PARAMETRIC GEOMETRY GENERATION OF WIND TURBINES

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Abstract. Wind energy is an alternative of interest to other energy forms, since it is renewable and can reduce the environment damage as compared to other more pollute forms of generation. Thus, understanding wind turbines and how they operate is a key to increase efficiency and production. For numerical analysis of wind turbines, the geometry must be adequately defined, which is a complicated task due to the shape of their blade profiles. Thus, this article proposes a way to create parametric wind turbines geometries using the software Grasshopper, a plugin from Rhinoceros 3D. Grasshopper is a visual programming language, allowing to produce parametric geometries as function of different input parameters. In this work, National Renewable Energy Laboratory (NREL) geometries are modelled, which are the horizontal axis wind turbine (HAWT) references proposed in the project known as Wind Partnership for Advanced component Technologies (WindPACT). As wind turbines have generally the same shape and their dimensions are proportional to each other, the intention of parametrizing the process is to facilitate the geometry creation when some parameters change, avoiding remodeling the entire turbine if it were produced in a usual CAD software. This paper shows how to model and obtain the final geometry, which is readily readable by any simulation software, such as Ansys. All the benefits and problems encountered are commented and the results are shown.

Keywords: *Wind Turbine; Parametric Design; Grasshopper*.

1 Introduction

Given the rise in energy consumption due the increase of the global population, new and more efficient methods of energy generation are required to supplement this demand. To reduce the environment damage and help in the diversification of the energetic matrix, it can be cited the wind energy, which is a renewable source, and its use is increasing every year [1].

To the generation, the modern wind turbines convert the kinetic energy of the wind into electrical energy. This conversion process uses the lift force applied by the wind on the blades, producing a torque on the axis of rotation of the turbine, generating mechanical energy that is transformed into electrical energy [2].

There are two principal types of wind turbine, the Vertical Axis Wind Turbine (VAWT) and the Horizontal Axis Wind Turbine (HAWT), defined by the geometric relation between the rotor orientation and the soil. This article focuses on the horizontal axis wind turbine, as they are the most commonly used. For this type, the main components presented in a turbine are the blades, hub, nacelle, and tower, besides the automation, mechanical and electrical gears used for transforming the rotor rotation to electric energy [2].

Due the complexity of the geometry, mainly because of the blades, to produce a computational model of a wind turbine it is a hard process, being necessary a paradigm shift [3]. As a solution, it is possible to create an algorithm to generate a complete HAWT according to some entrance parameters, known as parametric modeling.

The parametric design is a method where the geometry is shaped according to an algorithm. In this process, parameters and rules defined by the user generates a desired geometry, thus this capability significantly increases the efficiency of designing. Additionally, design updates typically required in the design-to-manufacturing cycle can be performed easily and quickly [4]. The biggest advantage of this modeling technique is that minor changes can be made by changing only a few input values, rather than having to remodel the entire turbine, as it would have been produced in a normal CAD software.

In this work it is proposed a generative algorithm created in the software Grasshopper, a plugin from Rhinoceros 3D, to generate parametric HAWT geometries. Grasshopper is a visual programming language that permits to produce parametric geometries in Rhino as function of different input parameters. Besides, Rhinoceros 3D is a three-dimensional modeling software based on NURBS technology that can export the files to several formats, allowing to the geometry to be used in multiple analysis software.

For testing the algorithm, it is modeled the single blades and the complete turbines proposed by NREL in the project known as Wind Partnership for Advanced Component Technologies (WindPACT). The WindPACT project was created with the purpose of improving reliability in the implementation of wind turbines and reducing final energy costs. One of the research lines of the WindPACT project was to study the main systems of wind turbines in order to analyze the effect of scale and alternative approaches to geometries, as seen in Malcom and Hansen [5]. The result of these studies were four different geometries, each with a different power rating.

Besides the eight geometries, four blades and four HAWTs, the algorithm includes the creation of custom control volumes according to the resulted geometry. Since wind is the most important load acting in a turbine, along with its self-weight, the choice of including these elements is to enable fluid dynamics analysis in other software, such as Ansys Fluent.

Lastly, after a fluid dynamics analysis it is possible to export the results obtained in the static module of Ansys to make a fluid-structure interaction. This last analysis uses the pressures and inertial effects obtained from the Ansys Fluent as structural loads together with the self-weight of all elements in order to obtain the distributions of stresses, strains and displacements. This procedure can be done considering the complete wind turbine or just the blade.

2 Objective

This article proposed an algorithm created in the software Grasshopper to generate parametric HAWT geometries. The goal is to generate the geometries and testing for the four NREL standard turbines.

In order to accomplish this, it is taken all the data presented in the reference work of Malcom and Hansen [5] as inputs in the algorithm, then define a routine to produce all the components of a wind turbine and baked it in Rhinoceros 3D according to the selected rated power.

3 Methodology

The proposed algorithm was developed using information of the NREL standard turbines exposed in Malcom and Hansen [5]. This work presents the main features of four different HAWT, each with a different power rate defined from a specific rating of 0.39 kW/m². The rated tip speed, rotor diameter, hub height and diameter, and the masses of all elements are some of these main features.

Beyond the information above, Malcom and Hansen [5] also define in detail the geometrical configurations of the blades and towers for each wind turbine. In both cases, as there is a lot of data, it is not convenient to expose them in this paper. For more information, please see the reference work.

For the blades, it is described the following characteristics, defined for each section: The radius measured from the center of the rotor, the angle of attack, the chord length, the chosen NACA airfoil, the linear mass, and the stiffness characteristics.

For the towers, as they have a conical shape, it is described other characteristics, also defined for each section: The height measured from the ground, the external diameter, the thickness of the wall, the linear mass, and the stiffness characteristics.

Lastly, it is also necessary to get the nacelle and hub geometrical information. In the reference work is not clear if the nacelles have the shape of a rectangular prism or a cone. Therefore, it was chosen for the nacelle a prism with rectangular shape, which dimensions are defined from the shaft rotor diameter, the hub diameter, and the external diameter of the top section of the tower. With all these background information, it can be extracted the required data to use as an input in the Grasshopper algorithm to generate all the NREL turbines.

Basically, a parametric design in Grasshopper can be split in three main parts: the inputs, where all the entrance values are defined by the user; the development, where all commands are defined, taking the entrance values and transforming into the expected results; and the outputs, where it is obtained the desired geometries. For better visualization, the commands are cluster in colored boxes according to its functions:

- The Orange one, which has a slider number to select the geometry that is going to be produced according to the rated power and a Boolean toggle to the user define if the control volume is baked with the desired geometry.
- The green ones, which have the values obtained from the reference work of Malcom and Hansen [5]. In these boxes there are two types of input: numerical values or the file location of a excel sheet.
- The blue ones, which have the resulted value or file location after the selection in the orange box.
- The purple ones, which have the procedure to generate each component of the turbine.
- The red ones, which have all the boundaries representations (BREPs), separated for each component.
- The yellow ones, which have only the merge command to make easier to produce the desired geometry.

With the brief explanation of the division in colors of the boxes, the Figure 1 shows an overview of the Grasshopper algorithm.

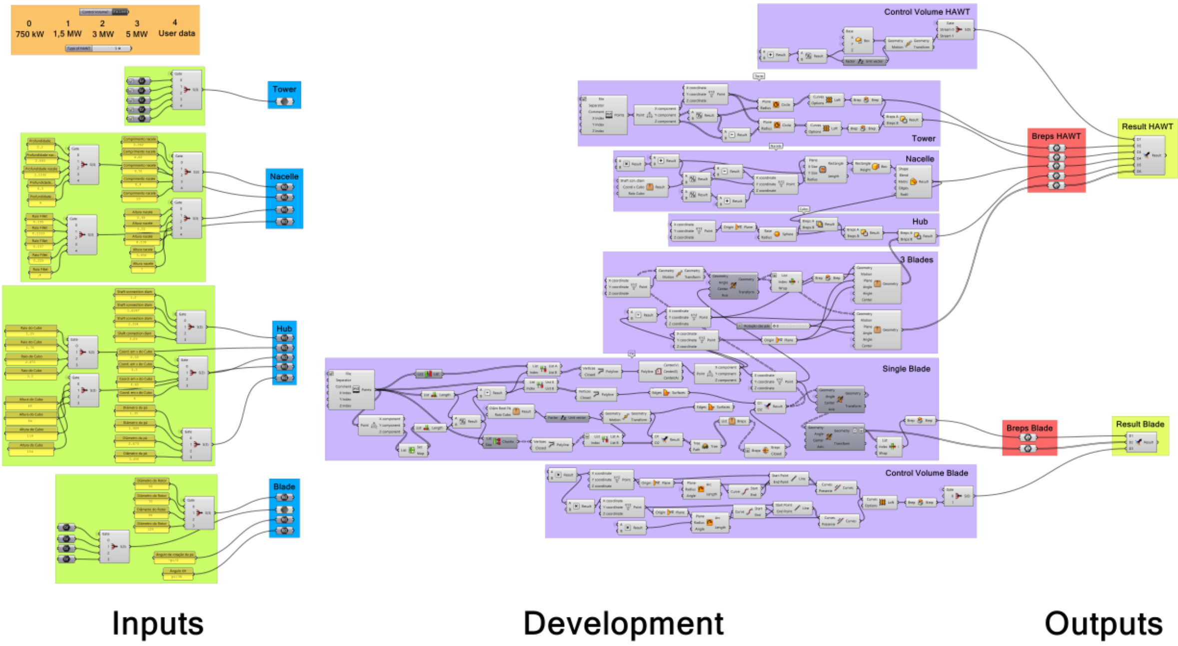

Figure 1 - Overview of the Grasshopper algorithm

Some important points of the algorithm must be addressed in order to fully understand its behavior. First, the orange box is necessary because the entrance parameters are already defined with the values of the NREL's turbines. As the user define the number slider, there are multiple stream gates in the green boxes that return in the blue boxes the respective value for the chosen turbine. If the user chooses to utilize different values than the standard of the WindPACT Project, the number slider needs to be defined as 4 and the values must be defined in each panel connected to the number four.

There are two green boxes with numerical values, the first one is related to the nacelle, which the box has the dimensions and the position of it in relation to the origin to produce it as a rectangular prismatic solid. The other green box is to generate the hub, which is a solid sphere trimmed on the intersection with the nacelle and the blades. The entrances are its diameter, the horizontal position of it in relation to the origin and the height of the center of the sphere measured from the ground level.

There are also two other green boxes that have multiple file's locations of a excel sheets. These files represent the geometrical configurations of the towers and the blades, detailing the multiple points for every section of each element. For the tower, the excel sheet contains three columns, which every line represents the values of a different cross-section: Height measured from the ground level, the external diameter, and the wall thickness.

From these data it is possible to produce a conic solid with a thin wall thickness using the command NURBS curve. This command allows to take multiple closed polylines and produce a unique surface that pass in all curves. In terms of referential, the center of the first cross-section, the one that is in the ground, it is considered the origin of the geometry.

For the blades, the sheets also contain three columns, one for each dimension of the points. Therefore, the file has the coordinates of all points to generate the surface of the blade. With all the points it is created multiple polylines, one for each section, and with these polylines it is generated an opened surface using the command NURBS curve. The term NURBS means non-uniform rational B-spline, which is a mathematical model that uses basis splines for representing curves and surfaces.

After the command NURBS curve, the last command used is the cap holes, that produces a closed BREP, which are a method for representing a 3D shape by defining the limits of its volume. This geometry is placed in the correct location and copied two times using the command of rotation, using the hub center as the reference.

It is worth mentioning that the blades are the hardest elements to produce. As the input data are only coordinates, it is an arduous job to compose the multiple polylines from it. To circumvent this situation, it is defined in the excel sheet that all section must have the same number of points.

After obtained the polylines, as explained above, it used the command NURBs curve considering the straight type. However, after many tests was found better to work with this command in pairs. This definition improved considerably the velocity of the geometry generation. The explanation is that if it is considered all polylines, the Grasshopper needs to create a complex surface that must pass exactly by all curves, resulting in a complex surface with multiple curves with smalls radius.

With these explanations, the Figure 2 shows in detail a part of the input, focusing on the number slider, the stream gate that returns the corresponded file location of the tower, and the multiple numerical values and stream gates to produce the nacelle.

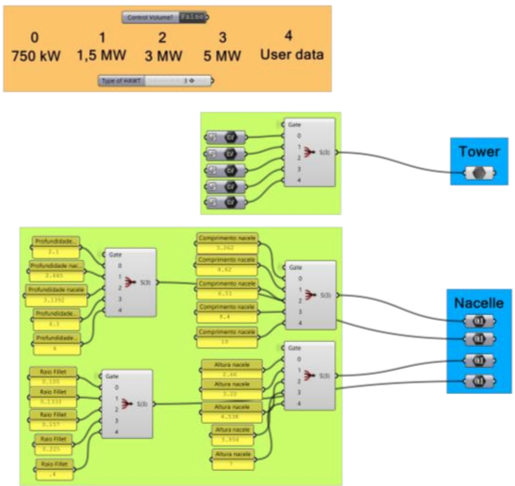

Figure 2 – Detail of the three types of input boxes

In short, there are four pairs of a green and a blue box in the input data. Each pair represents the entrance values of a component of the wind turbine, which are the tower, nacelle, hub, and blades. Also, there are seven purple boxes, two for control volumes, and five for the turbine component: tower, nacelle, hub, single blade and the last generate the three blades.

As described above, there are two control volumes presented in the algorithm, one for a single blade and other for the whole HAWT, which both are parameterized as a function of the rotor radius. These control volumes are produced to help in a possible fluid dynamics analysis in other software, such as Ansys Fluent.

Finishing the description, the last step is to bake the chosen geometry in Rhinoceros 3D, following what is showed in the Figure 3. In short, it is exposed in Figure 4 a flowchart with all the steps to the user correctly utilize the algorithm.

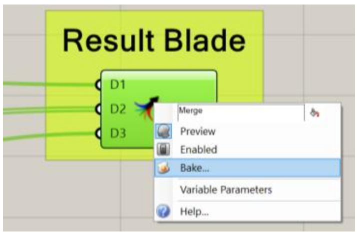

Figure 3 – How to generate in Rhinoceros 3D the geometry produced in the Grasshopper algorithm

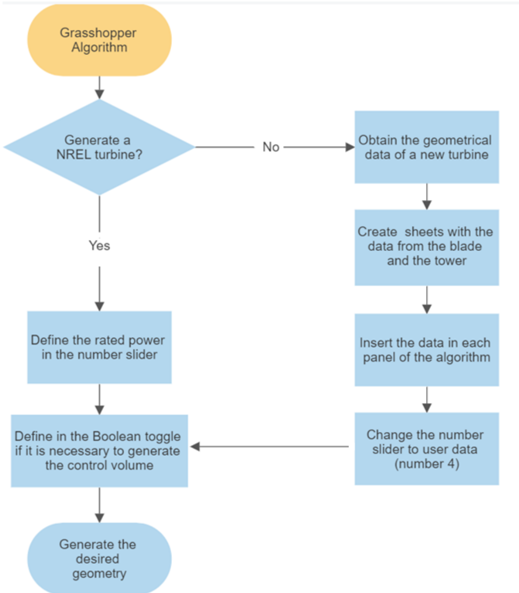

Figure 4 – Flowchart with the procedure of the algorithm

Thus, after all the explanations necessary to the reader understand the logic in the Grasshopper algorithm, the next section will show the geometries obtained from it.

4 Results and discussion

To generate a blade or a complete HAWT of the WindPact Project the first step is to define the chosen rated power. To exemplify this, the number slider is defined to the value of three, that corresponds to the 5 MW wind turbine, as can be seen in Figure 2. After this definition, the next and final step is to bake the geometry to Rhinoceros 3D, whether if it is just the single blade or the complete set, as showed in Figure 3.

Using the rated power of 5 MW to explicit the resulted geometries, the Figure 5 represents the control volume of a single blade, which is a slice of 120º of a cone, and the control volume of the 5 MW wind turbine, which is just a box. Lastly, the Figure 6 shows only the blade, while Figure 7 shows in detail the complete wind turbine.

(a) (b)

Figure 5 – Views of the control volume of NREL's 5 MW: (a): blade; (b): complete turbine

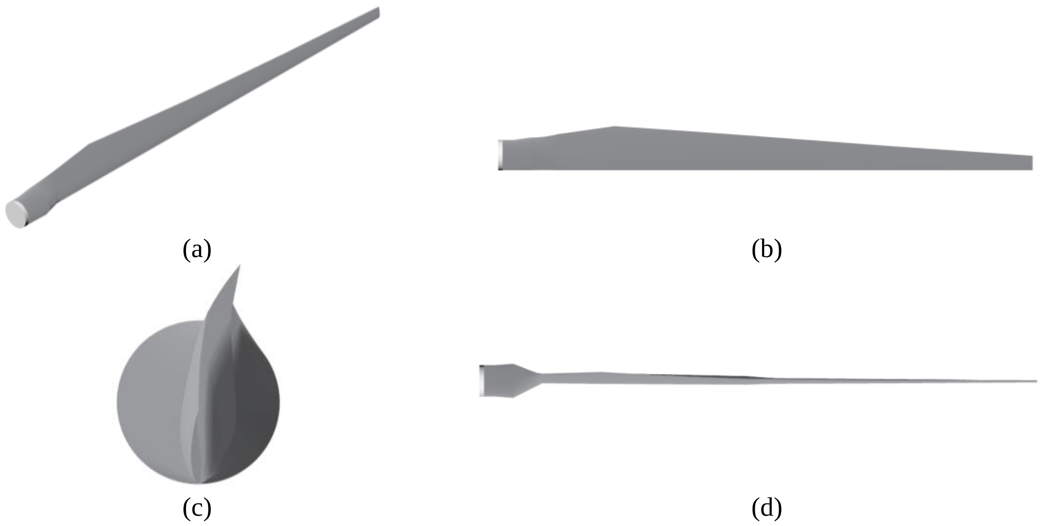

Figure 6 – Views of NREL's 5 MW turbine blade: (a) Isometric; (b) Front; (c) Side; (d) Superior

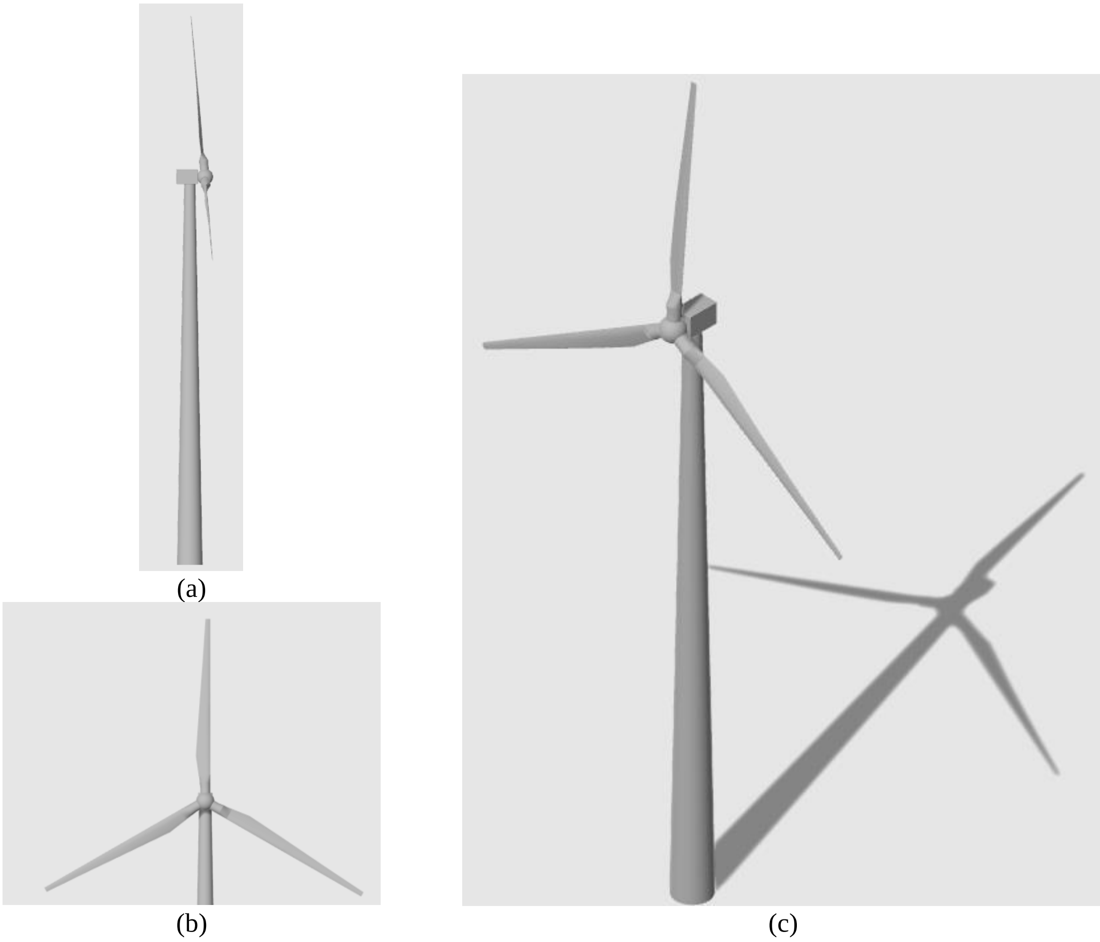

Figure 7 – Views of NREL's 5 MW turbine: (a) Superior; (b) Front; (c) Isometric

After generating the desired geometry, it is possible to save the Rhinoceros 3D file in various extensions such as 3dm (Rhino standard), dwg (Autocad Drawning), igs (IGES), x_t (Parasolid), skp (SketchUp), and many others. This variety of extensions allows the user to export the resulted geometry for most of the commercial software.

5 Conclusions

The Grasshopper is a powerful tool to develop parametric design. In this work, this software was used to obtain the geometries of blades and wind turbines from the project WindPact using the values detailed in the reference work of Malcom and Hansen [5].

For wind turbines, the hardest element to produce is the blades, which are defined by multiple airfoils with different chord lengths and angles of attack. Due this complexity, the big advantage of this technic of modeling is that small changes are done only changing some input value, not being necessary remodeling the entire turbine if it were produced in a usual CAD software. This produces a gain in productivity and efficiency in the stage of modelling.

From the algorithm itself, it is worth mention that the blades are produced as surfaces, which implies that it doesn't have a thickness defined in the algorithm. In contrast, the tower was generated with the real wall thickness, while the nacelle and the hub were created as solids.

Also, it was programmed that the control volumes are produced together with the desired geometry. This decision was thought to make easier a possible fluid dynamics analysis. If the user objective is only obtaining the geometry, it can be removed the connection between the control volume BREP and the merge command.

Lastly, the Rhinoceros 3D is a great tool in terms of changeability, which there is a great variety of extensions that allows the exportation of the geometry for an analysis software, such as Ansys. The intention of this algorithm was to produce the geometry together with the control volume and export to Ansys is to make a Fluid–structure interaction using the Fluent and the static module.

Authorship Statement

The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

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