R. Stouffs, P. Janssen, S. Roudavski, B. Tunçer (eds.), *Open Systems: Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2013)*, 3–12. © 2013, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong, and Center for Advanced Studies in Architecture (CASA), Department of Architecture-NUS, Singapore.

VISUAL ARCHITECTURAL TOPOLOGY

An ontology-based visual language tool in an architectural case library

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Abstract. This paper aims to develop a tool entitled "Visual Architectural Topology (VAT)" for encoding topological information within a case library. VAT can annotate design objects and their topological information within the unstructured information of a design case. By applying an ontology-based topological validation mechanism, VAT aims to establish a visual language for representing the "topological knowledge" of architectural design objects in a case library. The purpose of VAT is to extend the knowledge representation ability of a design case library, and to provide a foundation for development of a design-assistance tool performing the conversion and processing among semantic and geometric design information.

Keywords. Case-based design; case library; architectural topology; semantic ontology; visual language.

1. Introduction

Building information modeling (BIM) has been implemented by many commercial CAAD tools, and has been widely adopted in architecture, engineering, and construction practice. BIM was originally developed via research on building product modeling (BPM) (Eastman, 1999). BPM is composed of three types of information: semantic, topological, and geometric information concerning building components. Topology is the mathematical connections among building components, and is the fundamental aspects of parametric design (Eastman et al., 2008). Unfortunately, most BIM implementations lack necessary topological information for architectural design, such as spatial topology (Lobos and Donath, 2010). This shortcoming therefore impedes applications of BIM in the early conceptual design stage.

From the perspective of an information-driven approach, architectural design employing BIM can be regarded as the interconversion and processing of three types of design information. Experienced architects have meta-knowledge concerning conversion among the three types of design information. But novice designer must study past design cases, and try to reconstruct the conversion process. Design case libraries were originally assumed to play the role of knowledge depositories in the learning process. But case libraries are usually implemented employing database technology, which only extracts semantic information of case features as an index mechanism. Therefore most clues about conversion process among three types of design information are lost.

This paper is a follow-up study to the two previous projects "STR: Spatial Topology Retrieval" (Lin and Chiu, 2010) and "SSO: Smart Spatial Ontology" (Lin, 2013). This paper aims to develop a visual tool entitled "Visual Architectural Topology" (VAT) for the purpose of encoding architectural topologies within design cases of a house case library termed "OCS: Open Case Study" (Lin and Chiu, 2009). By applying previous research results, VAT aims to establish a visual language for representing the topological information of architectural design objects, and also to extend the knowledge representation ability of our design case library.

2. The Approach of Visual Architectural Topology

Knowledge representation in design cases is a major bottleneck in case-based design (CBD) and case-based reasoning (CBR) research (Heylighen and Neuckermans, 2001). Since design knowledge is usually implicit, especially in the case of ill-defined or unstructured information such as drawings, graphics and pictures, it is difficult to formalize this knowledge into a machine-processable format. As more BIM implementations are used in practical work, BIM may provide an "information-rich" depository of BIM-based case libraries in the future. However, for important precedents outside of practice or before the development of BIM, it is usually difficult to collect detailed information in order to construct BIM files. In contrast, unstructured information concerning design cases, such as the scanned design drawings and images, are nevertheless easily collected and stored in case libraries.

The current method for indexing unstructured information in design cases usually relies on the attachment of semantic tags. The advantages of this method are that it is open, flexible, and easy to implement. But simple semantic tags cannot adequately represent the topological information. Therefore, this paper proposes an open and adequately-formalized tool that can assist users to visually represent their interpretations of topological knowledge. Rather than providing a rigid representation framework of architectural topology, the approach is based on (1) the semantic ontology of topology, (2) graphic annotations attached to unstructured information, and (3) visual validation when encoding topology.

2.1. SEMANTIC ONTOLOGY OF TOPOLOGY

An ontology is a "formal, explicit specification of a shared conceptualization" (Gruber, 1993), A knowledge chunk in an ontology can be represented by a triple set of "subject," "predicate," and "object" (Fensel, 2003). Development of an ontology therefore consists of the establishment of a formal language to describe design knowledge. As a topology represents correlations between design objects, the "predicate" represents the semantic or causal relationship among knowledge objects. For example, a spatial ontology has been proposed (Brennan et al., 2004) to represent three aspects of spatial knowledge: connectivity, proximity and orientation. However, most proposed ontologies can only represent what topologies are contained in a case, but cannot represent why and how a topology is composed in a certain way within the case, let alone allow users to state different interpretations or new types of topologies.

To assist users to associate semantic ontologies with spatial topologies, a visual tool named "smart spatial ontology" (SSO) was proposed in previous studies (Lin, 2013). SSO allows users to annotate semantic predicates on spatial topologies, and therefore provides a bridge between the semantic ontologies and spatial topologies of architectural spaces. However, the functions of SSO focused on spatial topology, and were restricted to the same declaration level of an ontology. For improving knowledge representation ability, VAT adds the cross-level function of declaring the predicates associated with different levels in a semantic ontology. For example, VAT can assign two "has" predicate with "ventilation" and "lighting" to a connective topology of "bedroom" and "atrium" in order to represent the design concept of the Azuma House. VAT therefore can not only associate topologies of design objects assigned by users with existed semantic features in a library, but also associate topologies with abstract concepts interpreted by users.

2.2. GRAPHIC ANNOTATIONS ON UNSTRUCTURED INFORMATION

Appropriate interfaces, which go beyond textual search and can deal with non-textual information, are therefore usually absent from case libraries. Since architects are educated to think and reason through visual information such as sketches and diagrams (Oh et al., 2004), graphic interfaces such as "SpaceScope" (Hwang and Choi, 2003) and sketch-based interfaces (Langenhan et al., 2011) have been proposed in order to improve retrieval in a case library. Visual approaches must rely

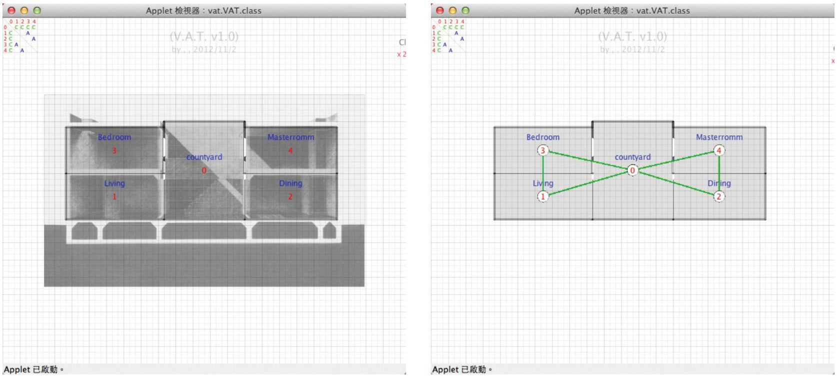

Figure 1. Graphic Annotations on the section drawing of the Azuma House.

on preceding mechanics, regardless of the topologies or ontologies of a case's contents. However, declaration of an ontology usually involves tedious expression of the semantic features of knowledge chunks. And while burdensome parametric inputs in BIM inevitably confuse architects, ontology-authoring tools such as Protégé perplex designers as well. Although visual alignment tools for ontologies have been proposed (Lanzenberger et al., 2008), alignment tools for semantic ontologies with visual knowledge resources are still absent.

In the previous studies, SSO therefore integrated graphic declarations with a search interface in order to deal with visual information in design cases. SSO can easily draw schematic spatial layouts while attaching graphic annotations for spatial topologies to the images of a house plan. VAT extends the graphic interface of SSO to the translation of more types of topologies than spatial topologies of plan drawings. For example, VAT can attach simple diagrams as graphic annotations to section drawings, site plan drawings, and interior and exterior photos, etc. For example, VAT can attach diagrams to a section drawing of Azuma House (Figure 1, left), and then the initial topologies of annotated object will be encoded (Figure 1, right).

2.3. VISUAL VALIDATION WHEN ENCODING TOPOLOGY

The knowledge-acquisition process usually employs a top-down approach and focuses on the validation and consistency of an ontology within a particular domain of knowledge. However, while this constraint may be adequate for most domains, it may not be able to satisfy the needs of the architectural design domain. Architects are typically educated to be creative, and are therefore encouraged to challenge pre-existing specifications of conceptualizations. Important precedents are therefore

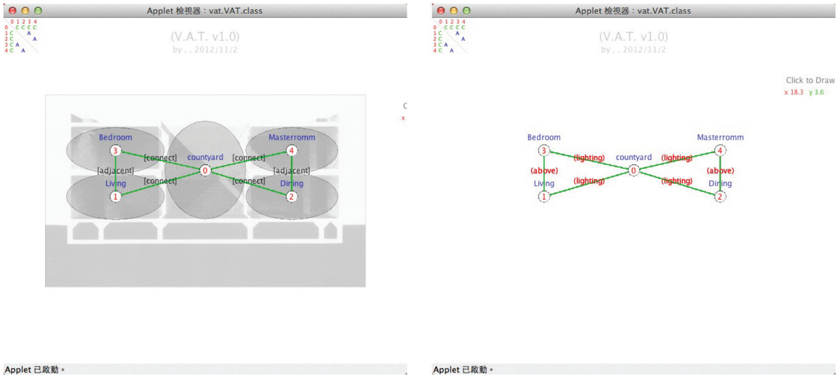

Figure 2. Interactive validation between encoded topology and semantic ontology in VAT.

collected on the basis of their unique concepts, but the more distinctive the concept of a design case, the smaller the valid domain of its design knowledge.

While a scholar has declared that "*designers reason from cases, not from principles*" (Boling, 2010), students are usually educated to transform or interpret cases, rather than to directly imitate precedents. Although most design information should be fixed and static within built precedents, designers' interpretations when analyzing built precedents may still vary with the times and technology. The valid domain of an ontology can therefore be restricted to the relevant information within a case, rather than a larger scope, such as building types. VAT can help user to interactively validate the encoded topologies by switching between schematic layouts of encoded topologies (Figure 2, left) and semantic ontologies (Figure 2, right). Based on the physically-oriented algorithm of STR, VAT will provide visual clues to help correcting conflicts by modifying geometric features within schematic layouts.

2.4. SUMMARY

Based on the prior knowledge consisting of the ontological techniques in SSO, and predefined topologies of STR, the VAT project is devoted to developing a visual language tool assisting users to represent the topological knowledge in design cases. VAT improves the topological knowledge representation of the OCS case library from the spatial topologies of house plans to free and open interpretations of other unstructured information in the library. Via the semantic association of ontologies with topologies, VAT can improve on SSO's graphic-based search mechanism, and assists users to retrieve and learn topological design knowledge more efficiently from unstructured information in design cases.

3. The Implementation and Primary Evaluation of VAT

The initial version of OCS consisted of a web-based application applying MySQL database software, and its access interface is implemented employing PHP and Flash. However, as a rational database management system, MySQL cannot easily be used to implement flexible metadata-authoring tools allowing users to develop different interpretations of case content. VAT therefore applies the MongoDB database software, which is a scalable, high-performance, open source, document-oriented NoSQL database management system (10gen, 2012). This system is used to store semantic ontology and graphic topological annotations within unstructured information. Since a “not only SQL” (NoSQL) database does not need a predefined schema of data tables, it is easier to represent open-structured design knowledge metadata and store flexible semantic ontologies. MongoDB is also a key-value store database, and there is no need for a fixed data model to store information. Through the use of MongoDB, VAT can thus easily store topological knowledge as objects, and can retrieve graphic annotations for unstructured information as documents from the library.

3.1. IMPLEMENTATION OF VAT INTERFACE

The initial version of SSO applied PROCESSING to implement an interactive interface for encoding spatial topology. PROCESSING is a simplified version of the Java program language, and offers a lightweight integrated development environment (IDE) in which visual design students can learn programing. In keeping with the emerging modern web-based interface technologies, VAT integrates the JavaScript based jQuery library and Processing.js, a JavaScript version of PROCESSING, to improve the compatibility of its interface with modern web browsers, which may not be compatible with Java plugins.

3.2. PRIMARY EVALUATION OF VAT

With the assistance of Web 2.0 technology, VAT aims to provide users a simple, efficient, and user-friendly means of representing, storing, indexing, and retrieving their acquired knowledge from unstructured information of design cases. However, the presentation of visual knowledge, such as topological knowledge contained in unstructured information, still faces challenges in both technological and user-experience aspects.

On the technological aspects, the prototype of VAT prototype can only attach 2D rectangle and ellipse shape object for now in order to simplify the validation algorithm of collision detection. This restriction can satisfy the interpretation of 2D drawings, which are the primary goals of VAT. But obviously, it is difficult to interpret 3D topologies within perspective drawings or photos, which usually were the major reasons for why a user selects a case when our students tested VAT. Although some CG technologies, such as "Photo-Match" function of SketchUp, can covert 2D photos into 3D models. However, it still needs more investigations for how to simplify the manipulation for annotating 3D topologies as easy as 2D drawings.

On the user-experience aspects, the manipulation of VAT inherits the CAD-like operations of STR, which provides easier means to interpret geometric features of design objects, and should be familiar by users who have learned CAD software. However, CAD-like manipulation sometimes perplexes our students with too much geometric information and limited topological operations. Freehand-sketch interface obviously should be easier to record various graphic annotations attached by users. However, how to recognize topological information within freehand-sketches faces technological challenges and goes beyond the primary purpose of VAT.

Although the prototype VAT system is still rough and sometimes not intelligent enough with regard to user-experience aspects when testing by our students, VAT has some advantages over other approaches: (1) Semantic ontology can be attached to topologies, providing explanations facilitating learning and reasoning. (2) The integration of semantic ontology, graphic topology, and their visual sources of unstructured information allow the alignment of different abstract forms of design knowledge. (3) Simple diagrams can be added as graphic annotations to visually represent topological knowledge. (4) VAT adds predefined topologies to SSO as a validation mechanism assisting users to correct conflicts in knowledge representation.

4. Discussion

An architectural design information processing cycle was derived in our previous studies: (1) Declaration of the "semantic ontology" of design objects based on the building plan. (2) Translation of this semantic ontology into appropriate "topological relations" of design objects in response to the design context. (3) Interpretation of "topological relations" using the "geometric properties" of design objects to represent the chosen solutions. (4) Validation of the required "semantic ontology" based on the given "geometric properties." This information-driven approach motivates the following discussion.

4.1. TOPOLOGICAL KNOWLEDGE WITHIN DESIGN CASES

Topology is the representation of relations among design objects, and is therefore the key to parametric design in BIM. However, most BIM implementations overlook topological information because of technical difficulties and the lack of consensus. From a mathematical point of view, the complexity of topological information increase linearly with the number of design objects when every topology involves only two objects. However, when a topology involves uncertain number of objects, such as “surrounding” relation, the complexity increase exponentially and the problem may even be insoluble. In addition, there seems to be no consensus in the academic and practical communities concerning what topologies should be integrated into a system. Unsurprisingly, most practical workers do not apply topology-based tools such as generating or automatic spatial layout software (Lobos and Donath, 2010). And even if BIM can be expanded with more topological information in the future, the implementation of BIM may only be able to represent what and how the topologies of design objects are, rather than why the topologies should be this way.

Architects obviously must apply different approaches to deal with topological knowledge. By extracting memories from past experiences or design cases, architects can employ abstracted patterns to reduce the complexity of topological problems. How architects can retrieve topological patterns, which usually are deduced from semantic information, in design problems, is the key to CBD and CBR. Since VAT has grafted semantic ontology with graphic topology, it should be very useful for designers who wish to retrieve, learn, and apply topological knowledge within design cases.

4.2. VISUAL REPRESENTATION OF TOPOLOGICAL KNOWLEDGE

Most of case libraries focus on the semantic features of design cases, but ignores the representation of knowledge within visual and graphic information in design cases because of technical difficulties in dealing with unstructured information. While a picture may be worth a thousand words, the original visual media within a design case may not be the best means representing topological knowledge.

Traditional methods of abstracting topological knowledge, such as topological matrices, graphs, bubble diagrams, and schematic layouts, can represent different degrees of abstraction for different purposes. However, as architects may deal with several different abstract levels of design information at one time, including mass sketches, schematic diagrams, and details of components, the one-time abstraction of topologies often cannot satisfy the needs of architects, and is not helpful to novices wishing to learn relevant knowledge. Since VAT can simultaneously represent topological information by matrices, graphs, and schematic layouts, and allows users to exclude unnecessary information from view, it should be easier for users to learn and use than systems presenting overly abstract mathematics or more primitive visual media.

4.3. INTERFACE FOR ENCODING AND RETRIEVAL

While one of the major purposes of developing a case library is to provide learning resources, some scholars claimed that important learning functions was absent from CBD systems proposed in previous studies, and noted that most such systems have no functions for acquiring and re-indexing design knowledge from cases (Heylighen and Neuckermans, 2001). To perform acquisition and re-indexing functions, it is necessary to have a user-friendly interface encouraging users to participate in acquisition actions, especially when acquiring unstructured information.

Regardless of whether textual tags or other visual approaches are employed, preprocessing is necessary to convert unstructured information into a machine-processable format. Since it is still difficult for machines to automatically recognize topologies within unstructured design case information, VAT provides a simple but intuitive interface assisting users in encoding and retrieving their perceptions. VAT can not only provide the results of analysis by users, which is performed through associations with semantic ontology, but also provide more clues about correlations among different cases in the library.

5. Conclusions

Since visual media can more easily represent architectural topologies, it is necessary to develop a visual tool in order to solve the problem of encoding, indexing, and retrieval of architectural topology meta-knowledge within a case library. This tool should provide necessary architectural topology functions, which can bridge the semantic and geometric information of design objects, and assist users in encoding and representing information conversion meta-knowledge among semantic, topological, and geometric forms of information.

The VAT project in this paper illustrates our methods of improving the representation of topological knowledge within the OCS case library. The recognition results of users applying VAT provide a visual language for communication between different agents in the system, including human designers and reasoning machines. VAT not only encompasses more topological knowledge within the design case library than spatial topologies in plan drawings, but also provides a foundation for development of the next generation of design assistance tools, which should be based on the conversion of the three types of design information used in BIM systems.

Acknowledgements

This paper is supported by the National Science Council of Taiwan under grant number NSC 101-2221-E-165-004.

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