A significant problem and a great solution: parametric modeling for architecture with an architect approach

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Abstract

This paper documents and reports an experience about the use of parametric design. The method of the parametric design is here applied like a tool to obtain a dynamic approach, with an advanced methodology that manages the complexity of the figure speeding up the processes allowing to achieve results previously unthinkable in the representation of architecture. The parametric design method has the advantage that the result of the design procedure is instantly visible after any update and in all of its aspects editable for applying enhancements. It is, therefore, easy to have hundreds of variants of the same project by adjusting the basic geometrical parameters. Underneath examples of procedures are shown by using the parametric generation of big elliptical roofing designed using Grasshopper (www.grasshopper3d.com). Grasshopper is a plugin of McNeel Rhinoceros (www.rhino3d.com). Parametric created geometries by using the method of form finding using Karamba (www.karamba3d.com) and, last but not least, examples of automatic generative geometries with versatile optimization using Karamba and Galapagos Evolutionary Solver (www.grasshopper3d.com/group/galapagos).

Keywords: Parametric Design, Karamba, Grasshopper, Rhinoceros, Galapagos

Introduction

One of the most significant problems encountered by architects and engineers during the design phase is finding the right form for a structure and/or its optimization. Nowadays, the research of the shape can be performed using computer programs, the software offer in this field is gradually becoming more accurate and faster, allowing the designers to explore and exploit an infinite variety of possible solutions.

The forms found through these methods can be more precise and efficient compared to those that are only adapted to the required functions via the traditional or standard way of design, non-taking into consideration the criteria of the optimization. Optimizations include the quantity of material used and of its structural behaviour [5]. The selection of the shape directly determines the amount of the necessary material to withstand the applied loads. A wise choice of the form can reduce the costs, but should never influence the detriment of structural safety. This strategic balance may extremely benefit from automatic controls, allowing the evaluation of the shape and visual results thanks to the 3D visualization while controlling the structural performance may be guaranteed by appropriate parameters inserted in the scripting [13].

With a parametric setting and management of the project, there can be changes in all its aspects at any moment. Furthermore, another advantage of working into the world of scripting is that the geometries created, and their dimensions can be changed depending on the designer’s choices with few clicks and with a minimum effort.

By using the method of the parametric design, it is possible to obtain a dynamic approach, with an advanced methodology that manages the complexity of the figure speeding up the processes allowing us to obtain results that before were unthinkable. This method resolves the problems simply and quickly, creating geometrical forms even very complex through the software of a virtual interface like Grasshopper [7]. The parametric design method helps the boundaries of architecture and design extend through the calculation entrusted at the computer program. Furthermore, the parametric processes require though a different way of thinking, and it is a sequence of operations that anticipates the final result. [1,2,3,4] The use of parametric design is not about generating forms with the computer, but it is about having solutions proposed by the computer-based on an aimed result. The parametric modelling involves a great versatility in terms of customization, of researches of the form and a parametrical control. A parametric approach, though, is not always user friendly due to the specialist computer skills required [6].
Generating architectural forms directly with the parametric design methods has, without a doubt, led to an extremely advanced dependence on the efficient use of the computer that it is not anymore, an exclusively instrumental tool. This method of design is obtained by a considerable amount of data and calculations, and it is implemented through algorithmic flows [2,3,4]. The parametric design process begins from an elementary level that afterwards becomes complicated by forming various hierarchies with their logic and details. It is always possible to have access to every single element and step of the project. It is, therefore, easy to have hundreds of variants of the same project by adjusting the basic geometrical parameters.

**Use of parametric programs and examples of parametric design**

Nowadays, there are a lot of programs in commerce that permit the parametric design, alongside the ordinary design programs. For example, Grasshopper, it is a visual editor for scripting and a plugin of Rhinoceros that gives the possibility to generate three-dimensional models by using programming codes and is based on algorithmic logic and parametric design. Grasshopper runs within the 3D computer-aided design application of Rhinoceros, which is a design program created by David Rutten at Robert McNeel & Associates. Albeit everything designed in Grasshopper, it can be seen only by a preview in Rhinoceros. The two extensions of saving between the two programs are different, and the two files remain connected between them. When creating a parametric geometry, at the same moment, when it is modified, it is possible to keep both the original and the modified geometry [10, 11].

When designing a parametric model, the parts taking part in the modelling are elements created defined not only by geometries but also by data. Each geometry has to be divided into smaller parametric parts [1, 2, 3, 4]. So, in the earlier phases of the project, there is the need to think in advance in which way to divide the specific complex planning into smaller parts then executed step by step. For working and designing in a parametric way, there is the need to start thinking abstractedly, then to start thinking in mathematical terms and then, finally, to start designing with an algorithmic approach.

The algorithmic approach in a parametric design deals with algorithms that are a set of rules defining a sequence of operations. Such an approach may show some difficulties:

1. The drawing shows the parameters and not its shape; this is a massive difference from the traditional world of design where the visual feedback.

2. One has to have a clear idea of what wishes to obtain and how to achieve it before starting modeling. Furthermore, one needs to know beforehand how every single part of the geometry is made and how to represent it.

3. Algorithms refer to every single input of the structure.

The visual programming on which Grasshopper is based is a language that allows users to create through the manipulation of graphic elements rather than specifying them by text. A pure codification of scripting is when text is used, for example, with the program that is called Python (www.python.org). It is possible to achieve the same result of text scripting by virtual programming “Fig.1”. The substantial difference lies in the process followed to obtain the same equivalent result. The virtual programming is an ambient based on nodes and wires that represent the dependency of the various components.
The parametric design offers automatic optimization that alters suitably the various elements composing the structure until they fulfil the requested criteria. When the procedure finishes, the geometrical configuration is updated. Parametric design is a very flexible design process with the great advantage of automatization. In this way, the designing method makes calculations with high speed and quality.

During parametric design, it is always possible to use genetic and evolutionary algorithms. Evolutionary algorithms have the advantage of being very flexible and can face a wide range of problems. They can even face problems poorly formulated. Such algorithms are chosen over other types of optimization when many parameters describe a phenomenon, and there is no apparent correlation between them. They can have an endless stream of answers from which the newer ones are of higher quality than the previous ones. They allow a high degree of interaction with the user with a highly transparent process. Their disadvantage is that they can be very slow to the point that a single process can perform for days or even weeks. If no default value is specified, the process will tend to run to infinity without reaching the answer or will not be recognizing the answer [8,9].

Galapagos Evolutionary solver, which was developed by David Rutten with McNeel & Associates, facilitates such processes within the Grasshopper platform. Galapagos is a genetic resolver that uses the procedure of optimization by genetic algorithms. It requires an accurate definition of the problem with an encoding of the variables in play, and it is necessary to predetermine the objective function of maximizing or minimizing. [8,9]

Underneath are shown examples of procedures using the parametric generation of big elliptical roofing and then parametric geometries by the method of form finding, using Karamba and last but not least examples of generative geometries with optimization using Karamba and Galapagos [5,8,9].

**Elaborations of elliptic paraboloids.**

The creation of a parametric elliptical paraboloid allows us to change it in every single aspect by using the various components of Grasshopper. The use of Voronoi and Voronax diagrams permits to have multiple options of roofing. "fig.2."
Fig. 2. Definitions in Grasshopper for the creation of roofings using the Voronoi and Voronax diagrams
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The Voronoi diagram gets the name after its creator, the Ukrainian mathematician Georgy Voronoi (1868-1908). It is known as the Voronoi tessellation or Voronoi decomposition because it is a particular method of decomposition of metric space. It consists of partitioning the space into polygons derived from focal points, where each polygon contains only one of such points. Each side of the perimeter of each polygon is halfway placed between two focal points.

This diagram applied to our geometry can be used to create reticular structures, always parametric, using the curves resulting from the diagram [12]. The creation of parametric tubular, square, and rectangular rods has the advantage of varying the measures at any time as desired by simply changing a numerical value by a simple click [11].

Another diagram used is that of Voronax. Milos Dimic developed Voronax, at the University of Stuttgart in 2008 as part of his doctoral thesis. Voronax is a type of specific structure obtained when a Voronoi diagram is “relaxed” on a free-form surface.

On the same parametric surface, the use of mathematical functions can enrich the diagrams of Voronoi and Voronax. With some other mathematical functions that resume the spiral, using the functions $x \cdot \cos(x)$ or $x \cdot \sin(x)$. The causal population of previous points will no longer be used, but the above mathematical functions will be used that will place the various points in a spiral on the entire surface. The previous components can be just copied and pasted, in any size desired to obtain reticular structures and create the multiple rods. The interval factor can change the arrangement of the various points to achieve a large number of variations very quickly and with extreme simplicity.

**Structure inspired by the Fibonacci spiral**

Using the method of parametric modelling can also allow creating structures inspired by mathematical functions—such as the Fibonacci spiral. Fibonacci sequence is a sequence of positive integers in which each number is the sum of the two preceding. As can be observed with great ease, multiple variants can be created of the same structure while remaining adjustable and entirely into the parametric field. “fig.3″.
Fig. 3. Definition in Grasshopper for the creation of a structure using the Fibonacci spiral (Copyright: the Author, 2020)

**Form Finding using Karamba 3D – parametric engineering**

Using Karamba, the tool for form-finding, by applying arbitrarily selected upper constraints and loads, different shapes can be obtained as a result [5]. This process creates the desired and more functional shape too. For the creation of a reticular structure on the obtained surface, applied weaverbird’s components create polygons forming the actual construction. Wooden structures can also be created by merely giving thickness to the obtained lines from the calculation of mesh surface. “fig.4“ The thicknesses can always be kept parametric; in doing so, this solution has the advantage of allowing their change/modification at any time.
The great advantage of working with a parametric design is that when the scripts created, these can be copied and applied to other geometries to obtain more suitable solutions based on the variable.

**Example of a complex parametric structure**

A simple circle with three fixed points is the start of the design, and then three arcs are designed to cross these points. The tower is the result of a series of copies of this arc, and by using a sinusoidal function. Specific components of Grasshopper can be used, such as the Graph mapper. This component shall ensure that all of the mathematic calculations are done by only moving the points on a graph. The final form of the structure updates in real-time in “Rhinoceros.”

The next step is to set the measure of the cantilever of the balconies of each floor. This procedure will allow us to obtain the summary structure of the tower. By maintaining a parametric design setting for all of the aspects of the project, modifications are still possible, and the result will be displayed automatically at any moment. They can be changed without any real effort, and as a result, the desired form of the structure can be chosen by numerous variants. “fig.5.”

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**Fig. 4.** Definitions in Grasshopper using the form-finding of Karamba for the creation of various structures. (Copyright: the Author, 2020)
Fig. 5. Definition in Grasshopper for the creation of a complex parametric structure (Copyright: the Author, 2020)

Another advantage of using the method of parametric design is to create geometries which dimensions vary according to their distance from a set point or curve. In our example, case sunscreens plates have created that stretch and shorten according to their distance from the sun. Therefore, obtaining an automated optimal internal lighting of the interior is very simple.

**Parametric optimizers used for structures**

The usage of optimizers for structures, which are simple to use, in combination with Karamba and Grasshopper, is widespread. Thus, automatic optimization is usable for the whole structure. Galapagos displays a list of solutions, and the designer can choose the most appropriate. The designer always has the freedom of choice, not all of the processes are done exclusively by the computer, and hence designing freedom and imagination remain present in the process [9].

In particular, the component of Karamba called Cross Section ought to be mentioned since this component is an optimizer that selects the cross-section, from a variety of cross-sections, that is the best at every single point of the structure to avoid waste of material [5]. Therefore, such optimization is more advantageous both economically and environmentally.

Karamba optimizer, called Cross Section, chooses the section of the beams. The selection is made in such a way that under the stress of the loads applied by the designer, the beams fulfill the criteria of ultimate load according to Eurocode3. If the designer prefers to set a maximum displacement, he can proceed to a second step that increases the cross-sections appropriately. To see which cross-sections have been used in every specific element, the resulting model of the optimization has to be decomposed and then take apart every element. "fig.6."
Conclusions

Entering the world of parametric design can be initially challenging. Users and many architects coming from a "traditional" approach to representation and design may have to completely change their way of thinking and planning the development of the project. The various programs are not very intuitive, and much effort has to be made at first until the necessary skills are acquired. They are not "instant" tools to use, the gap between direct representation and its accurate conceptualization has to pass by a specific interface. Fortunately, there are many resources from online communities that can help newbies. The various script languages may appear very complicated in the first approach, architects and designers often prefer a direct representation, where a line may have the value of a wall and may evoke a rich interpretation. In the first trials, it may be better to focus on visual programs like Grasshopper that allows entering the world of parametric design gradually, having some quick result that will stimulate the user to go on and in deep with the parametric environment.

The full discovery of the powerful advantage of parametric design can be considered a sort of "revelation," some kind of prize reached at the end of the various processes of elaboration. Very sophisticated and elegant results can be achieved with geometries that are not easily obtained using traditional methods of design. The articulation of these tools may be resumed in the concept "the more the subject is difficult to be developed using a traditional process of design and representation, the easier it will be in a parametric workflow. The possibility of having every variation of every value at any moment immediately visualized as a result in real-time is a high point of strength. It helps the user in getting soon familiar with all the available features.

The parametric design does not hamper the creativity of the imagination and opens to designers the possibility for remarkable achievements. Imagination and creativity have now new scenarios with powerful tools at their service, and the creative process of architecture is getting more versatile in the long path of "digitalization.”

References


