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# *Representing BIM-based design process*

*Representando procesos de diseño basados en Building Information Modeling (BIM)*

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## RESUMEN

Este documento se centra en el estudio de modelado paramétrico utilizando BIM (El modelado de información para construcción, BIM por sus siglas en inglés-Building Information Modeling), una herramienta para el diseño conceptual. Con el fin de comprender el uso de BIM en el proceso de diseño arquitectónico, se compara el proceso de diseño de detalle y el diseño conceptual utilizando una herramienta paramétrica de diseño basada en BIM. Se presentan los resultados de dos estudios empíricos: el diseño de un sistema paramétrico de muro cortina, sobre la base de la labor de tres equipos de dos estudiantes cada uno, vs. el diseño de un componente cinético paramétrico, desarrollado en forma individual por cinco estudiantes. Un análisis comparativo de ambos procesos se utiliza para obtener un modelo óptimo del proceso.

*Palabras clave: proceso de diseño paramétrico.*

## ABSTRACT

This paper focuses on the study of parametric modeling using a BIM tool for conceptual design. In order to understand the use of BIM in the architectural design process, we compare the process of detail design and concept design using a BIM-based parametric tool. We present the results of two empirical studies: the design of a parametric curtain wall system, based on the work of 3 student teams; and the design of a parametric kinetic component, based on the work of 5 individual students. A comparative analysis of both processes is used to derive a process model.

*Key Words: Parametric design process.*

## INTRODUCTION

The tasks of architects using CAD systems have changed. CAD tools initially supported the production of 2-dimensional drawings to describe spaces and buildings. Now CAD systems are used for modeling data, storing all of the design-related information of the physical building, including its 3-dimensional geometric description (Eastman, 1999). In architecture, these new CAD tools have been labeled Building Information Modeling, BIM. BIM applications, used initially for detailed design development, are increasingly being used for exploring architecture design concepts (Khemlani, 2006). With academic institutions and architectural offices incorporating BIM tools in curricula and practice, it is necessary to develop a clear approach to provide architecture students with the necessary BIM skill set. Studies have shown that the knowledge of design tasks together with the knowledge of the tools necessary to carry out such tasks is not quite sufficient for efficient design problem solving, and that design management strategies have to be adopted in order to achieve such efficiency (Bhavnani, Reif, and John, 2001). In order to understand the use of BIM tools in architectural design, we compare the process of detail

design and concept design using a BIM-based parametric tool. Results provide information relevant to integration of BIM in design education, and point to future research directions.

### Comparative study of BIM-based parametric design process

Building Information Modeling incorporates parametric modeling as a powerful tool for visualization and analysis. By modeling design objects as parametric, multiple design variations can be generated, modified, and evaluated (Aish, 2005, Anderl, 1996).

Because of these additional functionalities, the parametric modeling interface in applications such as Digital Project is initially very complex, adding a cognitive load to the designer as he or she engages in design problem-solving. In this section, we report on two empirical studies: the design of a parametric curtain wall system, based on the work of 3 student teams; and the design of a parametric kinetic component, based on the work of 5 individual students.

#### *Design of a parametric curtain wall system*

The case study of 3 projects by students participating in an instructional course on Digital Project provides data as to the process of teams to design a parametric object. The design task is the final project of a semester long course. It is assumed that this assignment is comparable to the task architectural designers perform during the detail development phase of a design project. Subjects work in pairs to design a parametric custom assembly for a curtain wall system, based on a commercial product. The project, including a detailed report, is developed in 2 weeks.

- Team One proposes a curved curtain wall with a curved surface and a plane as input to generate the entire component as a user-defined feature. The team uses Visual Basic scripting to have the system generate equally spaced points along the input curve, and lines for mullions and glass panels. The number of vertical mullions along the curved surface and the spacing between horizontal mullions are parameterized for multiple variations. The team creates 3 vertical mullions with parameterized depth, length, and the number of intermediate reinforcements based on the length of the member. The reinforcement profile is also parameterized to change configuration based on its location at the head, intermediate, or sill.

The team splits the overall task into modules and creates an outline of the general framework and approach. One subject works on the struts and another implements the framework. Planning the updates of the model proves to be difficult when parameters are changed. They report that Digital Project “kept getting stuck” due to the fact that their code interfered with the internal update cycle. This problem is partly resolved by reorganizing some of the elements and the code. Update-cycles have to be manually initiated several times for everything to work.

- Team Two’s curtain wall system consists of 3 user-defined feature components: a corner mullion, with angle and height variations, a parametric mullion with width and depth variations, and a shading device, with variations in the angle of tilt of the shades. Three lines are the input for the corner mullion. Two lines are the input parameters for the mullion, one to determine the height, the other the orientation. The shading device has 4 input parameters. Two planes to determine the width of the shading device and two lines to determine the insertion height. The component has rules coded in Visual Basic to control the angles, and alert the user if the component will work.

The team members split the tasks and each team member worked separately on the components. This team experienced difficulties in the insertion of the corner mullion orientation, and the insertion of the shading device along a curved wall.

- Team Three's curtain wall system consists of an assembly of 2 powercopies, a parametric corner mullion and parametric flat panel. The parametric panel has 2 inputs for insertion: a line to determine the panel width and a plane to determine the panel height. The flat panel has 5 parameters: height, width, number of vertical mullions, number of horizontal mullions, and mullion depth. The corner mullion has 3 inputs for insertion: two lines to define the corner angle and a vertical line for the extrusion height.

Three corner mullions profiles are based on 2 parameters: corner angle and mullion depth. 2 profiles include 35 different variations in a design table. The other profile includes 10 variations.

Coordination of all the constraints for the mullion profile sketches was difficult so that the variations would create an outline that was not over constrained or overlapped.

#### *Design of kinetic parametric component*

Six architecture students participate in this study, as part of a two week intensive course in Digital Project. The design task is the second and final exercise. Students are asked to design a kinetic architectural building component, and to parameterize the mobility or geometric variations of the component with a minimum of 3 settings or positions. Students are given 3 days to complete the task and submit a detailed report. It is estimated that students worked 12 hours in this task.

- Subject A has designed a circular roof with an adjustable oculus, as a radial array of hinged supports. The design process starts with the design and analysis of a single hinged support. A vertical line determines the radii of two intersecting arcs, with the hinge at the intersection. A horizontal line determines the distance between the two arc centers and the spread of the hinged supports. This initial wire diagram is tested and parameters are created to control the hinge angle. Pads are created to model the support geometry.
- A powercopy is created and instantiated in a new part body in a circular array. The original idea is to create an asymmetrical composition from the repetition of a component. During testing, the design changes from a gate to a canopy, changing a linear array to an array supported by points on 2 circles. The overall assembly is tested to explore the design limits. Blend surfaces are created between the edges of the supports. A final test of the parameters confirms that the surfaces will change with every parametric change. Subject A completes the exercise in approximately 6 hours and spends an additional 4 hours to study and refine the system.
- Subject B proposes the design of a canopy with adjustable ribs supported on a central spine. The array of ribs is generated from 3-dimensional curves generated from points on a surface. The process begins with surface geometry, so the ribs would follow the changes in the surface geometry. Through trial and error, the subject generates the surface using three different methods; each method informs the subsequent approach. An array of equally spaced curves is extracted from the fill surface defined by edge curves. The center point and end points of each curve are created to generate a new set of splines for the ribs. In a new part, a single rib is modeled to create a powercopy, using a line and a point as input geometry. The powercopy is then instantiated in the original part.
- Subject C focuses on the design of a geometric component that is repeated and mirrored to create a spider clamp for a curtain wall. The subject defines a plane and a line, as the input to support sketches and other geometry. Additional planes with parametric offsets are created to support the sketch for the clamp component. A powercopy is created to test that all planes are referenced correctly. Sketches and pads are created to complete the model. A second test of the powercopy reveals that a sketch

in under constrained, and that the sketches of the circles are constrained to the absolute axis. Subject proceeds to edit the constraints and redefining the support of sketches to have a correct instantiation of the powercopy. Additional errors are encountered in the instantiation of the powercopies; mirroring the geometry is done to complete the overall clamp. Subject spends 11 hours to complete the task, with 3 hours devoted to editing constraints.

- Subject D designs a system of pivoting panels embedded in an exterior wall, as a series of coplanar planes for each pivoting panel. The initial design idea is a wall system with rotating panels of equal shape and dimension. The concept changes to an interactive wall with panels of different shapes. Reference planes and a grid of lines are created to support different planes. This grid is later not used. The model for the pivoting panels begins with a sketch for the outline of the wall. A separate sketch is created for the pattern of pivoting elements. A pad and pockets are generated. The sketch is copied and separated into 9 geometrical sets for each panel. Pads are created for the panels. The rotation of the panels is tested. New planes, at parametric angles from the ZY plane, are created to support each sketch. To achieve the proper rotation, the point of origin of each sketch is to be the pivot point. Errors are still encountered when rotating planes at 0 and 180 degrees. To prevent the sketches from “flipping”, 1 and 179 degree angles are used.
- Subject E proposes the design of a vertical partition with adjustable openings, as an array of paired triangular elements. The design idea is to control the complexity of the system using a “simple geometrical unit”, with variations in aperture to create an undulation of the initial closed partition. Through trial and error, the subject determines the appropriate geometric structure and parametric definition of the first unit. One triangle is created with 3 lines, a fill surface, an offset surface, and 3 developable surfaces to created edges. The triangle is mirrored along the hypotenuse edge. Three additional units are created, forming a quadrilateral structure of static and pivoting triangles for the openings. A powercopy of this component is then instantiated as grid array.

## DISCUSSION

In the curtain wall exercise, teams used similar strategies for the detail design of the parametric component. Teams 1 and 3 had one meeting for planning the system implementation before starting to model. The subjects in these 2 teams worked separately on their tasks. The subjects in Team 3 had one planning meeting, and scheduled time to work together on similar tasks. They found this approach helpful to troubleshoot and continuously assess their design goals. Team 1 uses scripting to define the parametric behavior of the points along the curved surface and to automatically generate input planes and lines. Team 2 and 3 create rules to check the valid insertion angles for the components. The teams differ in their choice of parametric definition for the component. Team 1 and 2 created user defined features, which only allows the user to change the top-level parameters. Team 3 created powercopies, showing the entire component tree structure, and therefore enable the user to change all parameters. All teams imported profile drawings found in the manufacturer’s website, and edited the profile.

In the kinetic component exercise, all subjects took time before modeling, to breaking down the design into geometric parts, and planning a modeling strategy. All subjects test the parameters of the model at different times, to identify errors. During testing, some subjects refine the original design concept. Subjects A and E conduct test early and spend less time editing and correcting errors, and show a more developed design.

Although the design of Subject D appears to be very simple, 50% of the time is spent in editing the support of the sketches to achieve the desired rotation. All subjects express the need for scripting to avoid manual iteration of steps. Scripting is not part of the 2-week course.

## CONCLUSION

The process of concept design using a BIM tool involves a) analysis and planning, b) input geometry and parametric definitions, c) 3-dimensional modeling, d) parametric testing, and e) redefinition or revision. We find that analysis and planning are embedded in the work of design teams coordinating tasks; and when individual designers take time to analyze the geometric structure and parameterization before beginning the model, they spend less time correcting errors. Without preliminary planning, individual designers engage in a process of trial and error. We conclude that a deeper understating of how to represent geometry in CAD systems is necessary, in order to reduce errors in modeling. During modeling, we describe as testing, the verification of parametric definition and the visual analysis of the design. Testing occurs as a transition between sub-tasks. As a result of testing, designers redefine, revise, and refine their design ideas.

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