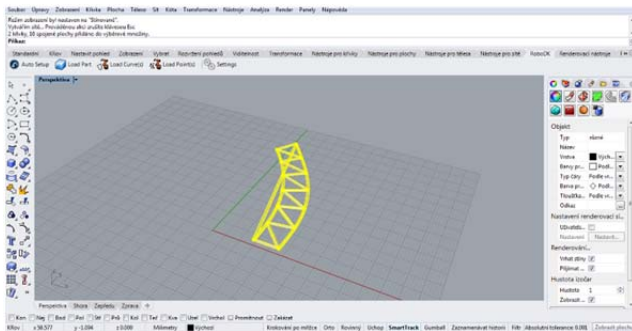


Figure 6. Marking of the surfaces of the selected component and transfer of the model to RoboDK using *Auto Setup*

Auto Setup function will automatically set up the transferred generative model for further work with the robot in RoboDK. If it were a model with the curves marked, the robot could automatically trace them with a tool. At the beginning of the design of the simulation model, it is necessary to define the position of objects located at the projected workplace on the basis of Cartesian coordinates, and only then implement the design of a program for the movement of the robot. Figure 7 shows an example of the

objects' layout in the working environment of a selected robotic arm with a 3D print head attached for 3D printing and a printed object (enlarged scale) created in a generative way of designing in the Rhinoceros software.

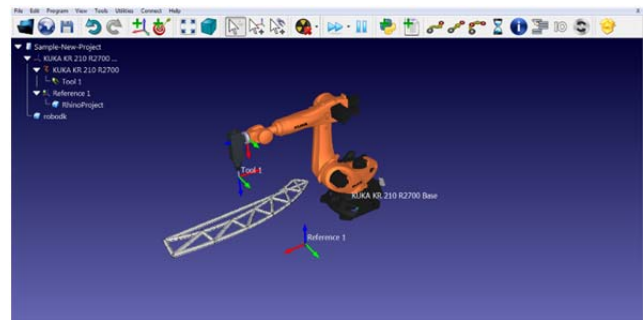


Figure 7. Demonstration of the transferred generative model and simulation in the RoboDK environment

For the correct functioning of the simulation model, it is necessary to define reference points in the model for the inserted 3D object, the robot and the fixed tool on the robot flange. Reference points are added to the project via the *Add a reference frame* function and their task is to correctly define the position of the object relative to the workplace.

The *3D Print project* function is used to load and import the generated G-code of a 3D model, which was created via the external application Slic3r in the form of a text entry of the code. Subsequently, it is necessary to modify the simulation model in the settings as needed in the RoboDK software environment and then generate it as a robot control program for a specific robot type. After the settings have been entered correctly, the simulation model is ready to simulate the 3D printing via a robot arm.

6. Conclusion

Excellent visual design is not the only indicator of the industrial design quality. The products themselves have to meet certain quality-specific criteria and they need to be created faster than the competition is able to create the same. Properly processed designs become effective products only when a suitable tool is available at hand to enable the designer to autonomously and arbitrarily capture exactly what the designer has in mind. The Rhinoceros is software where one can let their imagination loose and immerse themselves completely in their ideas, while it is also a work tool for translating one's ideas into real products. Using the tool, the designer can follow his ideas from sketching to modelling and also watch their development up to the final product's actual production.

The paper has also addressed the description of the use of tools and procedures in the design of

components in the software designed for the generative design approach. Based on the brake pedal arm model created via the parametric design approach, the same model was remodelled with generative design tools, with the emphasis on the use of tools of the Rhinoceros and the Grasshopper software, respectively. The basic geometry of the brake pedal arm model was created in the Rhinoceros, and in the Grasshopper plug-in, the final design of the model was created using functions and components of the generative design. The model was then transferred to the RoboDK plug-in due to the need to simulate the robot's movement, to create a control program and then to perform a 3D print simulation using a print head attached to the robot flange.

Generative design is widely used in various fields such as mechanical engineering, automotive, aerospace, architecture and other industries. A great advantage of this design approach is quick and easy modification of designs in case of changed market requirements. Thanks to these features, generative design has a high potential to become a sought-after and preferred technology for component development and production.

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