PARAMETRIC GAUDI

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Abstract

This research is a work in progress in the development of parametric systems for modeling of complex shapes. The research takes on the fundamental rules for form generation of column knots of the Expiatory Temple of the Sagrada Familia in Barcelona. Designed by the Spanish Architect, Antonio Gaudi, the forms of the Sagrada Familia represent a synthesis of manipulation of simple geometrical rules and the use of basic procedures which result in a rich language with no precedents in architecture.

Key words: *parametric modeling, design variations, evaluation of designs.*

1. Introduction

Parametric modeling (PM) CAD systems and rapid prototyping (RP) devices, which until recently were high end commodities in the architectural domain, are becoming standard tools to aid the design process in academy, practice and research. Together, they are challenging the traditional process of computer systems like CAD two-dimensional drawings and renderings, as foremost representational systems in design. This paradigm poses a challenge to expand the design process beyond current limitations of CAD systems by:

- Offering more flexibility to design parts and assemblies of complex nature.
- Provide reliable systems to test real life situations both in the digital and physical domain.
- Expanding the opportunity for innovation of conventional building systems.

At the foremost of technological and computational capabilities, architects and designers are just starting to explore the universe of possible applications of integrated design systems combining the power of parametric modeling and rapid prototyping devices.

Parametric Modeling for Design

Parametric modeling systems, initially intended for the aeronautical industry, are making their way into the architectural domain since they provide a powerful framework for conception of design allowing the description of multiple instances from a single modeling schema. However PM requires rigorous thought in the process to build a model that is appropriate for the needs of the designer and a very sophisticated structure. Even though this task can be time consuming, a good parametric model has the advantage to provide a solid structure that will act as a container of information of the design history. Furthermore the model can be flexible enough to be constantly evaluated, revised, and updated if different components are added, changed and deleted, within the same structure of the PM.

1.1. Reconstruction of the column knots of the Sagrada Familia

The work started by the reconstruction of the columns knots of the lateral nave of the Sagrada Familia shown in Figure 1. For this purpose we choose a parametric modeling system, CATIA V5R9 (Computer Aided Three-dimensional Interactive Application, Version 5 Release 9). The first challenge was to find a suitable modeling procedure that will yield an accurate representation of the knot. CATIA V5R9 did not have the appropriate tools to reconstruct the knot shapes according to the counter rotation procedure described by Gaudi [1]. This initial challenge called for alternate ways to represent the column knot. After a series of experiments it was found that using the bottom (initial) and top (top) shapes of the knot and filling the space in-between with a blend surface procedure, the resulting form will generate the knot shape that was visually equivalent to the original plaster model by Gaudi. Figure 2 shows the CATIA model of the column knot.

Figure 1: Rectangular knot of the lateral nave columns

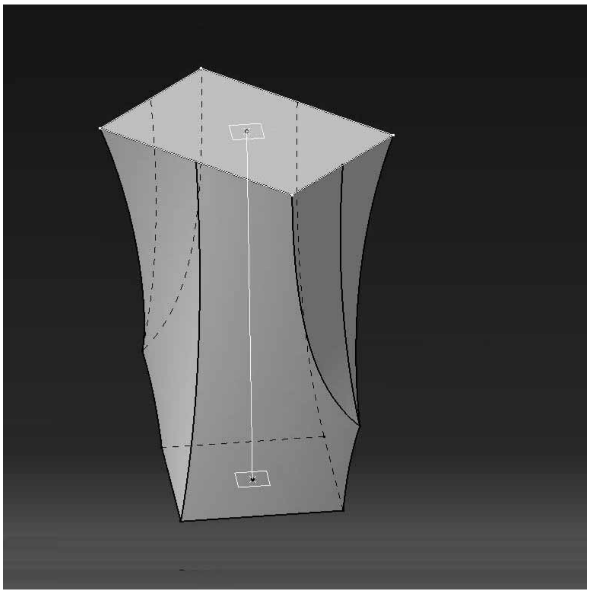

Figure 2: CATIA model of the rectangular knot

1.2. Comparative analysis of the knot shape

After the initial modeling procedure done in CATIA it became necessary to assure the accuracy of the CATIA to the original column knot. The problem was that Gaudi used ruled surfaces to generate the shape of the knot and most of the current PM commercial software is based on a non-uniform rational b-spline (NURBS) curve representation which did not exist when Gaudi made his models. The CATIA model was subject to *Gaussian* curvature analysis to find the most suitable surface fitting procedure. Out of the three surface procedures used for the CATIA model, the *Blend* surface proved to be the most accurate since to a *ruled surface* since they both have a *non-positive Gaussian curvature* along the whole surface and they both have a least one *ruling line* at every point on the surface.

The second analysis was done by comparing the original plaster model with the CATIA model. A series of rapid prototypes (RP) were printed in a plaster 3D printer (Figure 3) and were visually compared to the models in the Sagrada Familia plaster shop. Both models were visually equal and both models showed evidence of ruling lines.

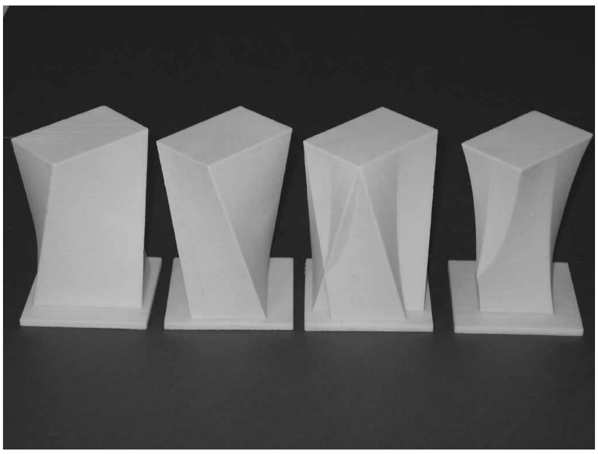

Figure 3: Rapid prototypes of the parametric model

2. Parametric modeling procedures

The parametric model was embodied in a parametric skeleton schema. A parametric skeleton is a wire-frame model that provides a powerful driving infrastructure for the interaction of parts and components of the system. A parametric skeleton was implemented as a controller for the geometric variations of the components. The parts and components were depending on parametric relations from the single skeleton allowing variations in design with the use of local and global parameters. The skeleton offers a high level of precision and, at the same time, grants speed in the reconfiguration process when parametric transformations are performed. The skeleton is a representation of the system that is used as schematic design tool which can be modeled in the CAD system with relative easiness and speed. It allows a powerful representation for schematic design and proof of concept.

2.1. Parametric variations

The second stage called for the generation of design instances from the original parametric schema. The main idea was to expand the universe of designs that were created from a single design procedure. As a result of the parametric variations, more than 60 instances of design were generated with a single parametric model (Figure 4) which was done in three phases as follows:

1. The first set of parametric variations was accomplished by performing alterations to the relations of the geometrical components without changing the topological levels. For the most part the resulting designs were very similar to the original column knot.

2. The second phase was to change the topology of the geometrical components. The shapes introduced were kept as closed polygons.

3. The third stage introduced curved shapes like circles and ellipses. When curves are introduced as the initial shapes, the resulting surface of the knot becomes a ruled surface of single curvature.

4. One last stage was a combination of straight lines and spline curves. With the combination a new shape emerged with a sense of axial torsion or rotation.

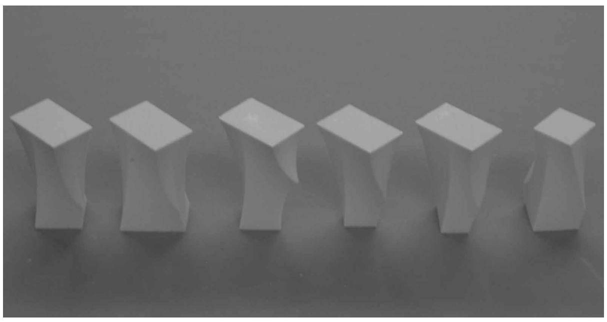

Figure 4: Variations of the parametric model

2.2. Validation of the designs

All the designs obtained by the procedure were tested for accuracy. For the curvature, a Gaussian analysis was performed in some of the designs selected randomly. The result was that in each of the selected designs the Gaussian curvature yields a non-positive value, which is characteristic of the ruled surfaces. All of the surfaces of the column knot.

3. Designs in the gaudinian language

The third stage of the project aimed to create a system that would determine which of the generated instances of the parametric model would satisfy the criteria to be a valid design in the Gaudinian language. Two provisos were established to determine the category of the designs:

1. The generated designs must be the result of the application of the generation procedure used by Gaudi to create the original models of the Sagrada Familia columns; and

2. To be in the Gaudinian language, the generated designs must be composed of second order surfaces (ruled surfaces) just like the ones used by Gaudi.

The first of the two provisos was relatively easy to achieve in the parametric model. Once a parametric model was created, all the resulting designs were extracted from the same parametric model, which kept intact the generation procedure. As a result a diversity of shapes from the same model was grouped in a "Family of Shapes".

The second proviso called for a comparative analysis of surface features that would determine which of the shapes were composed of second degree surfaces and which were not. As a result of the surface analysis from a sample of the universe of the generated designs, all designs yield a non-positive Gaussian curvature, which is a fundamental characteristic of ruled surfaces. The analysis included the generation of ruling lines and the curvature of them (Figure 5). The lines of ruling showed a zero curvature along the whole surface.

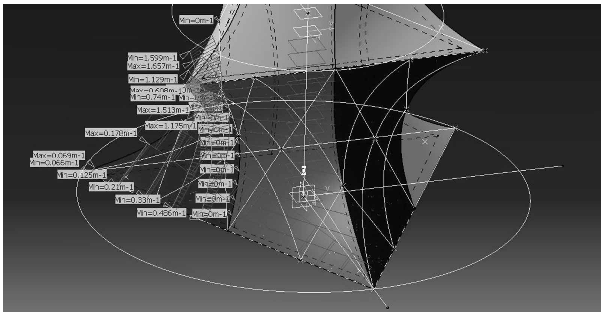

Figure 5: Curvature analysis showing ruling lines.

As a result, all the shapes generated from the parametric model satisfy the design criteria of being in the Gaudinian language. On the other hand, none of the generated designs was found to fail either of the two provisos established for the evaluation criteria.

4. Conclusion

Without an integrated parametric modeling environment, this process would have been very difficult to accomplish and most of the design variations would have been difficult to make in a short period of time.

With the possibility of expanding the number of designs to higher number of instances, the parametric model proved to be a powerful system for quick generation of designs from a single parametric schema.

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