DISCIPLINES & DISRUPTION

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PROCEEDINGS

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Representing the Aesthetics of Richard Meier's Houses Using Building Information Modeling

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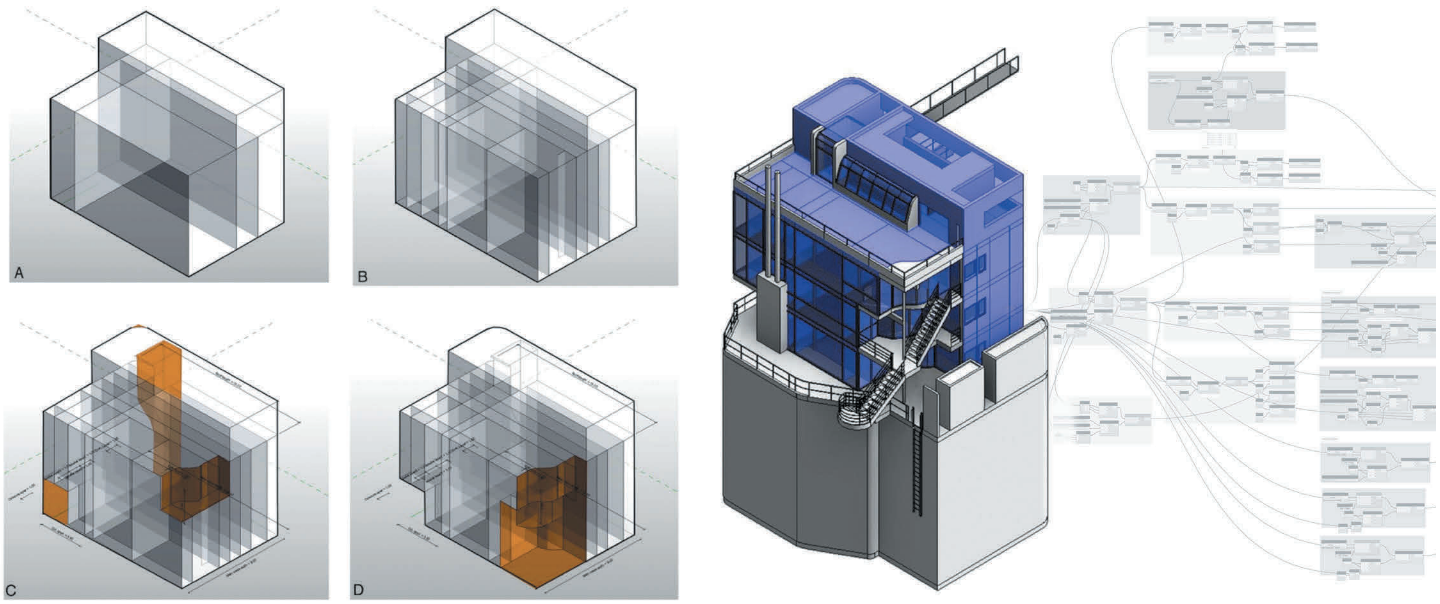


1 The Douglas House: modeled in BIM (Autodesk Revit) and Dynamo

ABSTRACT

Beyond its widespread use for representing technical aspects and matters of building and construction science, Building information modeling (BIM) can be used to represent architectural relationships and rules drawn from aesthetic theory. This research suggests that BIM provides not only vocabulary but also syntactical tools that can be used to capture an architectural language. In a case study using Richard Meier's language for single-family detached houses, a BIM template has been devised to represent the aesthetic concepts and relations therein. The template employs parameterized conceptual mass objects, syntactical rules, and a library of architectonic elements, such as walls, roofs, columns, windows, doors, and railings. It constrains any design produced using the template to a grammatically consistent expression or style. The template has been used as the starting point for modeling the Smith House, the Douglas House, and others created by the authors, demonstrating that the aesthetic template is general to many variations. Designing with the template to produce a unique but conforming design further illustrates the generality and expressiveness of the language. Having made the formal language explicit, in terms of syntactical rules and vocabulary, it becomes easier to vary the formal grammar and concrete vocabulary to produce variant languages and styles. Accordingly, this approach is not limited to a specific style, such as Richard Meier's. Future research can be conducted to demonstrate how designing with BIM can support stylistic change. Adoption of this approach in practice could improve the consistency of architectural designs and their coherence to defined styles, potentially increasing the general level of aesthetic expression in our built environment.

INTRODUCTION

Although building information modeling (BIM) has achieved widespread acceptance in support of the architectural production process, scant attention has been given as to the best means to capture and express formal and aesthetic information within BIM. Nevertheless, an ambition for a complete model of an architectural work must clearly be an ambition to include formal qualities that address aesthetic theory. As a test case of whether BIM is adequate for representing formal qualities of architecture, we have mapped the syntactical relationships and vocabulary of Richard Meier's style for detached houses into a BIM template. Using BIM, two fundamental concerns in design, the *analysis* of styles in design and the creation or *synthesis* of new designs, are addressed in this research. The analysis of Meier's houses and production of the BIM template reveal insights into the architectural language of the houses. The template aids in the rapid production of house designs that are either duplicates of those actually done by Meier or are grammatically consistent new designs. This research has implications for dramatic and even disruptive change in both architectural practice and education.

Architectural theorists have long made a distinction between building and architecture, asserting that building is a translation of practical, functional requirements and socioeconomic conditions into physical constructions, and relies upon the idea of usefulness, while architecture further addresses an intellectual dimension (Winter 2002; Hendrix 2012).

We suggest that BIM not only provides a vocabulary but also syntactical tools that can be used to capture and enforce an architectural language, aiding a designer in the creation of successful and consistent expressions. BIM can represent a formal language explicitly and provide a generative description of an architectural style. In addition, this paper is part of an ongoing research project that aims to explore and develop a pedagogical shift to integrate BIM technology and design theories to prepare students for emergent digital design methods. BIM is used to address analysis and synthesis in architectural design education to teach multiple skills in a coordinated way. In some sense, we are exploring an *architectural information model (AIM)* for representing architectural languages. Analyzing the Douglas House by Richard Meier, representing it as a template within Autodesk Revit, and creating designs with the template has enabled us to support a conclusion affirming this hypothesis.

BACKGROUND

Our research is based on foundations in architectural aesthetics, BIM theory and tools, and writings on Richard Meier's architecture.

Aesthetics and Architectural Language

Rather than claim generality to all architectural aesthetic theories, we have focused upon the notion that an aesthetically appealing architectural expression relies upon conformance to a coherent style that can be understood in terms analogous to a language (Norberg-Schulz 1965; Knight 1981; Forty 2000; Hillier 2007). Language is defined as a formal system of signs structured by grammatical rules of combination or syntax to communicate meaning. This definition, which stresses the necessity of rules to convey meaning in language, was first introduced by Ferdinand de Saussure between the years 1906 and 1911 in *Course in General Linguistics* (Agrest and Gandelsonas 1973; Nesbitt 1996). Norberg-Schulz defines the formal language of architecture as "all the elements, relations and structures which form a meaningful system," employed in such a way that "f*orms are given with meanings*" (1965, 184). Knight (1981) has offered a similar definition, in which architectural design can be understood, compositionally, as a complex of vocabularies governed by grammatical spatial relations. We will use *architectural language* to denote not a universal means of creating architecture, but as a particular limited family of dialects that are tied to a particular time and culture. Thus, there is a Palladian language, a Wrightian language, a Miesian language, and a proliferation of architectural languages associated with one or more architects. Therefore, architectural language is considered a formal equivalent to the notion of *style* in architecture (Knight 1995).

The use of an architectural language opens the door to imbuing a building with meaning, crossing the line into architecture. A work of architecture acts as a self-referential sign that can communicate formal, intellectual, spiritual, or expressionistic ideas (Gadamer 1986; Goodman 1976; Hendrix 2012; Norberg-Schulz 1965). Our research is focused upon vocabulary and syntax but does not address lexical semantics or conceptual semantics.

Definition and Derivation of an Architectural Language

One must begin with an architectural language to explore whether that language can be represented in a particular modeling environment. The discovery or definition of a language involves two operations: *dissection* and *articulation* (Barthes 1972).

First, to *dissect* an object is to find in it reusable fragments or vocabularies whose differential situation produces a specific meaning and forms a specific class or *family* with a specific relation of affinity and dissimilarity (Barthes, 1972). In architecture, the vocabulary of a building includes its floors, walls, ceiling, partitions, doors, etc., but may also include abstractions such as a conceptual mass, or a void. Accordingly, before the design elements are fixed as a composition, each *generic* element is subjected to transformational rules that can generate a virtual group of instances that are similar but distinct.

Second, in the activity of *articulation* the architects/designers establish certain rules of association or combination for the separate parts of the composition (Barthes 1972). We can identify two types of these rules: *syntax* and *configuration*. The syntactic relations in architecture are similar to those in linguistics, where they associate the different elements together; therefore, syntax defines a relation between elements. For instance, using a modular system and proportions as well as axes to locate elements in relation to each other are examples of this type of relation. On the other hand, configuration refers to the overall pattern of relations, not only in terms of pairs or single connections, but also with respect to the overall form (Peponis, Zimring, and Choi 1990). Therefore, syntactical rules are "*subsets or aspects of a configuration*" (Peponis, Karadima, and Bafna 2003). Accordingly, the critical activity of articulation begins with syntactical steps that create subordinate sets of relations that are then configured into an overall pattern of relationships.

BIM and Aesthetic models

During the last few years, the adoption of advanced digital technology, such as BIM and generative design, have profoundly changed the process and product of architectural design (Ambrose 2009). BIM is object-based parametric modeling that represents architectural elements by parameters and rules in order to determine geometric and non-geometric properties, from the level of a single design element to the overall configuration (Eastman et al. 2008). In contemporary practice, BIM has the potential to be a single, intelligent digital model that supports many aspects of the design process, such as automated parts and assembly production, checking for spatial conflict, construction sequencing, material research and testing, performance assessment, cost estimating, design documentation, and visualization (Garber 2009). Most research focuses upon BIM as a tool for modeling technical aspects of architecture and building within this understanding of the scope of the technology.

However, BIM need not be understood merely as a tool for technical design and documentation; it is a design process and a way of thinking that could alter design education (Ambrose 2009; Clayton et al. 2010). According to Christenson, "the act of creating parametric building model in Autodesk Revit, a BIM application, requires that a designer be able to intelligently define relationships between and within building elements" (2006, 55-62).

Using Autodesk Revit as representative of BIM, the families of architectural elements correspond directly to the vocabulary of a language, while the constraints, reference lines, parametric relations, and conceptual masses may be used to define and apply syntactical rules (Clayton 2014). Autodesk Revit is thus a defensible and expedient choice for modeling an architectural language.

Meier's House Language as a Test Case

In studying formal language, researchers often start with a precedent, as a language is revealed by examining an expression that uses the language (Knight 1981; Flemming 1989; Knight 1999). *Style*, as a formal equivalent to architectural language, is composed of vocabularies and syntactical rules. An explicit definition of a style is essential to achieve stylistic change. A style can be transformed by changing the vocabulary and changing the rules through three operations: *rule deletion*, *rule addition*, and *rule change*. Therefore, a generative description of a style can be used not only to generate new designs but also new styles (Knight 1995). Accordingly, the proposed approach of using BIM in this research is not limited to one style. Each style can be exemplified in a BIM template by defining the syntax and the vocabulary of that style, and each template can be then transformed to generate new designs and styles. However, in this research we focus on using BIM to create multiple designs that express one style.

Our choice of a test case is guided by the need to choose an architectural work within a family of similar work that may be dissected and articulated to document the language. Richard Meier's work is unusual in that it has consistently employed a clear set of organizational principles that can be traced throughout a wide range of building types, and defines a formal language that has been investigated by many authors and researchers (Frampton 1975; Rykwert 1999; Dahabreh 2013). The Douglas House was a milestone in Meier's career, through which he formulated a consistent and mature formal language that persists throughout his later works (Dahabreh 2013). By dissecting and articulating the Douglas House, it is possible to derive Meier's architectural language.

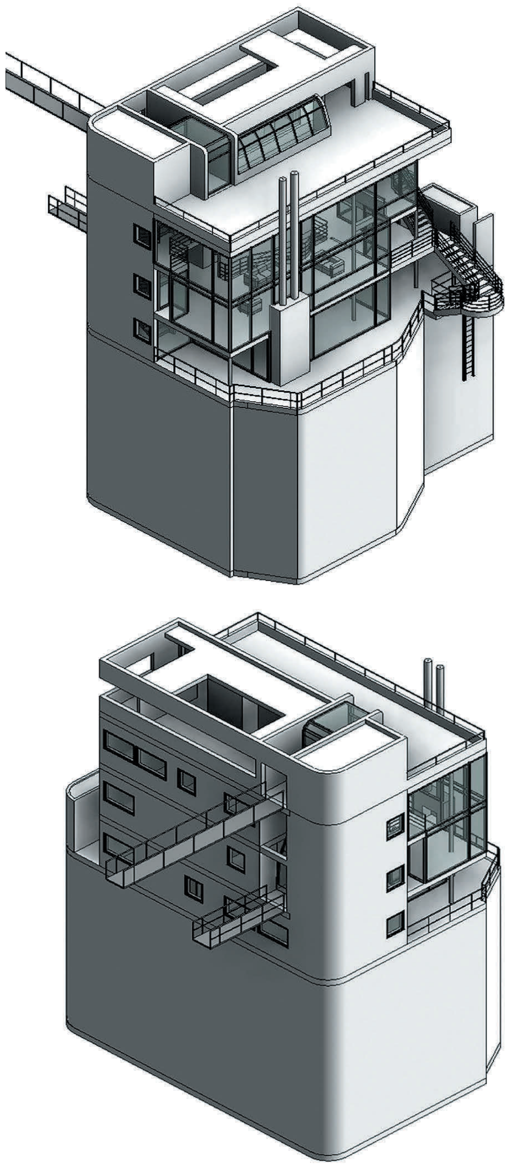
Meier developed his architecture based on the syntactic structure of *abstract* geometrical form. Meier's formal language uses abstracted vocabularies and a syntax that emphasizes modularity and proportion, axiality, frontality or spatial layering, duality, and syntactical centrality (Dahabreh 2013). The formative concept of frontality is a technique to create spatial stratification in "layered architecture." The established spatial layers are aligned perpendicular to the main access, creating a sense of progression (Flemming 1989). Syntactical centrality, distinct from shape-geometric centrality, refers to a process of spatial configuration that constructs an architectural space (Hillier 1999). Syntactical centrality is typically a multi-volumetric space that implies the main function of the building with an open visual field that penetrates to the surrounding areas (Kweon 2002).

The Douglas House, designed and built between 1971 and 1973, is located on a steep slope in Harbor Springs, Michigan. The four-story house is perched on a site of evergreen trees like a machined object and can be accessed through a flying bridge at roof level. In July 12, 2016, the house received recognition of its architectural and historical significance by the U.S. Department of the Interior's National Park Service and has been included on the National Register of Historic Places (Figure 2).

The following paragraph decribes the syntax of the house, with words in italics emphasizing the syntactical concepts (Figure 3). The house was conceived as a white rectangular prism with a base of 51 x 30 ft. The overall geometry of the house is determined by a *module* of 3 x 3 ft. Columns follow a *shifted module* with a fixed interval of 12 ft. Beside the modular system, the main rectangular prism is divided by the *longitudinal axis* into *two paradoxical prisms*; a solid one that represents the private zones and a glass one that hosts the public zones. The private zones are located at the road-facing façade in the form of closed cellular spaces, while the public zones, such as the living room and dining area, embrace waterfront views as platforms floating in a multi-volumetric glazed enclosure. A *corridor* running parallel to the lake mediates these zones on each floor. The dialog between the binary oppositions of private and public is reflected in the facades' treatment and the type of structure in each zone. The private zone is marked by *opaque walls* fenestrated by few windows and *load-bearing walls*. In contrast, the public zone is manifested by *glazed walls* and mullions aligned to the free-standing columns. The two prisms, public and private, are further divided into several s*patial layers* that are parallel to the longitudinal axis. In this spatially layered architectural expression, a *transverse axis* penetrates all the layers, defines the entry, and locates the chimney as well as the bridges. At the intersection of the two axes, a *syntactical center* is created as an expansive open zone by subtracting the floor *slabs* in the public zone. A series of formal additions and subtractions also takes place.

METHODOLOGY

We have used a worked example approach to investigate whether the tools and data structures of BIM can be used to represent a formal architectural language and expressions within that language. An initial step was to choose a test case. This test case was analyzed to derive a set of syntactical concepts. These concepts were then expressed in Autodesk Revit as reference planes and conceptual mass objects related to each other through parametric constraints. A vocabulary of elements



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The Vocabulary	
Conceptual/ Abstract elements	Architectonic elements
Masses: rectangular prism, cylinder	Public and Private sectors, cylindrical columns
Planes: horizontal and vertical planes	opaque walls, curtain walls, slabs, flat roof
Lines	mullions, handrails
Combined elements	Stairs, bridges, chimney, balconies
The Syntax / Configuration	
Module: 3x3 ft.	2 axes: Transverse and longitudinal
Frontality or Spatial layering	Duality: solid/void, public/private, subtraction/addition
Syntactical centrality	

3

2 The Douglas House: modeled in BIM (Autodesk Revit)

3 Table: the vocabulary and the syntactic relations in Douglas House

was created using *families* in Autodesk Revit to conform with the vocabulary used in the Douglas House. The syntactic framework was then used for the placement of elements to model the Douglas House in order to show that the framework could guide the production of a coherent and faithful architectural expression within the language. As an exploration of the generality and completeness of the syntactic framework, another house by Meier was modeled. As a final exploration, other houses were designed using the Meier syntactic framework and the vocabulary.

BIM(ING) THE DOUGLAS HOUSE

This section demonstrates the use of BIM to represent the formal language of the Douglas House. The method for representing the architectural language employs Revit's Conceptual Design Environment (CDE) to create conceptual mass elements, reference lines and planes, and parametric constraints that may be saved as a template. Revit Family Editor is used to create a vocabulary of conceptual design elements of Meier's architecture that can be used as additions in CDE. A vocabulary of Revit families for architectonic elements fosters the production of an architectural expression using the Revit project environment.

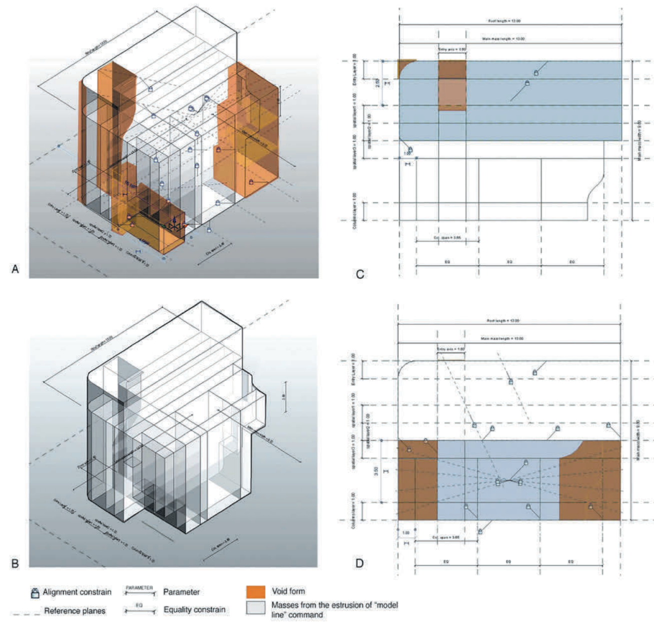
Modeling the Architectural Language

To model the architectural language behind the house, we explored two methods. The first method uses *only CDE* to create the conceptual mass while the second method integrates *CDE and visual programming* (Dynamo).

In the first method, we started by specifying the level of each floor. Then, we used the "model line" command to create two rectangular prisms to exemplify the public and the private zones. The boundaries of these two prisms are "aligned" and locked (alignment constraint) to four "reference planes." The distance between any two reference planes can be parameterized by using a specific number or a formula. After that, several "reference planes" were added to represent the spatial layering in the house in each zone. Using "model line," several planes were "created," "aligned," and locked to the reference plane of each spatial layer. These planes represent the entry axis, functional and spatial layers, as well as the column-span. Several parameters were added to these layers to control their width. Subsequently, a series of formal additions and subtractions to the main two rectangular prisms were implemented. A rectangular prism was added on the roof and its length and width are both controlled via parameters. Moreover, several subtractions were created to animate the mass via using "void form" (Figure 4).

In this BIM model, the syntactical relationships are represented by alignment constraints, equality constraints, and reference lines and planes. The overall conceptual mass, consisting of reference planes, mass objects, and void objects that are related together through parameter values, represents the form configuration and the grammar of the Douglas House. This grammar can be altered by adjusting parameter values, creating permutations of the Douglas House. In Figure 5, the table shows the list of parameters that elucidate how this model can be flexed. The BIM is not merely a single instance of a Meier house, but a language that allows for multiple expressive compositions.

Using CDE alone makes controlling the behavior of design parameters problematic because BIM is an object-based program that does not expose a coordinate system, and each object has implicit constraints that emerge from the way in which that object was modeled.



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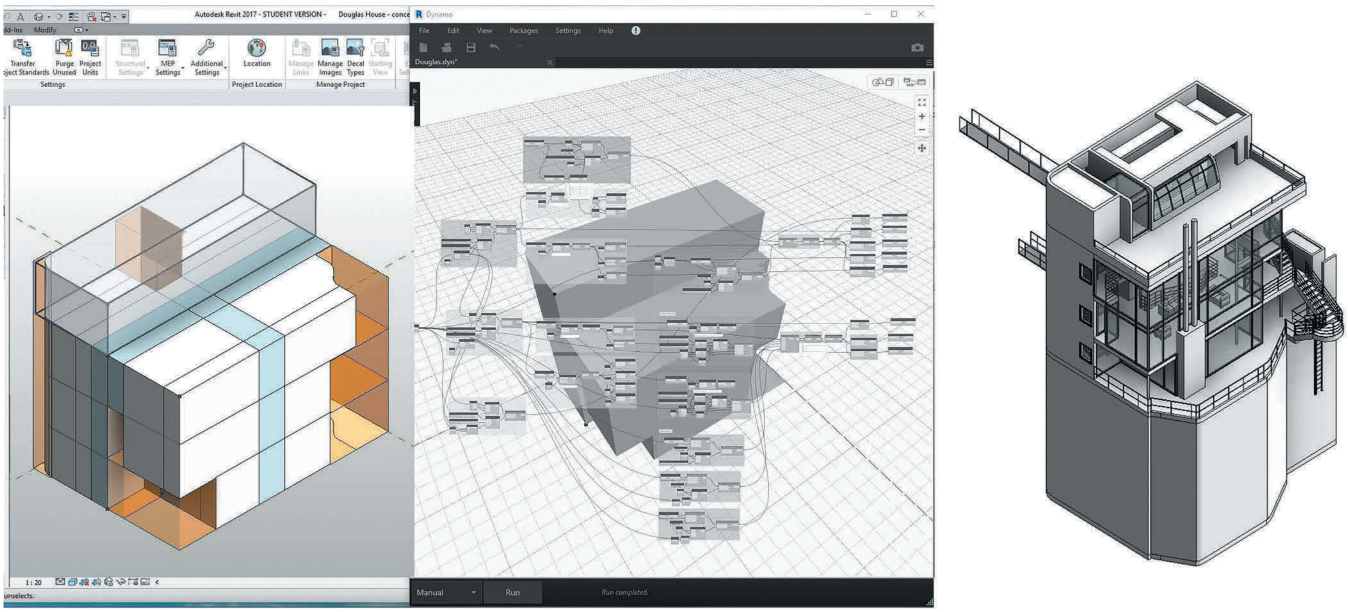
List of parameters	
Elements	**Parameters**
Levels	Level one, two, three, and four.
Public mass	Length parameter, width parameter (the height of the mass is connected to a level parameter).
Private mass	
The roof	
Entry axis	Width parameter
Spatial layers	Width parameter
Columns location	Span parameter

5

4 Modeling the conceptual mass of house in CDE (A & B), C: private sector, D: public sector.

5 Table: the list of parameters of the Douglas House using CDE



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List of parameters	
Elements	**Parameters**
Levels	Level one, two, three, and four.
Public mass	Length parameter, width parameter (the height of the mass is connected to a level parameter).
Private mass	
The roof	
Entry axis	Width parameter
Spatial layers	Width parameter
Columns location	Span parameter

7

6 Creating the Douglas House using CDE and Dynamo

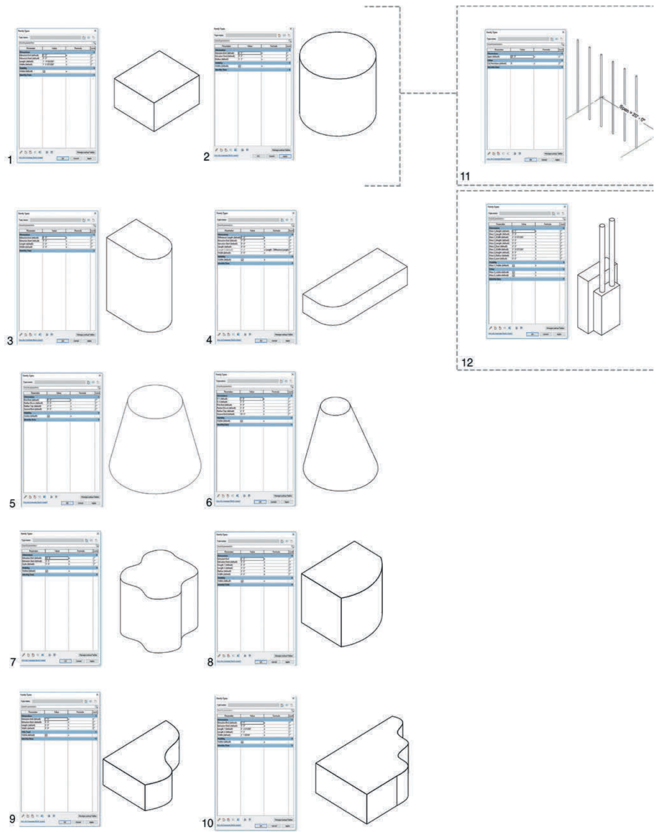
7 Table: the list of parameters of the Douglas House using CDE and Dynamo

Our second method utilizes visual programming (Dynamo) to create the conceptual mass in which all parameters and constraints are explicitly defined. We started by creating three rectangular prisms inside Dynamo. The location and the dimensions of each mass are controlled through parameters. A relationship between these parameters is established. For example, when the width of one mass increases, the location of the adjacent mass will change. The spatial layers and the transverse and longitudinal axes can be created by deconstructing the topology of each mass and creating offsets of the desired faces in the horizontal and vertical directions. Since the dimensions of each layer are connected to the dimensions of its mass, only the offset distance is controlled by an additional parameter. Voids were created either by importing 2D profiles from Revit or by creating them inside Dynamo (Figure 6). The location and the dimensions of these masses are controlled by parameters. In Figure 7, the table presents the list of parameters that suggest how this model can be flexed using CDE and Dynamo.

In Richard Meier's architecture, there is a common set of abstract geometries that he uses as additions to main mass of the building. In our research, we used the Family Editor in Revit to create a parametric library of those geometries as families. These families can be used to create combined elements or nested families (Figure 8). In CDE, any family can be imported as a geometrical addition and the parameters of that family can be altered according to the design. Then, all the imported families are aligned and locked to the vertical levels and horizontal layers in the main conceptual mass.

Douglas House Model

For the conversion of the conceptual architectural expression to a constructible building, the main conceptual mass that was created in CDE was loaded into the Revit project environment. It represents the overall configuration and the main organizational rules in the house. The built-in base object families represent the building vocabularies and each one has multiple parameters that *transform* it according to the design requirements. After we set the level of each floor, the elements within the *architectural vocabulary* of wall, column, slab, beam, roof, stair, railing, curtain system, and mullion were used to create a detailed architectural model by attaching and locking them to the conceptual mass (Figure 9). In this way, we preserve the relation between the abstract conceptual mass and the detailed specific form (Figure 10).



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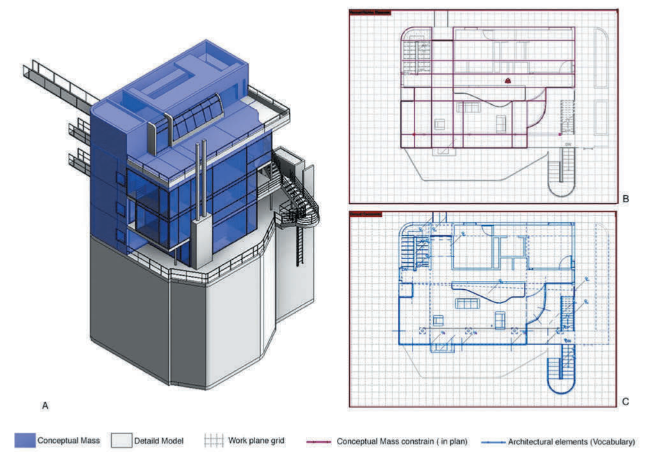

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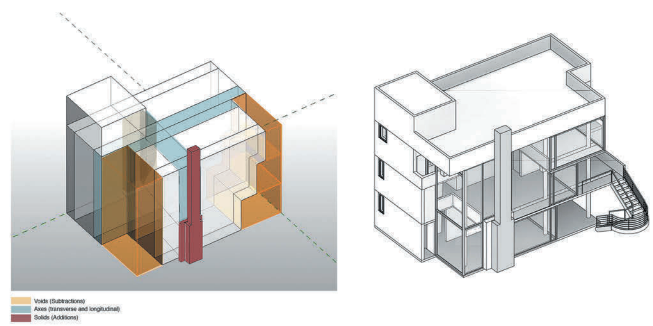

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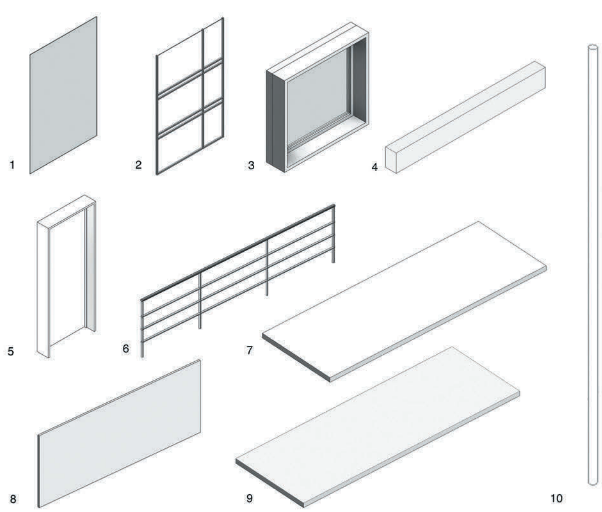
10 Detailing the model in project environment and the conceptual mass constraints

11 The Smith House



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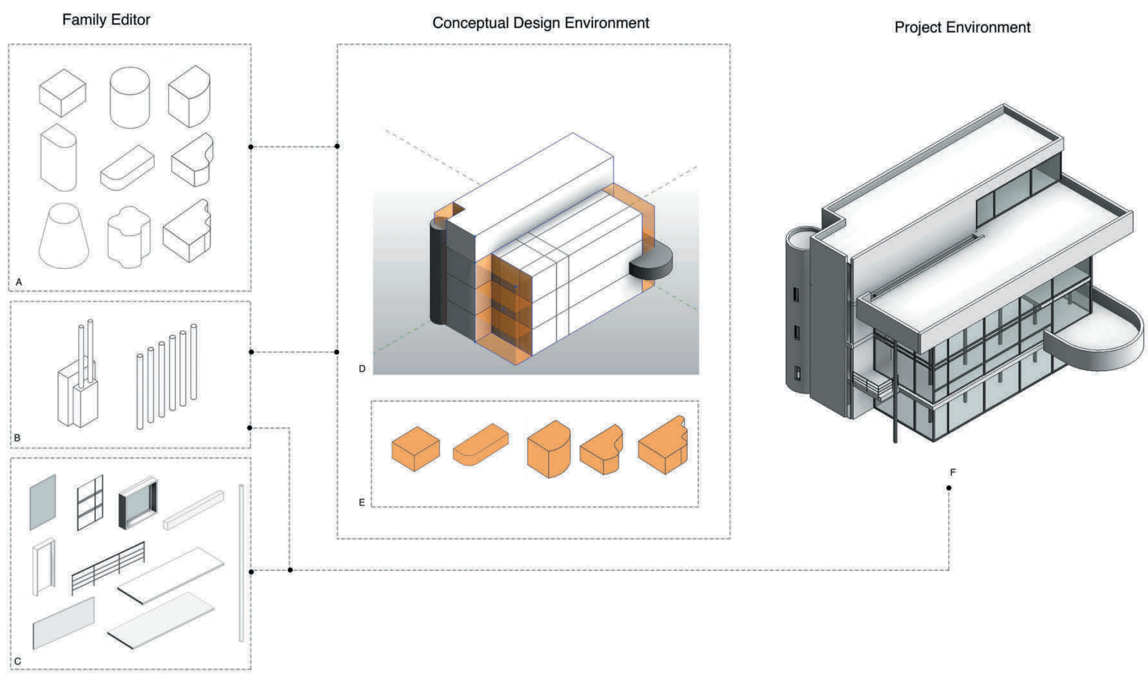
8 A parametric library of the abstract design elements in Meier's architecture in Revit family editors. Left: basic families, Right: nested families

9 A visual representation of the architectonic elements used in modeling the Douglas House in the project environment: 1. curtain wall, 2. mullions, 3. windows, 4. beams, 5. doors, 6. railings, 7. slabs, 8. walls, 9. flat roof, 10. circular column

While detailing the model, BIM offers many features that help us to organize and control the syntactic relation between elements. The most important one is "work plane grid;" which is a modular system with user control of spacing that applies not only while working on plans, but also on elevations, sections, and 3D. The second feature is alignment; an important example was using it to relate the mullions grid of the glazed façade with the internal organization of the house, such as the location of slabs and columns. Accordingly, any change with the location of these elements will be revealed on mullions pattern. Other features may include "Datum" in form of "grid" and "level" and grouping elements together.

Smith House by Meier

Many of Meier's houses shared the same underlying logic: two main rectangular prisms, a series of spatial layers, and two perpendicular axes that are composed into one conceptual mass and animated by a series of subtractions and additions. This logic can be found in the Smith House, which represents an earlier version of the Douglas House (Dahabreh 2013). In our research,



12 The workflow of using Meier's syntactic framework and vocabulary: the activity of dissection: conceptual vocabulary (A, B), Architectural vocabulary (C), CDE (D), subtractions or voids (E). The activity of articulation: CDE (D). A constructable building in project environment (F).

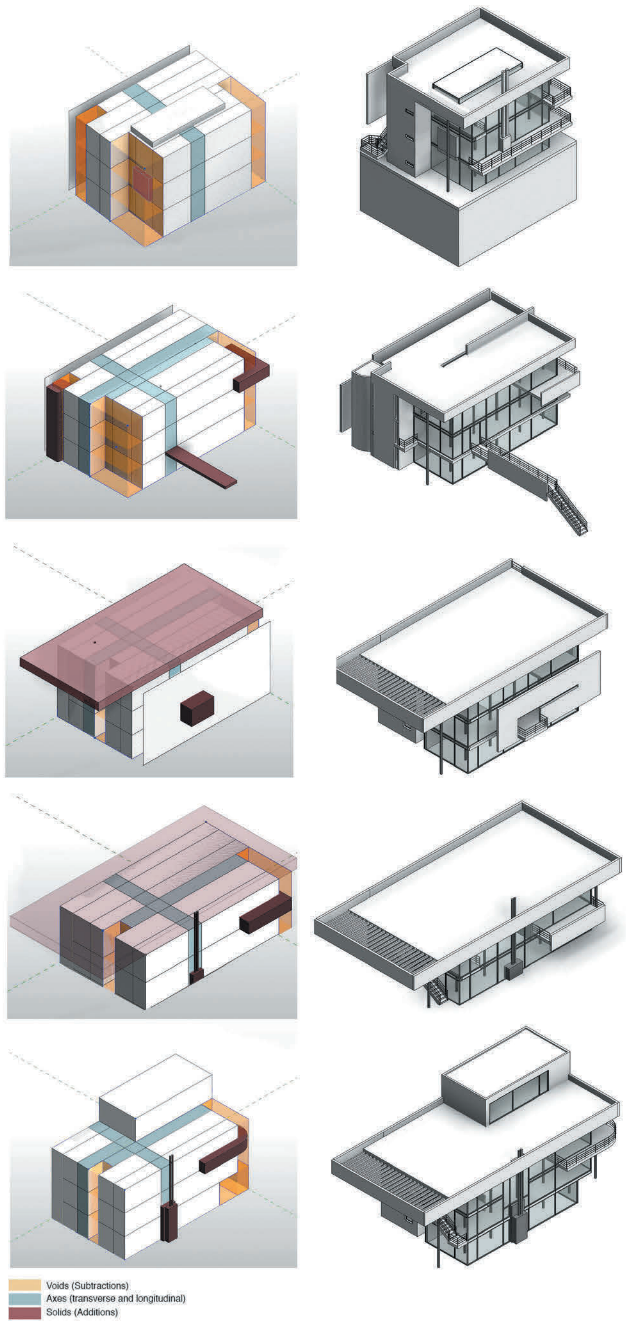
we used the same template of the Douglas House to create the Smith House. We changed the width and the length parameters of the public, private, and roof masses. The offset parameter of the spatial layers and axes was adjusted too. Additionally, the curvilinear voids were replaced by rectangular ones and the chimney family was also replaced by a different one. Then, the conceptual mass was reloaded to the same project file of the Douglas House to replace the old mass and overwrite its parameters. The walls, slabs, and roof are updated to the new mass. A few more changes were applied in the project environment for the doors, windows, and other details (Figure 11).

Other Houses

Similar to the case of the Smith House, the generative potential of the presented template was explored. To create new houses that have Meier's syntactic framework and vocabulary, the parameters in table 3 were changed, and accordingly, the conceptual mass and its parameters were changed too. To animate the conceptual mass, each architectural expression explored a different way to utilize Meier's language of subtractions and additions (Figure 12). Correspondingly, the generated architectural expressions maintain a consistent formal language that emerged from having a predefined library and syntactic framework (Figure 13). The representation of the architectural language greatly aids and facilitates the creation of an architectural expression that is grammatically correct.

CONCLUSION

This research presents a shift from BIM as a modeling tool that is composed of 3D-building vocabulary into *architectural information modeling (AIM)* for representing architectural languages through vocabulary and syntactical rules. Using Richard Meier's language for single-family detached houses as a test case, a BIM template has been devised to explore the *analytical* and *generative* power of BIM in architectural design. Autodesk Revit proved capable of modeling many of the language aspects of the Douglas House. It further proved powerful as a "meta-tool" for modeling a language through the creation of families to define the vocabulary, parametric constraints, and masses to model the syntax. It opens the door to perceive BIM as part of the design process instead of only a professionals' tool to aid the production stage of design. The similarities here between the theory of formal language and BIM cannot be marginalized. BIM offers a library of building elements or vocabulary, but in order to utilize BIM as an aid to design thinking, the designer must master the "how" (the syntax and configuration) through the means of diagrams. The three types of relations in any formal language can be easily demystified here. First, the transformational rules in BIM refer to how each element has distinguished parameters that can change its properties, such as length and width. Using modular systems, alignment relation, and datum are examples of syntactic relations in BIM. The ability to start with an abstracted diagram in CDE, which underlies the main relations that control



13

13 New architectural expressions using Meier's syntactic framework and vocabulary.

the overall form, is a significant example of configuration in BIM. In view of this, BIM as a tool for design thinking can be reached when placing the new knowledge of computed design within architectural theory.

Modeling with BIM may be a way to teach the principles of formal language in design through starting with a precedent. Applying the architectural language represented in BIM is extremely easy; future tests will include an exercise for sophomore architecture students to produce grammatically correct expressions using the Meier language. Other exercises can focus upon learning how to *dissect* and *articulate* an existing formal language and representing it explicitly in BIM, and then engaging students to learn essential design principles. However, while this research takes Richard Meier's formal language as a test case, it is not limited to one style. Having made the formal language *explicit*, in terms of syntactical rules and vocabulary, it becomes easier to vary the formal grammar and concrete vocabulary to produce variant styles. Future research can be conducted to demonstrate how designing with BIM can support *stylistic change*. Any investigation in this area might be confined by the ability of designer to comprehend and analyze an architectural style in order to encapsulate its underlying logic. After that, any style can be exemplified in a BIM template by defining its syntax and vocabulary, or an existing template can be transformed to generate a new style.

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IMAGE CREDITS

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