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Testing the Relevance of Parameterization to Architectural Epistemology

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Abstract: Advances in building information modeling (BIM) deeply impact the production of new architecture; its benefits are obvious and its acceptance widespread. But how does BIM impact the study of existing architecture? Can BIM be assumed to operate as a neutral framework, equally applicable to the study of architecture anywhere? Using as a point of departure a recent outline of the conceptual structure of parametric modeling prepared by Sacks, Eastman, and Lee (2004), this paper compares parametric models of two existing works of architecture: Mies van der Rohe's Crown Hall and Peter Zumthor's St. Benedict Chapel. The processes of parametrically modeling each building are specifically compared in two ways: first, parameters are established for each model; second, each model is "flexed" as a means of disclosing possible semantic relationships within each work of architecture. Because each building demands a different parameter-establishment strategy, and because the models permit different degrees of flexibility, the comparison illustrates the shortcomings of a "neutral framework" assumption to an architectural epistemology.

Keywords: Existing architecture, Parametric modeling, Representation

Introduction

The epistemological relevance of architectural researchers' selection of study media is a well-explored question (Bermudez & King, 2000; Hewitt, 1985, Crowe & Hurtt, 1986; Leatherbarrow, 1998; Porter, 2004). In particular, it is widely acknowledged that specific media are uniquely capable of disclosing significant attributes of works of architecture, and that in some cases, these attributes are strongly tied to a specific medium. Consider the study of an existing work of architecture using traditional (i.e., non-digital) tools such as a pencil, straightedge and compass. As a means of studying a building, such as St. Paul's Cathedral in London, the tools are well suited insofar as they enable the straightforward translation of observation to paper. However, the same set of tools is likely to be poorly suited for studying Frank Gehry's Guggenheim Museum in Bilbao, the geometry of which is difficult to register with traditional tools. This simple observation obviously reflects formal differences between two buildings conceived at different times using different technologies, but more importantly, it suggests that existing works of architecture can be differently susceptible to being studied in a specific way (i.e., using a fixed set of tools). The comparison indicates that study media are not neutral epistemological frameworks: *researchers' choice of study media limits the kinds of questions they can ask of architecture.*

Building information modeling (BIM) software is marketed to the architecture profession primarily as a tool to aid the design and construction administration of new buildings. BIM has obvious benefits and widespread acceptance throughout the profession. A principal component of BIM is parametric modeling, which enables modelers to establish a deep layering of architectural fragments, components, assemblies, and sub-assemblies, fully categorized and cross-referenced, and capable of automatically propagating changes to linked components. Moreover, BIM is proposed as a means of transparent information exchange: the United States National Building Information Modeling Standard calls for a "standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable [sic] by all throughout its lifecycle" (NIBS, 2005). The current trend in BIM is to establish means by which the constituents of the construction industry (e.g., architects, engineers, contractors, agencies, owners) can freely exchange information in a digital form during design and construction of a work of architecture (Plume & Mitchell, 2007). It is obvious that software interoperability development depends on BIM becoming wholly transparent as a means of supporting the seamless exchange of information between constituents.

These observations, coupled with the substantial contemporary interest in the use of parametric modeling as a tool for the study of existing architecture (e.g., Barrios, 2004; Barrios, 2005; Burry & Burry, 2006; Potamianos & Jabi, 2006; Potamianos, Turner, & Jabi, 1995), prompts the question of whether all existing works of architecture are equally susceptible to the kind of studies which parametric modeling can productively support. Can parametric modeling, or BIM generally, be assumed to operate as a transparent or neutral framework, equally applicable to the study of architecture anywhere?

This paper considers this question by examining:

(a) How a process of parametrically modeling existing works of architecture may demand strategies unique to specific works.

(b) How such a process may be capable of revealing architecturally significant attributes not otherwise obvious.

BIM and Existing Architecture

Exploring the implications of parametric modeling to the study of existing architecture requires a review of the conceptual structure of BIM. The recent overview conducted by Sacks et al., (2004) provides a point of departure from which we can extend observations specifically to parametric models of existing works of architecture. For this and the following discussion, we introduce the term "EB model" to refer to a parametric model of an existing building, as distinct from one of a new building, for which we introduce the term "NB model".

Design Intent and Semantic Relationships

Sacks et al., (2004) write that:

"Parametric modeling makes a significant contribution to design in that, along with solid modeling, it allows modelers to generate computer representations of physical objects not only as they look, but *also to define semantic relationships* between the objects' representations..." (Sacks et al., 2004: 295) [emphasis added]

Following Sacks et al., (2004), we can assume that semantic relationships within NB models explicitly incorporate original design intent. However, with the exception of cases where intent is explicitly known and modeled, the semantic relationships (i.e., the parametric constraints) within EB models cannot be expected to explicitly incorporate original design intent. Instead, the establishment of semantic relationships within an EB model is simply a way of concretizing *assumptions* about unknown or imperfectly known attributes of the existing building.

Existing Documentation and "top-down" vs. "bottom-up" Modeling

In distinguishing between possible processes for constructing parametric models, Sacks et al., (2004), describe "top-down" and "bottom-up" modeling (Sacks et al., 2004: 297). A top-down model begins with an explicit definition of a whole product (e.g., a projected work of architecture) and proceeds through refinement to detailed parts, while a bottom-up model reverses the approach. To the degree that the act of modeling an existing building requires translations of existing documentation, or of direct observations of a completed product, into a model, we can expect that EB modelmakers can productively employ bottom-up processes. However, documentation of existing buildings tends to be limited; it is often contradictory or inconsistent; and in those cases where the subject building is wholly or partially inaccessible, direct inspection alone will fail to provide a modelmaker with sufficient information to construct a robust bottom-up model. Whether an EB modelmaker can productively construct a bottom-up model therefore seems to depend on the thoroughness, accuracy, and consistency of existing documentation in reference to the subject architecture.

Anticipated Change and Modeling Function

Modeling function is the representation of functional relationships between modeled elements (Sacks et al., 2004: 298-299). There are practical reasons for modeling function within an EB model: for example, a properly functional EB model can be used to test possibilities for building renovation, as when existing load-bearing walls must be removed to permit new construction. Or, if an EB model is constructed to adapt its structural configuration in response to simulated loads, it can help researchers isolate the original designer's reasons for selecting a specific structural solution. In addition, if an EB model includes correctly modeled function (i.e., properly corresponding with the physical limitations on materials), it can be *flexed,* or dynamically tested to reveal the extents of its parametrically constrained flexibility. The act of flexing a given model can in this way reveal the functional limitations on the original designer's options. It follows that an EB model with correctly modeled function should exhibit a certain *degree of flexibility* (i.e., that it should be capable of expansion or compression over a specific range before exceeding its constraints). The difficulty of establishing a uniform metric for the degree of flexibility stems from its dependence, at least in part, on constraints established by the modelmaker. For example, a modelmaker could establish a wholly arbitrary constraint on overall building area or volume, preventing the model from being expanded beyond a certain size.

Inhabitation and Occlusion-Based Constraints

Sacks et al., (2004) do not explicitly discuss parametric modeling constraints related to visibility and occlusion. An example of such a constraint is the situation of a specifically defined sight-line or angle of vision which must be maintained from one point within the building to another (see, for example, Potamianos, Turner & Jabi, 1995) or from a point within the building to a point outside the building. Such constraints are common in architectural design; to refer to them here we introduce the term *occlusion-based constraints*.

Illustrating the Application of BIM

Modeling the Subject Buildings

The preceding observations and assumptions are illustrated through a comparative analysis of two parametric models, constructed by this paper's author using commercially available BIM software (Autodesk Revit). The first model is of Mies van der Rohe's Crown Hall on the campus of IIT in Chicago, Illinois; the second model is of Peter Zumthor's St. Benedict Chapel in Sumvitg, Switzerland. Documentation of both buildings is freely available from public sources, though Crown Hall is more widely published. Sufficient information is available for both buildings to enable the construction of detailed "bottom-up" models (Sacks et al., 2004).

Establishing Parameters for Crown Hall

Crown Hall, designed by Mies van der Rohe, was completed in 1956 as the home of the School of Architecture at the Illinois Institute of Technology (Fig.1).

Figure 1: *Crown Hall. Source: By author.*

Consider the following general observations about the building:

1. The exterior perimeter of the main floor, with the obvious exception of the front and rear entrances, is structured using a repeating window-bay component employing upper panels of clear glass and lower panels of translucent glass (Fig. 2, left). Registering the degree to which the architecture relies on standardized parts, the window-bay component contains a small number of extruded profiles and is hierarchically structured.
2. The structure of the building includes four identical steel frames spanning a column-free space (Fig. 2, center). At the perimeter, the columns of each steel frame are aligned to correspond to window bay mullions.
3. The building exhibits a dense concentration of parameters at each of four identical exterior corners (Fig. 2, right). The corner of the building establishes the basic relationships, which reappear hierarchically and symmetrically around the perimeter of the building.

In response to these observations, the parametric model of Crown Hall was designed to reflect three primary attributes of the building:

(1) A high degree of repetition.
(2) A strongly hierarchical component structure.
(3) Locational concentration of parameters, specifically at the building corners.

Flexing the Crown Hall Model

Compressed and stretched versions of the original building can be easily generated by adjusting the value of specific parameters at the building perimeter (Fig. 3). Each of the distorted versions of Crown Hall embeds contextual design intent by selectively preserving specific fixed relationships (e.g., at the building corners) while allowing others to vary (e.g., the depth of the spanning beams increasing as their span increases).

As the building model increases in size, the average distance from the exterior wall to the center of the building increases correspondingly. As this distance increases, the sectional angle of vision from a point at the center of the building becomes narrower (Fig. 4). This suggests a specific kind of structuring of visibility present in the architecture and raises the importance of establishing an *occlusion-based constraint* within the model.

Such a constraint, if modeled, could limit a particular angle of sectional visibility to a fixed minimum, effectively preventing the model from being expanded beyond a certain size. In this way, the occlusion-based constraint would function like a constraint on beam depth, limiting a beam from spanning too far. The relevance of this observation is simply that the use

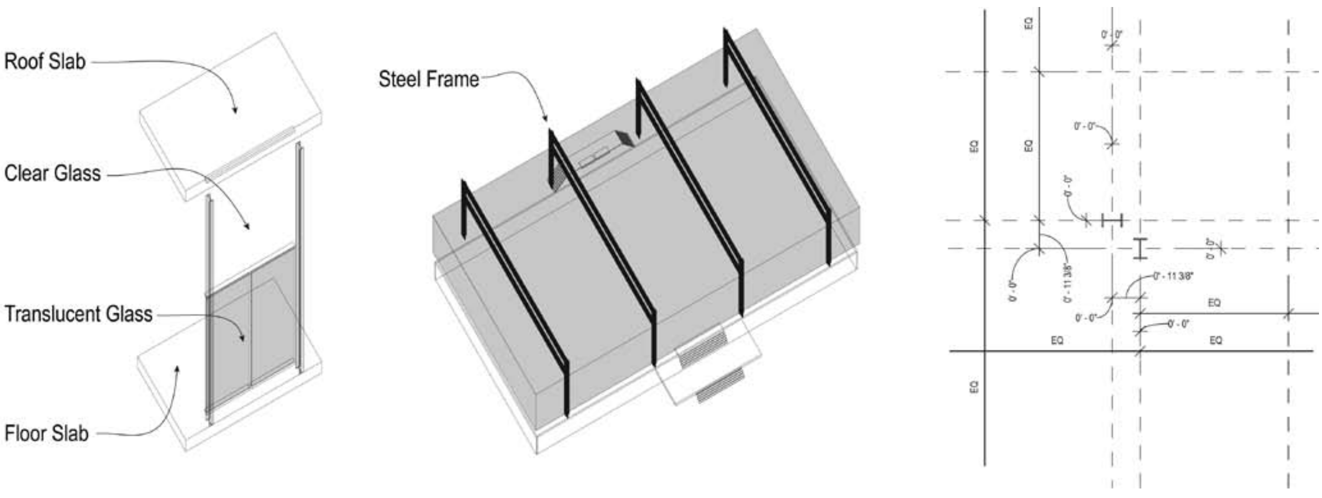

Figure 2: *Uniform perimeter bay (left); steel frames (center); parameters at building corner (right). Source: By author.*

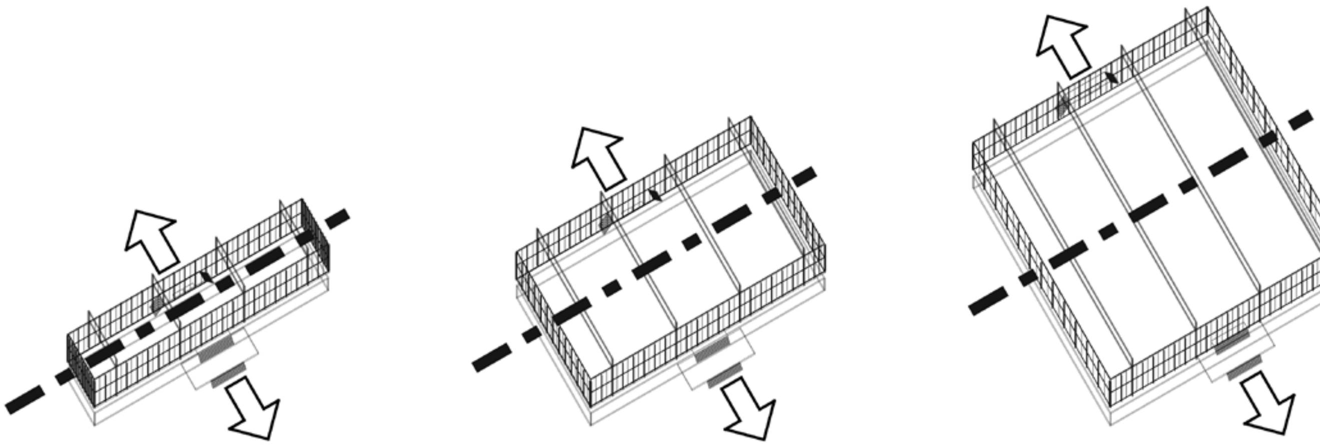

Figure 3: Compressed configuration (left); existing configuration (center); expanded configuration (right). Source: By author.

of parametric modeling software disclosed an architecturally significant attribute, which was not otherwise obvious: the necessity of a parametric constraint on the sectional angle of vision.

Establishing Parameters for St. Benedict's Chapel

St. Benedict's Chapel in Sumvitg, Switzerland, was designed by Peter Zumthor and completed in 1988 (Fig. 5).

Consider the following general observations about the building:

1. Its exterior enclosure, with the obvious exception of the single entrance, is bilaterally symmetrical about its center (Fig. 6, left). The building foundation includes variation to account for an uneven site.
2. The leaf-shaped floor plan of the building describes a curve, at least two segments of which approach parabolas, and which can be approximated on circles (Fig. 6, center). Construction documents establish the curve by a metes method (i.e., by providing the length of each straight segment of the exterior wall).
3. The exterior wall at the main floor level includes thirty-six identical vertical column assemblies (Fig. 6, right). These column assemblies are apparently equally distributed around the perimeter; however, careful inspection shows that there is a progressively pronounced narrowing of their distribution at the rounded end of the building.
4. The roof includes a single ridge beam, which follows a non-trivial curve in section (Fig. 6, right), as well as several rafters (Fig. 7). The outer ends of the rafters rest on the exterior column assemblies and the inner ends tie to the ridge beam. One end of the ridge beam coincides with the pointed end of the building while the opposite end is held away from the rounded end of the building. Considered in plan, the perpendicular relationship between the rafters and the exterior skin is constant (Fig. 7, left), but because the column

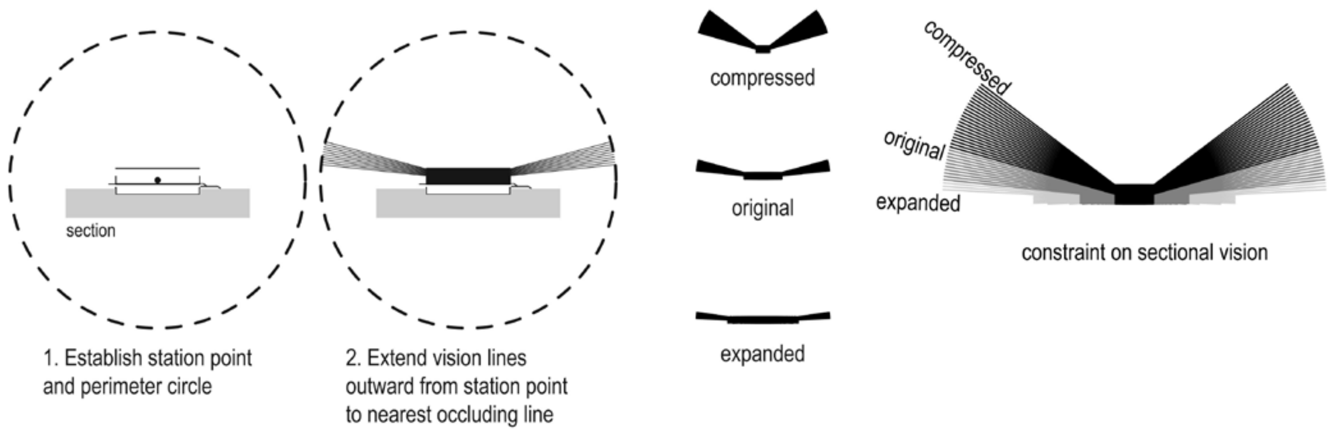

Figure 4: Changes in sectional angles of vision in model of Crown Hall. Source: By author.

Figure 5: *St. Benedict's Chapel. Source: (Binet & Zumthor, 1999)*

assemblies are placed at varying distances from the ridge beam and because the exterior surface of the building follows a changing curve, the length and slope of each bilaterally symmetrical pair of rafters is unique (Fig. 7, right).

In response to these observations, the parametric model of St. Benedict's was designed to reflect the following attributes of the building:

(1) Strong bilateral symmetry.
(2) A non-constantly curved exterior wall divided into unequal segments.
(3) Rafters which are constrained to remain perpendicular to the skin while their length and slope are permitted to vary.
(4) A ridge beam which maintains a fixed relationship to the building ends.

Flexing the St. Benedict's Model

The curve at the building perimeter is highly sensitive to flexing, though this becomes apparent only as changes to its shape in plan affects the configuration of the rafters. A flexed model (Fig. 8) quickly generates rafters, which are incapable of simultaneously remaining perpendicular to the skin and intersecting the ridge beam. This failure upon slight change to maintain basic parametric constraints suggests a very narrow degree of flexibility at St. Benedict compared to Crown Hall.

As also seen at Crown Hall, changes in the perimeter of the building model have an effect on sectional angles of visibility. Figure 9 shows the changes in these angles corresponding to expanded, original, and compressed configurations of the St. Benedict model. Each set of diagrams was generated from transverse sections taken at regular intervals across the space. (We use the term "occlusion map" to refer to a set of such

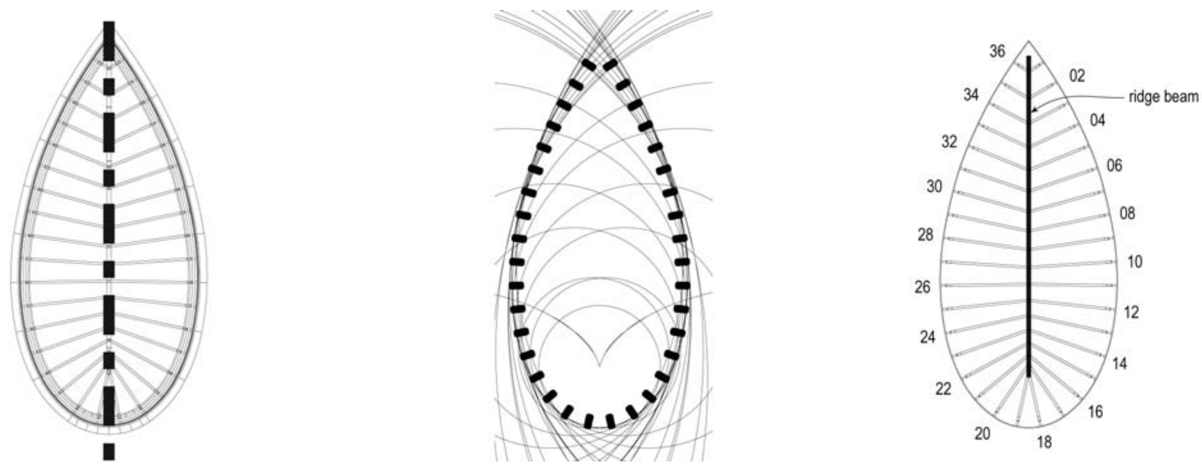

Figure 6: *Bilateral symmetry (left); approximation of curves (center); column assemblies and ridge beam (right). Source: By author.*

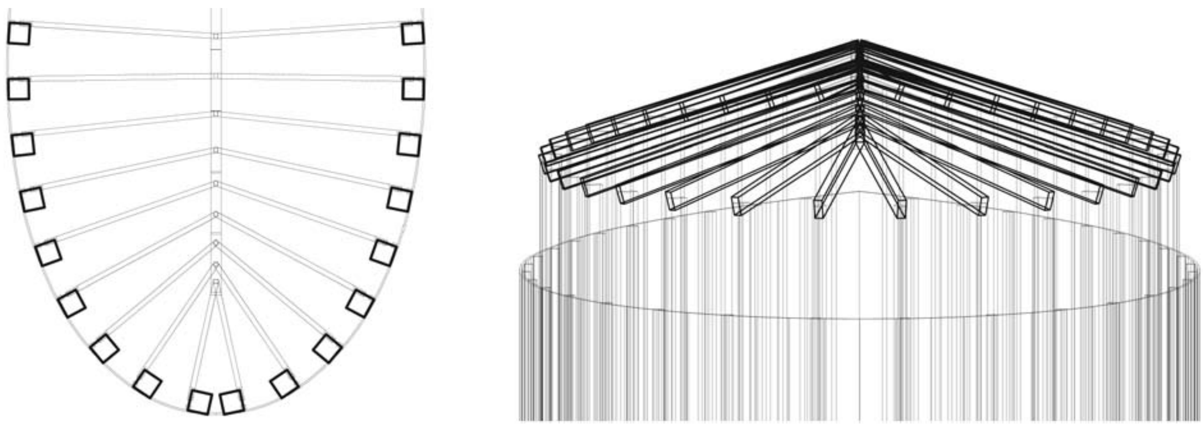

***Figure 7:** Consistent rafter configuration in plan (left); varying rafter configuration in section (right). Source: By author.*

diagrams.) The larger the space becomes, the more the clerestory windows tend to frame views outward toward a horizon and less toward the sky; the precise constraining of which may be significant for liturgical reasons.

Conclusion

Each of two existing buildings were modeled using parametric solid modeling features in commercially available BIM software. In the process of modeling each building, specific approaches to modeling were identified and employed in response to observations taken from existing documentation. These approaches were designed to permit selected semantic relationships within the models to vary. Comparison of the two models prompts the following conclusions:

1. Each of the two subject buildings necessitated a different tactical approach for establishing parameters. The difference derived primarily from differences in building geometry: Crown Hall is organized on a rectilinear grid while St. Benedict is organized on non-trivial curves.
2. As a consequence of their specific parameters, each of the resulting models permit different *degrees of flexibility*. Crown Hall's parameters enable a wide range of possible configurations without exceeding established limits on semantic relationships. However, flexing the St. Benedict model is possible over a much smaller range than the model of Crown Hall.
3. Varying the established semantic relationships within each model highlighted other architecturally significant relationships within the subject works of architecture, which were not obvious before model construction. In both cases, we considered the example of angles of sectional visibility and the possibility of establishing a constraint on these angles.

These points suggest that semantic relationships may be established in EB models which may not explicitly reflect original design intent, but which instead constitute disclosures of *latent though significant architectural attributes,* such as a building's degree of flexibility or the necessity of constraining sectional vision (e.g., for liturgical reasons). We conclude that the use of parametric modeling in the study of existing architecture constitutes an opportunity to *reveal possible semantic relationships* within a subject work of architecture. Because

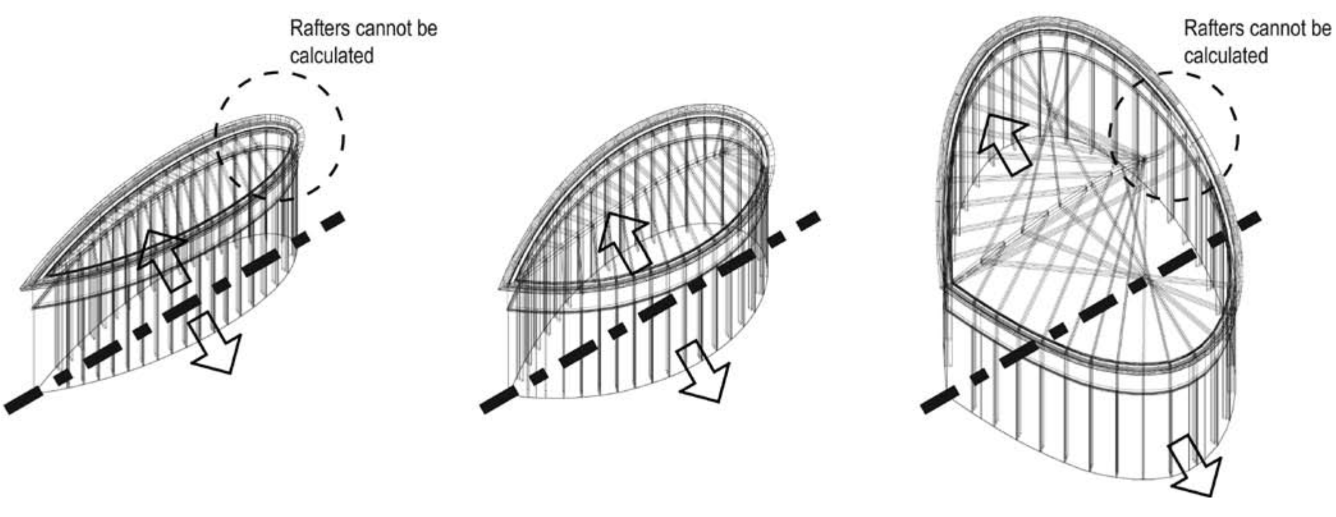

***Figure 8:** Compressed configuration (left); existing configuration (center); expanded configuration (right). Source: By author.*

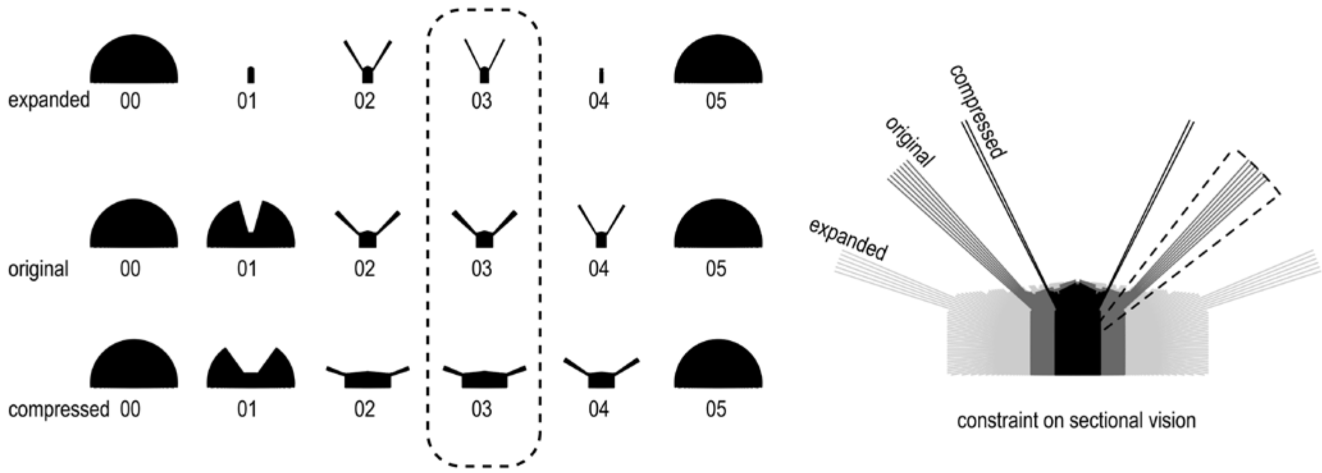

Figure 9: *Changes in sectional angles of vision in model of St. Benedict. Source: By author.*

of its ability to disclose unanticipated attributes in modeled works of architecture, a transparent or "neutral framework" assumption for BIM does not seem viable. Future work in this area should attempt to categorize and prioritize the different kinds of studies which parametric modeling can productively support.

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