Abstract. This paper aims to develop a visual tool named Spatial Topology Retrieval (STR) for integrating a physical-based spatial allocation tool, which offers a visual interactive interface for architectural space layout in early design stage, into an online case library, which is based on rational database technology with ontology-based authoring tools of metadata of case features. STR services the case library as a tool for representing and retrieving the plane views of a design case.

Keywords. Case-based design; case library; knowledge representation; implicit knowledge; spatial topology.

1. Introduction

Design precedents are considered the containers of the required knowledge for past design problems, experience and solutions (Kolodner and Leake, 1996). By collecting and analysing the design precedents, architects and students will be able to recognise the design problems, and acquire the relevant knowledge and the solution experience. One purpose for developing a design case library is to accumulate the design knowledge and experience obtained from case
studies. However, the means for abstracting, encoding, and indexing the case information determine the way for how to retrieve, represent, and reuse the knowledge in the design cases.

Currently, a case library is usually constructed by rational database technology, which requires selecting the most specific common features of a case then converts those features into metadata of the case information. The selected explicit features serve as the index mechanism and knowledge representation of the design cases in the library. However, the index mechanism using the explicit features often overlooks the acquisition, re-index and generalisation of the implicit knowledge of a given case.

Eastman proposed the building product models, which categorised a building’s information into three types – geometric, semantic, and topological information – and initiated the researches of building information model (BIM) (Eastman, 1999). Nowadays, BIM is applied in commercial CAAD tools, and is widely adopted by the AEC field, thus assuring easy coordination, management, and indexing of the geometric and semantic information of the physical components of a complex building project. Every popular commercial CAAD software, such as Autodesk Revit, Bentley MicroStation and Graphisoft ArchiCAD, has its own BIM implementations. However, those implementations seem to be more aligned to documentation production and final construction application rather than to early architectural design and performance analysis (Howell and Batchele, 2005). Consequently, those implementations all lack the topological information of the indoor and outdoor spaces, which is required for the early architectural design and performance analysis.

The purpose of this paper aims to combine two previous investigation results: (1) Space Layout Game (SLG): a physical-based interactive allocation tool for the architectural space layout in the early design stage (Lin, 2005); (2) Open Case Study (OCS): an online case library with the rational database technology as an ontology-based authoring tool of the metadata of case features (Lin and Chiu, 2009). A visual tool named Spatial Topology Retrieval (STR) is developed to integrate SLG into OCS case library. Via Internet-ready visual interface and database connecting capabilities, STR thereby services OSC as a tool for modelling, representing, and retrieving the plane views of a design case.

2. Approach for modelling, representation and retrieval of spatial topology

Modelling, representing and retrieving the spatial topology are critical to the investigation of the geographic information system (GIS), but are often overlooked by the recent CAAD researches. Early investigations involving case-based systems such as CADRE, FABEL, and SEED attempted to directly
include spatial topology in their systems; however, due to the IT limitations in earlier times, those systems were either difficult to use or limited in terms of the function scope. Furthermore, earlier systems failed to link other existing case libraries to expand the indexing and retrieving capabilities of the case library.

Many design theories, principles, and rules of the architectural design and performance analysis are expressed in terms of the topology relationship. Common examples are space coordination, viewing sights, or circulation relationship. There are at least three approaches for modelling, representing and retrieving the spatial topology: (1) automatic, (2) BIM, and (3) content-based.

2.1. AUTOMATIC APPROACH

Design automation was one of the initial motivations to develop CAD and AI, and automated spatial layout was one of the first desired tasks. Many different methods and almost every AI algorithm for solving this problem have been proposed. Since the spatial topology is actually determined by the geometric information of spaces – such as the relevant positions and dimensions of spaces or components within the architectural layouts, it is possible to establish a tool for automatically recognising, then indexing and retrieving the spatial topology from the spatial layouts. For example, algorithms were proposed for recognising, then indexing and retrieving indoor furniture’s topological relation and their layouts from the existing architectural plans in FABEL (Coulon, 1995).

The automatic approach is based on three criteria: (1) geometric information of the relevant spaces or physical components, (2) semantic attributes of the spaces or physical components for recognition, and (3) algorithms that can convert the geometric information and the topological relations to each other. Nevertheless, even modern BIM implementations usually fall short of the necessary geometric information of architectural spaces and the feasible algorithm for spatial topology. Let alone those old design cases without useful digital geometric and semantic information. Hence, even the automatic approach is practical, but how to extract the useful geometric information from the old cases and to integrate algorithms into a case library remains a critical problem.

2.2. BIM APPROACH

The geometric and semantic information is the key to the spatial topology, and many BIM implementations have modeled the essential information of building design objects. Therefore, one feasible approach is to extend the informa-
tion models and necessary algorithms into the existing BIMs. To replenish BIM with spatial information, which obviously distinguishes the current BIM implementations from Eastman’s original intention, should be one reasonable means. For example, a space syntax-based model is proposed to enhance the BIM capabilities for the early architectural design (Li et al., 2009).

However, the relations between the physical components and the vacant spaces are dialectical, and four walls or two floors cannot define all spaces of a spatial layout. To name one example, Azuma House in Sumiyoshi, an early masterpiece of architect Tadao Ando. Azuma House is characterised by an atrium within the middle of this small row house, which has a stair without a handrail attaching to the wall of the atrium, and a bridge with two concrete parapets connecting two rooms over both sides of the atrium. The physical components are too simple to clearly define spaces of the atrium, so there is more than one single way to model this case in BIM. The second floor of the atrium in the house can be modeled as: (1) a bridge in the middle of an atrium without floor; (2) two excavations on both sides of a bridge; or (3) an excavation, a bridge, and a staircase. The definition of a space not only depends on the geometric information of physical components that enclose the space, but also depends on the semantic contents of the space and the building type. However, present BIM cannot accommodate multi-interpretations of the space in one single model.

2.3. CONTENT-BASED APPROACH

The definition of a space varies with the semantic contents of architectural design. In other words, the next feasible approach traces back to the contents of a building. The building type, the functions of the space, and the physical components collectively define the spatial topology. For example, an information model named “SpaceScope” was proposed to improve the retrieval of a house floor plan in a case library by a graphic interface (Hwang and Choi, 2003). Another model was also proposed for representing a special building type. This second model classified the school building in Netherlands into three types of spaces: the corridor, the hall, and the pavilion (Steijns and Koutamanis, 2005). The content-based approach creates a building-type-specific information model based on the domain knowledge of the case contents. These contents include domain-specific semantic metadata and spatial topology, such as representing a hall of a school as a multi-nodes space in the topology.

The content-based approach must depend on the case contents such as a special building type, and it is inevitably restricted by the domain knowledge about the case contents. As a result, the multi-types of a design case usually
become a problem in the approach itself. At the same time, a structured plan of the spatial layouts, such as CAD drawing or BIM model, still is necessary for this approach to analyse spatial topology of a case.

3. The STR approach

All the approaches elaborated in this paper require a structured floor plan for analysing, modelling, or indexing spatial topology. However, due to the data source problems, copyright issues and many other reasons, we cannot always obtain a well-structured floor plan or a complete BIM file of a design case for storing into a case library. For the purpose of teaching or early case study in practices, image files of a floor plan are easier to be collected from the historical documents, the architect’s portfolios and Internet. Although possible, it is usually strenuous and unnecessary to rebuild a detailed structured floor plan from those image files simply for analysing spatial topology. On the other hand, technological difficulties imply more investigations to understand how to integrate the semantic and geometric information of a structured floor plan, regardless of CAD drawings or BIM files, into the indexing machine of an existing case library. To sum up, STR proposes a visual and intuitional approach to improve the capabilities of a case library in modelling, representing, and retrieving spatial topology from the unstructured floor plans.

3.1. TOPOLOGICAL LAYOUT AS VISUAL ANNOTATIONS

Although the image files of a floor plan are easier to be collected and then to be stored in a case library, they fall short of the structured data for indexing. Except for some special patterns such as human faces, machines cannot automatically recognise most of the useful design information in an image file for now. Since a space usually cannot be easily defined by physical components of BIM, an alternative of automatic recognition by machines is to attach textual or other annotations with human efforts, such as the textual “tags” of image files on Flickr. However, simple textual annotations obviously cannot represent most of the implicit information in a floor plan, such as spatial topology. A visual interface for annotating graphic information such as spatial geometry and topology of the floor plan then becomes necessary in this situation.

Another problem with extracting geometric space information from the image files is scale precision and correctness. Some basic image processing tools, such as scaling, rotating, and measuring, and manipulative skills, become necessary for a visual approach to improve the precision of geometric information. For example, an image file of a house floor plan may not be in appropriate scales. Assuming that the normal dimension of an interior door
is 90 cm wide, we can reproduce this image in the new scale. After simple adjustments, most of the image files of a floor plan can be used to annotate their spatial topology in STR. However, on account of API’s limited abilities in image processing, not all necessary pre-processing of a floor plan image can be implemented in STR as of today.

3.2. PHYSICAL-BASED VALIDATION FOR SPATIAL TOPOLOGY

Annotations attached by human efforts cannot be free of mistakes and inconsistency. Therefore, a validating machine helps users to check up the inputs to determine whether or not these inputs are acceptable. STR is based on SLG. SLG has a physical-based algorithm to check every space whether it is overlapped, separate, adjacent, or connected by accesses or not, and to automatically modify the relative positions of the relevant spaces to satisfy assigned topologies. When a user wants to validate the inputted topology, STR will then (1) check every space whether it complies with the topology assigned by the user or not, and (2) try to modify the relative positions of the relevant spaces, and/or (3) prompt the conflicts if any problem goes beyond the algorithm of SLG.

Since the SLG-based algorithm is very simple for now, STR cannot automatically correct all conflicts caused by the inconsistent topologies. However, by comparing the previous layout inputted by the user to the new layout modified by STR, and by the visual cues of conflicts provided by STR, the user should be able to detect any inconsistency in the topological layout and to correct the inputted topological relations by interactions of relevant spaces in STR.

3.3. TOPOLOGICAL LAYOUT AS VISUAL RETRIEVAL

When a user finishes the topological layout of a floor plan, the layout will be stored in OCS database and, there, the user can retrieve it and its relevant image files of the floor plan. STR provides the same interface for annotating and retrieving topological layouts in the case library. By drawing spaces and assigning topological relations to those spaces, the user can enter a partial topological layout as a query in order to retrieve a similar layout in the case library.

Based on the features of a queried layout, STR can rank the similarities of the query and the stored layouts in OCS database by comparing the semantic attributes – the name of a space, dimensions, relative positions, assigned topological relation, etc. Then, STR can retrieve cases with the similar topology and sort the similarities by the ranking results. Via STR’s visual and instinct
manipulations, OCS can be a visual and interactive encoding and indexing tool for spatial topology. STR can then assist the designers in coding the existing design cases, indexing, and retrieving spatial topology of the design cases by searching and mapping functions of the OCS database, and further derive the similarities and differences among the retrieved cases.

3.4. THE IMPLEMENTATION OF STR

OCS is an online case library of house design cases, which is developed in MySQL rational database, PHP script language for server-side data accessing, and JavaScript for client-side interface. The semantic information of the case features and their semantic relations can be modified and extended in OCS by an ontology-based metadata-authoring tool. STR is developed to extend the representing and retrieving capabilities of OCS in the implicit topological knowledge.

Just like SLG, STR is developed in Processing, a simplified software IDE developed by MIT based on JAVA programming language for teaching fundamentals of the computer programming in the visual art and design education (Reas and Fry, 2007). Via a visual, interactive, Internet-ready interface and the MySQL database connective capabilities of Processing, STR thereby serves as a visual and interactive tool for encoding, representing, and retrieving the plane views of a design case within the OCS case library. A user can interpret a floor plan by drawing space objects, modifying dimensions and positions of spaces, assigning topological relations to spaces, and validating those relations (figure 1).

4. Conclusions

Case libraries developed by the database technology usually fail to help the users to be aware, then to acquire the implicit design knowledge such as spatial topological information of a design case. For students and beginners, a visual
and graphic tool is more satisfying than the complex textual and numeric indexing tables. Although the present BIM implementations may be very useful to digitalise the geometric and topological information of a building’s physical components, most BIM implementations are still found deficient in the necessary spatial information model and effective algorithms for converting physical geometric information into spatial topology. As a result, a visual and graphic tool like STR emerges and should be able to assist a teacher or an expert in coding the existing design cases, indexing, and retrieving spatial topology of the relevant cases. Then, by applying searching and mapping functions of database technology, OCS can further derive the similarities and differences among the retrieved cases and help students and beginners to learn the implicit knowledge of spatial topology. Finally, assisted by STR, OCS is able to (1) derive the design patterns in the spatial topology of building types, such as the different types of local dwellings based on the entered cases, and thereby (2) assist the user in teaching or learning the design knowledge of the spatial layouts in relevant cases.

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References