EVALUATION OF PARAMETRIC MODELS: TWO PROVISOS FOR THE SAGRADA FAMILIA COLUMNS

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Abstract

This paper presents a research in progress in the development of parametric models for geometric manipulation of complex shapes, and introduces a methodology for evaluation of the design instances of a parametric model. The research presents a case study on the designs of the Spanish architect Antonio Gaudi, and takes on the fundamental rules of the form generation of the nave columns of the Expiatory Temple of the Sagrada Familia in Barcelona. The evaluation is done applying two provisos that determine if a shape is part of the design language and is an instance of the parametric model is a Gaudinian design.

1. Introduction

In a previously published paper, the author proposed a methodology for the generation of the columns of the Sagrada Familia based on a parametric modeling schema that allowed the generation all the columns in the Sagrada Famila nave plus a large number of columns that were not designed by Gaudi. The experiment proved that the parametric model was able to generate multiple instances of the columns far beyond the original Gaudinian designs, both in numbers and variation types. However, the parametric model could not discriminate which of the designs were the original from Gaudi and which were not.

This paper introduces a methodology specifically designed for the evaluation of the columns that discriminates the original columns from the new designs. A brief review of the generation process of the Sagrada Familia columns and the construction of the parametric model precedes the proposed provisos for the evaluation criteria, which are presented with the corresponding results for each of the evaluations. A sample of randomly selected designs was tested with the evaluation criteria and the results are later discussed.

2. Parametric models of the Sagrada Familia columns.

2.1. The Parametric Model

A *parametric model* is defined as *geometric representation of a design* in which some components have *attributes* (properties) that are fixed, and attributes that vary called variables or *parameters*. *Parameterization* is the process of transforming the explicit attributes of a geometric model into parametric. *Parametric modeling* is the process of making geometrical representations of designs with components that have parameterized attributes. Parametric design is the process of designing with parametric models or in a parametric modeling setting.

2.2. The Sagrada Familia columns.

Antonio Gaudi initially proposed a helicoidal shape column, like the salomonic columns from the renaissance, but with less twisting. However, Gaudi considered that the single twist was visually inappropriate, since it produced a visual perception of a weak column that could be squashed or deformed when compressed. The visual imperfection of the single twisted column bothered Gaudi for a number of years. Gaudi sorted

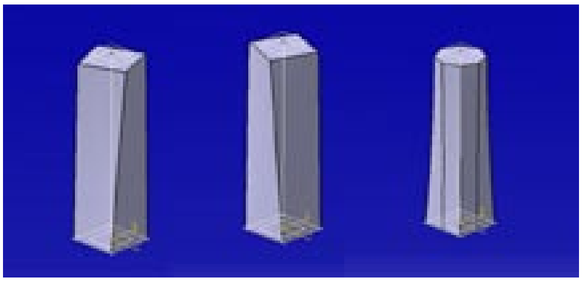

Figure 1: Generation process of the Gaudinian column.

to search for an alternative solution, and after years of experimentation, he applied two simultaneously opposite rotations. This methodology, which has no known precedents in architecture (Gomez et al, 1996), is the result of eight years of work and experiments and Gaudi's interpretation of the helicoidal growth present in trees and plants. Gaudi's novel solution in the use of two opposite rotations consisted of the same shape that was to be rotated in two directions, once clockwise and another counter-clockwise. Figure 1 shows the generation process of a twisted column based on a single rotation of a square shape and the corresponding counter-rotation. When the two shapes are superimposed and a Boolean intersection is performed, the resulting shape is the actual column as develop by Gaudi.

All the columns on the Sagrada Familia nave follow the same procedure, where the only variations are the shape that is used for the rotation, the height of the column, and the angle applied to the rotation, which in most cases is a function of the height of the column. A hierarchical arrangement of the columns is present throughout the temple. The columns of the central nave are based on an octagonal shape, the columns of the crossing area are based on two pentagons, the central columns on the crossing are three squares forming a 12 sided polygon, and the columns of the lateral nave are made of two triangles to form a hexagon.

2.3. Parameterization of the Column.

The parameterization of the column knot was done by building a wire-frame model (skeleton), implementing surface fitting procedure to generate each rotation operation of the column shape, and performing the Boolean intersection. Figure 2 shows the generation process of the square column located in the upper portion of the lateral nave.

2.4. Generations of existing Designs

The parameterization schema will determine which attributes of the models are subject to parametric transformations. In this case, the parametric schema selected for the model included the parameterization of the following attributes:

- The total height of the column
- The angles of rotation and counter-rotation shapes
- The heights of each rotation and counter-rotation shape
- The initial shape (square)

The first three parameters are based on numerical values,

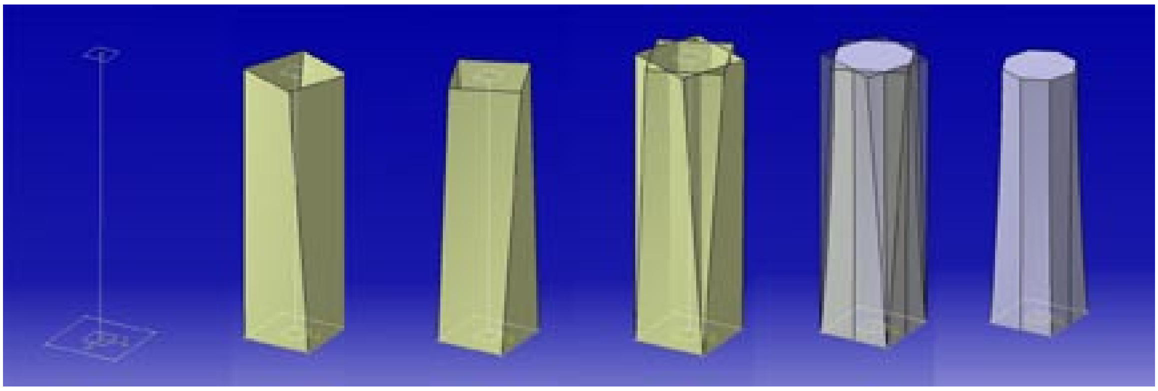

Figure 2: Generation process of the column. Parametric skeleton, surface fitting for rotation and counter-rotation and Boolean intersection.

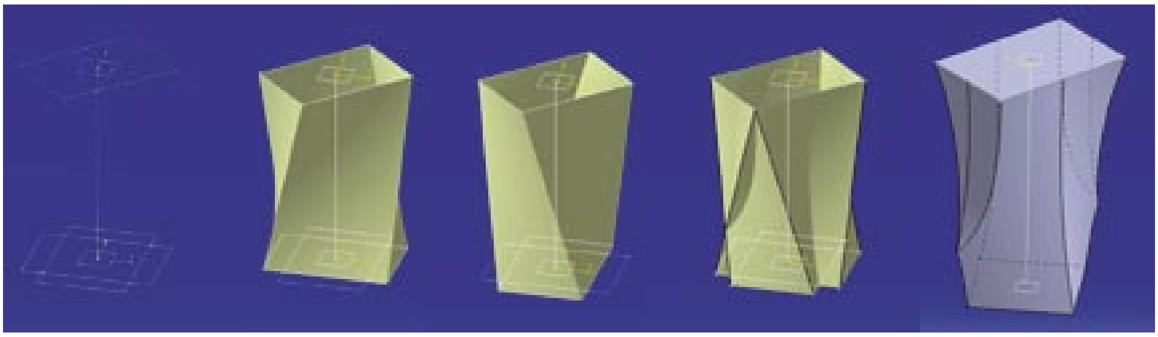

Figure 3: Rectangular knot generated from the same parametric model. The square is transformed into a rectangular shape and the angles and the column height are changed accordingly.

with means that the parametric variations are produced by changing the numerical values of the parameterized attributes. The last of the parameters is an interesting case that deserves attention. The shape itself is not parameterized, which means that the shape is explicit. However since the shape can be changed for another one without altering any of the other parameters, we can consider the shape to be a parameter in itself. By changing the initial shape without variations on the other three parameters, the procedure generates a different column. Figure 3 shows a different column generated from the same parametric model. The column shown bears the name of the rectangular knot and is formed by the forty five degree double rotations of a rectangular shape. The procedure for obtaining the shape is the same as the square column, but the initial squared shapes are substituted by a rectangle.

2.5. Generation of new Designs

The parameterization schema allowed for transformation on the selected attributes and at the same time for generation of new designs based on the substitution of the initial shape. New designs where obtained by transforming the rotation angles and the height of the column. However the most interesting designs emerged from the changes in the initial shapes. Figure 4 shows different design instances as a result of different transformations performed on the initial shapes of the parametric model. The designs generated from the substitution of the initial shape were of special interest, since it extended the repertoire of new designs. This included regular and irregular polygonal shapes, curved shapes and a combination of both.

There are some important restrictions to consider: 1) the initial shape must be a closed shape, and 2) the initial shape must not be self intersecting (8 figure shapes and knots). Self intersecting shapes will generate cusps in the 3D model while open shapes will generate 3D surfaces. Apart from the aforementioned restrictions, the model is very powerful, since it allows for an undetermined numbers of initial shapes and an infinite number of new possible designs.

3. Evaluation of designs

3.1. Evaluation of designs

A natural question for a generative procedure of this kind is how to evaluate the produced results within a specific context. Performance driven design is one of the most widely accepted form of evaluations when a specific set of optimization standards are desired. Each design is evaluated intrinsically and result values that are then compared within different design options. The evaluation procedure iterates between different solutions to find an optimal result. This kind of evaluation tends to be objective in the sense that the criteria are determined before the instances of the model are generated. Alternatively qualitative evaluation of designs is more complex.

According to Gips and Stiny, there is no single answer to the question of aesthetic value of designs which depends

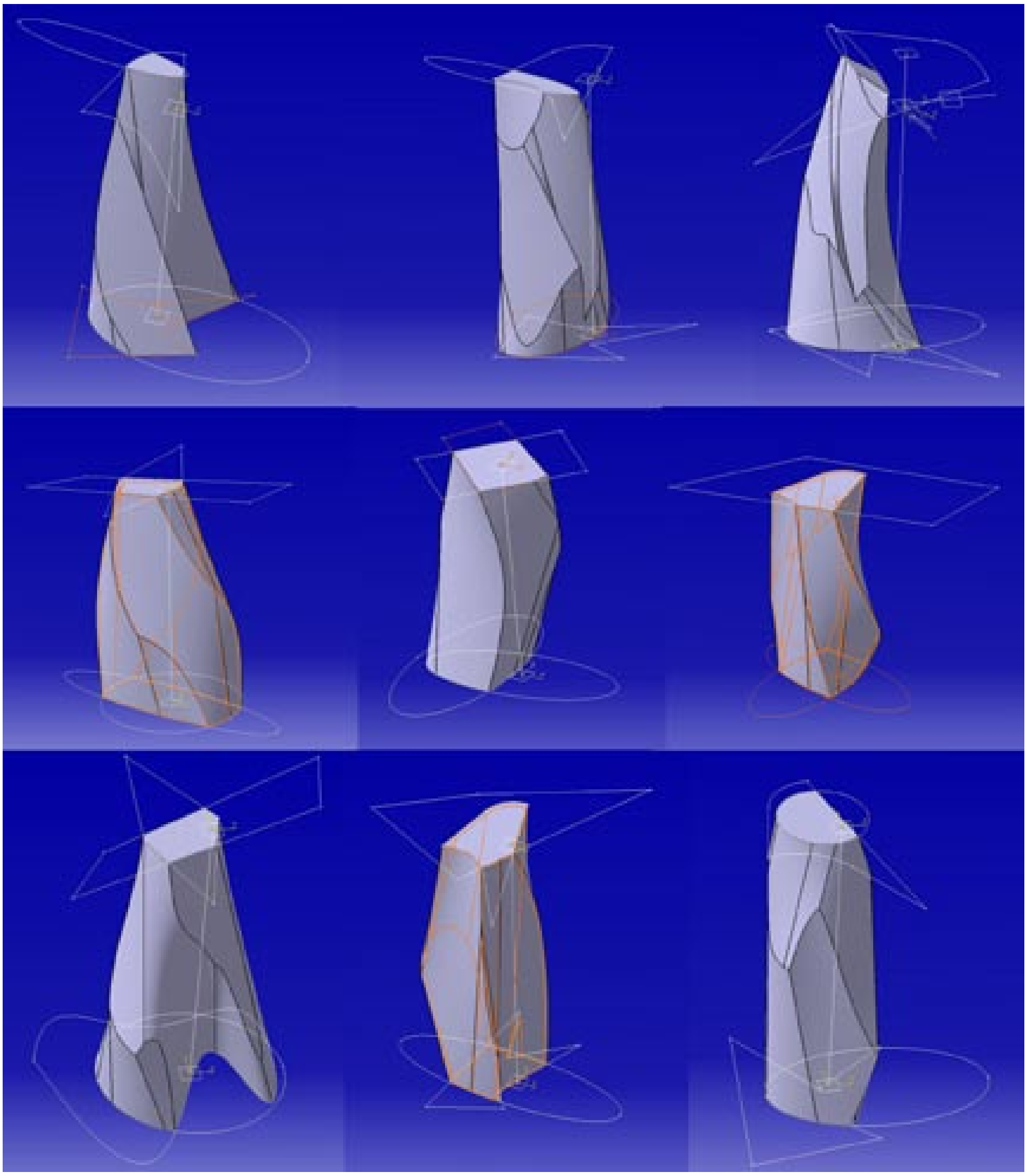

Figure 4: New designs generated from the parametric model.

on the criteria used by the designer and the conventions of the observers (Stiny and Gips 1978). They propose a model for aesthetic evaluation of works of art and designs, and assign values in reference to an evaluation criterion. If the evaluation criteria changes, so will the values of the designs evaluated. The evaluation system will depend on criteria and conventions used by the evaluator (designer or critic) and the aesthetic value assigned to each of the evaluated objects (designs).

Based on this premise, I proposed two provisos for evaluation of the designs generated by the parametric model. The evaluation system is based on general criteria for aesthetic evaluation of the design language by Gaudi. The first proviso determines if a generated column is in the design language of Gaudi, and the second proviso distinguishes which columns where originally made by Gaudi and which are new designs.

3.2. First Proviso: Gaudinian Designs

The first proviso consists in determining if a column generated from the parametric model belongs to the design language of Gaudi. We define that a shape is in the language of Gaudi if the generated design and the original from Gaudi produce same results when a comparative analysis is performed. Since the parametric model is based on a similar procedure that Gaudi used for the columns it can be assumed that all shapes generated by the parametric model are in the language, however it is necessary to perform a careful analysis to make appropriate comparisons. The analytical test determines the nature of the generated designs and compares them with the original columns as follows: 1) The original columns made by Gaudi consisted in rotating shapes that produced ruled surfaces. It is widely know that Gaudi made extensive use of ruled surfaces in different designs throughout the Sagrada Familia. A ruled surface is defined by:

- A continuous curved shape formed with straight lines (ruling lines).
- It has a non-positive value on the Gaussian curvature analysis (less or equal to 0).

A sample of the generated shapes was tested to determine if they where made with ruled surfaces yielding the following results:

- All the generated designs that where tested showed that they had surface continuity in each patch of surface of the shape (Figure 5)
- All the surfaces had ruling lines making them ruled surfaces such as the original Gaudinian designs as shown in Figure 6
- The analysis of Gaussian curvature was either negative value or zero (Figure 7)

3.3. Second Proviso: Gaudinian Language

The second proviso discriminates which designs are original by Gaudi and which are not. This proviso does not discriminate among the procedure used to generate the designs, therefore if two different procedures

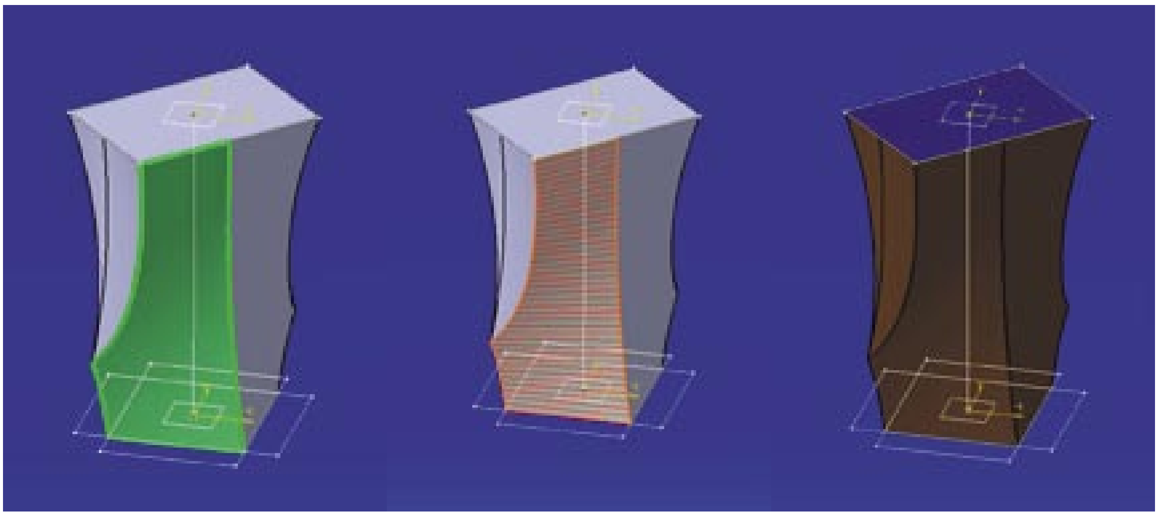

Figure 5: Column Shape showing surface continuity.
Figure 6: Column Shape showing ruling lines.
Figure 7: Column Shape showing Gaussian curvature analysis.

generate the same design, they are considered equal. The evaluation criteria applied to the generated designs independently of the procedure that was used. The rules of evaluation are extracted from the original columns are applied to the new generated shapes. If the evaluation criteria produces a match, the column is considered a Gaudinian design, even if the shape was obtained by a different procedure than the one used by Gaudi. On the contrary, if the evaluation criteria produce discrepancies between the original column and the generated shape, the generated shape is not considered a Gaudinian design, even though it can be considered to be in the language of Gaudi.

Figure 8 shows the original design of the rectangular knot, which is compared with a generated shape from the parametric model (Figure 9). The parametric model was done with a different procedure than the one used by Gaudi. The new procedure was tested for accurate representation of the column shapes and the results were compared with the original columns by Gaudi. Even though both designs were obtained by different procedures, no discrepancies were encountered when the two shapes were compared side by side using a rapid prototype of the column knot at the same scale of the original designs. the evaluation criteria for the second proviso produced a match. Therefore the generated shape is considered to be in the language of Gaudi and at the same time is a Gaudinian design.

Other designs generated from the parametric model where compared with the original designs by Gaudi, where some of the designs match and some did not. If a match is found the generated design is marked as an original design by Gaudi and put on one side of the catalog. If a match is not found, then the generated design is not an original design by Gaudi and placed on a separate catalog.

Figure 8: Column knot.

4. Conclusion

The columns of the Sagrada Familia represent a synthesis of manipulation of simple geometrical rules and the use of basic compositions which result in a rich language with no precedents in architecture. Gaudi developed a unique language for the temple manifested in the plaster models he used for design exploration. After the Gaudi's death, different models of representation of the have been develop as a result of interpretations of the original designs.

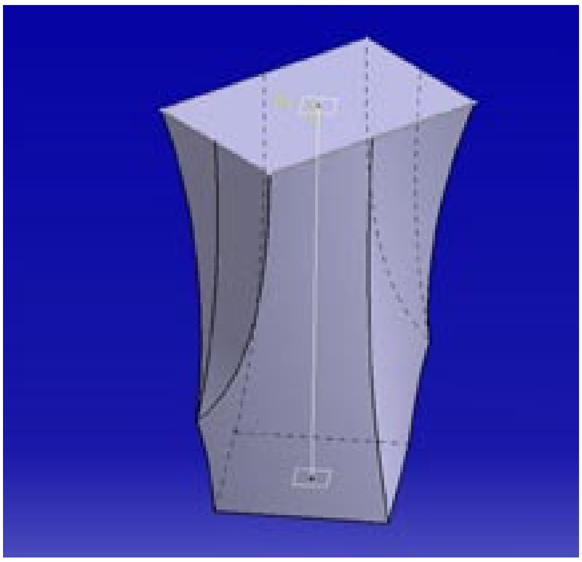

Figure 9: Generated design.

Figure 10: Rapid prototype model.

The parametric model is able to encapsulate, as a general procedure, the method of generation of the columns, including all the original designs by Gaudi plus new designs all in one single source. As a result all the columns can be obtained by modifying the parameters instead of modeling them individually.

The evaluation system is limited to determine if one instance of the parametric model is part of the Gaudinian language or if matches with and original design. Other criteria can be incorporated to discriminate between different solutions, like structural performance of a particular design or to minimize the surface area to economize materials.

The provisos proved their usefulness in the design process as an evaluation tool for instances of parametric. The parametric model offers the ability to encapsulate the knowledge of the generation procedure of the columns, while the evaluation criteria contains the knowledge of the design intentions expressed through the design language.

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