Title:
Design Criteria Modeling – Use of Ontology-Based Algorithmic Modeling to Represent Architectural Design Criteria at the Conceptual Design Stage

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Introduction:
Building Information Modeling (BIM) applications have gradually replaced CAD as a means of solving information integration problems among different disciplines within the AEC (architecture, engineering, and construction) industry. However, the world's first BIM claim revealed the critical problem of information loss when the mechanical, electrical, & plumbing engineering (MEP) contractor ran out room in a ceiling plenum[5]. If BIM can be used to present critical criteria, such as the maximum height of an MEP installation, then it is not necessary to remind the contractor to retain sufficient ceiling height. BIM applications encourage architects to model every detail of a building in order to foresee and resolve constructability issues in advance by means of visualization. BIM applications are based on the product modeling theory and methodology proposed by Eastman[4], which deals with buildings as products in an effort to boost productivity and constructability. Unfortunately, not all critical design information, such as minimal clearance of MEP installations and other design criteria, can be represented in the visualization of the final building products. The problem of losing critical information in BIM not only causes communication issues among different disciplines, but also marginalizes the roles of architects in the AEC industry[7].

One critical role played by architects in AEC industry is the suggestion of creative proposals that go beyond basic requirements. So far, not all architectural design issues have, been integrated within the finite parameters of product-oriented BIM. For example, the living qualities of a house cannot be evaluated solely by means of cost or energy-saving performance, and must also by reflecting formal aesthetics, views from openings, activity circulation, and the privacy qualities of each room and the building as a whole. Some design criteria may be too axiomatic, and thus need not be indicated, such as minimal space requirements, sufficient ventilation, daylighting, and ceiling height in a habitable room, and are therefore inevitably lost in BIM. There are numerous architectural design criteria, such as minimal clearance above a stairway or in front of a door[2], which are invisible or non-obvious in 3D models of a building[2]. BIM lacks tools for representing some basic architectural design criteria, let alone means of validating whether a model meets other criteria proposed by architects.

This project is a follow-up study to the previous projects "Visual Architectural Topology: An Ontology-Based Topological Tool for Use in an Architectural Case Library [10]" and "Architectural Knowledge Modeling: Ontology-Based Modeling of Architectural Topology with the Assistance of an Architectural Case Library[11]." Applying previous results in such areas as the visual ontology of design knowledge and predicate tools of architectural topology, this study seeks to apply Grasshopper (an open source algorithmic plugin of Rhinoceros) as a 3D modeling tool, and integrate existing semantic ontologies of an architectural design case library. The project's goal is to develop a design knowledge modeling tool based on a semantic-topological-geometric (STG) information conversion pattern.

Main Idea:

BIM involves three types of design information: the semantic, topological, and geometric information concerning a building's components[4]. Based on an information-processing perspective, architectural design can be regarded as the conversion and processing of these three types of design information. Unfortunately, the conversion and processing of design information is usually implicit and packaged within architects' design drawings, and architects therefore utilize other visual media in representing design criteria, which may be invisible or non-obvious in design drawings and 3D models. Such visual media usually consist of a series of diagrams or precedents able to represent architects' beliefs and intentions[14]. Since these media are separate from design drawings and models, their information cannot be easily exported into BIM or directly validated by other software.

With the emergence of generative 3D modeling software, a growing number of architects have begun using generative models when engaging in geometric creativity during early design stages. However, unlike BIM, algorithm-based generative models usually lack semantic information concerning the basic components of a building, and therefore require other tools that can be imported into or linked with BIM in order to validate basic performance aspects. In recent years, graphic programming tools such as Grasshopper have become popular among architects for composing algorithms to generate complex building forms, and Grasshopper is a very useful means of representing geometric criteria through the use of algorithms. However, except for abstruse issues where communication must be performed using graphic algorithms, composing algorithms in order to meet the requirements of design criteria still faces more challenges of programming skills than conceptual creativity of architectural design[8].

Inspired by the model-view-control (MVC) pattern, which is a best practice approach of programming GUI applications[6], this paper proposes the use of the semantic-topological-geometric (STG) information conversion pattern to help users compose algorithms for modeling their design criteria. By mapping the conversion of BIM design information with issue-concept-form schema[12] and a function-behavior-structure path[13], which are two important paradigms in modeling architectural design thinking and reasoning, the STG pattern provides a means of classifying architectural design tasks into three programming classes: (1) semantic objectives, (2) topological algorithms, and (3) geometric features of building components (Fig. 1).

The semantic ontologies is the semantic information concerning design objectives, such as names, areas, and qualities of indoor and outdoor spaces of a building project. The topological algorithms are the means to achieving or validating design objectives assigned by algorithms. And the geometric features of building components are generative from achieving or validating algorithms of topologies and ontologies (Fig. 2).

Based on the proposed semantic-topological-geometric pattern, this paper develops an algorithmic modeling tool termed "Design Criteria Modeling (DCM)" as a plugin of Grasshopper. By applying the results of previous projects, including a visual ontology of design knowledge[9] and a predicate tool of architectural topology based on the web ontology language (OWL)[1] of Protégé, DCM seeks to first assist users to model invisible and non-obvious architectural design criteria, such as the minimum clearance of physical building components, and topological relations among multiple physical and spatial objects, which are usually lost in product-oriented BIM. DCM applies the GhPython plugin of Grasshopper to quote a Python-based reasoner using OWL to validate the semantic ontology of composing algorithms in Grasshopper. Since topology consists of the mathematic connections between components, as well as functional definitions in parametric modeling[3], topological algorithms are therefore the key to the conversion of the three types of design information. As a prototype in development, however, not all possible topological algorithms have been implemented in DCM, and further investigation is needed to determine how many atomic algorithms of architectural topology are necessary for basic architectural design criteria.

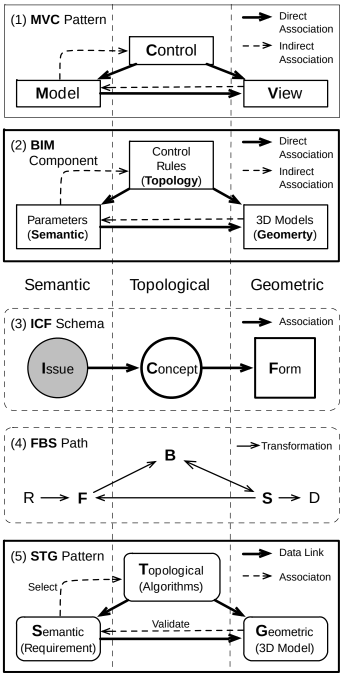
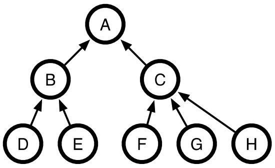
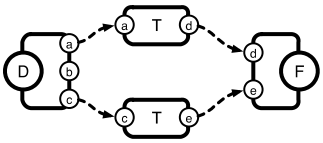


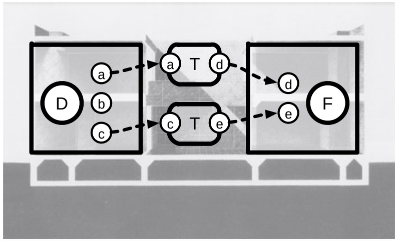
Fig. 1: Mapping information processing from MVC, BIM, ICF, and FBS to STG pattern.



(a) Semantic ontology of design objectives;



(b) Graphic composition of topological algorithms



(c) Generative geometric features of objects;

Fig. 2: The approach of DCM based on the STG pattern[11].

Conclusions:

The MacLeamy curve, which is the best publicity for BIM when it was displayed at the 2007 CURT by the CEO of HOK[3], reveals that earlier decisions in the design process have a greater impact on the quality and cost of a building project. Design criteria developed by architects in early stages, therefore should be the critical parameters of an architectural design, but commonly are lost in present BIM applications. While BIM has gradually become a widely-used communication platform for different disciplines in the AEC industry, use of the limited parameters of BIM in representing design criteria may not only be costly and time-consuming for architects, but also make it harder to automatically validate whether those criteria are satisfied or not. Although generative 3D modeling tools are useful in exploring complex and elaborate geometric forms, how to convert design criteria into generative algorithms still faces stiff programming skill challenges.

To help architects in representing, exploring, and validating design criteria by means of algorithmic 3D modeling, this paper proposes a knowledge-based architectural design criteria modeling tool termed "Design Criteria Modeling (DCM)," which applies the results of previous projects, including a visual ontology of design knowledge and a predicate tool for architectural topology based on OWL of Protégé. This study seeks to apply Grasshopper as an algorithmic tool for modeling architectural design criteria. The project's goal is to integrate an existing knowledge base and case library with parametric design tools. By applying an OWL reasoner, DCM provides a design information conversion pattern that can assist architects in deriving conceptual models through the composition of semantic, topological, and geometric design criteria information. Through the assistance of a semantic ontology reasoner, DCM aims to help architects determine whether conceptual models meet the semantic ontology of proposed design criteria.

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