SMART TOPOLOGY

An Intuitive Tool for Architectural Space Allocation

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Abstract. This paper describes a prototype of an intuitive tool named Smart Topology for the architectural space allocation in the early design phase. Smart Topology focuses on the manipulations of virtual spaces and can build and operate the topological relation among them by instantly modifying the geometric properties of spatial allocation so as to comply with the topological relation defined by the user. Based on a prototype of an interactive tool for the spatial allocation named Spatial Layout Game (SLG), Smart Topology adds more topological operations into SLG, such as the connective, combining, orientating, and opening. It also tracks the manipulating process and results by applying the database technology.

Keywords. Spatial allocation; spatial topology; knowledge representation; intuitive manipulation.

1. Introduction

The current CAAD software, such as Autodesk Revit, Bentley MicroStation and Graphisoft ArchiCAD, have introduced the building information model (BIM) with parametric design and database technology to maintain the consistency of the geometric relations among constructional components through the whole process of design development and modification. BIM is popular in the field of AEC applications because it can significantly reduce the mistakes and tediousness of geometric coordination among various components and equipments in the engineering and construction process of the initial design phase of a building project.

However, the nature of architectural design is to create and arrange appropriate relations between architectural spaces and physical components,
including topology and geometry. In the early phase of the architectural design such as the spatial allocation, an architect usually first considers the “topological relationship” among architectural spaces rather than the geometric properties of physical components. For example, an architect may consider the adjacency among relevant rooms, the circulation formed by the connection of accesses and corridors, and directions of views formed by the opening, etc.

The topological relation among spaces is not only the key to spatial allocation, but also the guide to geometric relations of physical components that shape the spaces. However, BIM usually focuses on the geometric properties of physical components and ignores the construction and maintenance of the topological relations among architectural spaces. Hence, BIM is not suitable to tasks in the early design phase, such as the spatial allocation.

2. The Approach of Smart Topology

2.1 APPROACHES TO ASSIST SPATIAL ALLOCATION

Many relevant spatial allocation methods, algorithms, and prototypes have been discussed and developed since the first wave of CAD and AI development in the 1970s. In view of developing a CAAD system, the research could be divided into three approaches: (1) automatic generation, (2) interactive manipulation, and (3) simulation technology.

The automatic generation approach applies algorithms to generate design solutions, such as rule-based generation (Flemming and Chien, 1995), case-base learning, neural networks, and genetic algorithms. However, the over-constrained phenomenon, where too many possible solutions exist and not a single best solution could be found (Balachandra and Gero, 1987), causes a common disadvantage to most automated systems. Although evaluation methods have been developed to filter generated results, most approaches are too complex for architects to understand.

To avoid the drawbacks of automated systems, an ideal system should have graphical and interactive procedures instead of rule-input and generating-testing. Many methods, such as the virtual grid search method (Mitchell, 1971) and interactive spatial layout (Ruch, 1978), have been proposed to construct this type of system since the 1970s. However, due to the constraints of preliminary technology, these approaches do not really focus on the manipulative interactivity of the system interface in the design process.

The simulation approach applies simulation technology to model the interactive behaviors among different spaces within a building project. For example, “Physically Based Space Planning” applies the laws of physics to convert the relationships between spaces into various forces so as to dynamically
change the relative positions of spaces within a layout (Arvin and House, 2002). This physical simulation based method provides a “living” design process with dynamic responses.

This paper describes a prototype of an intuitive tool named Smart Topology for the architectural space allocation in the early design phase. Smart Topology is based on the previous study named Space Layout Game (SLG). SLG takes the interactive and simulation approaches to assist users allocate architectural spaces (Lin, 2005). SLG models two basic design objectives of spatial allocation problems: topological and geometric (Arvin and House, 2002). Topological objectives reflect the designer’s intentions on the relative positions and inner correlations of spaces. Geometric objectives reflect the designer’s intentions on the size and shape of spaces. Smart Topology focuses on manipulations of topological relations among virtual spaces. Through the survey of spatial topology and its graphic representations, Smart Topology also modelled interactive behaviours between topological and geometrical manipulations of architectural spaces.

2.2. SURVEY ON THE SPATIAL TOPOLOGY

The modelling, which represents and reasons topological relationships among spatial features, is an important issue in research of geographic information system (GIS), but it is usually ignored in present CAAD tools. Basic topological relationships within GIS include adjacency, overlapping, and disjointed (Rigaux, Scholl and Voisard, 2002). However, those relationships can only represent geometrical features of geographic spaces at the loss of some important architectural design features, such as circulation. Therefore, other topological relationships, such as the accessibility proposed by Hillier (1996), are also necessary for architectural design.

SLG has modelled the adjacent relationship of rectangular spaces. It is quite obvious that the adjacent relationship itself is not enough to represent most of intentions for spatial allocation. Therefore, Smart Topology extends topological relationships among rectangular spaces to the connective, combining, orientating, and opening.

The connective relationship, which is built by attaching an access between two adjacent spaces, can represent the interior circulation (Figure 1.2). The combining relationship, which is built by removing the boundary between two adjacent spaces, can represent a compound space such as a living room combining with a dinner room (Figure 1.3). The orientating relationship, which is determined by relative positions of two adjacent spaces, can represent the inner requirements such as a response to the climate or context of the site (Figure 1.4). The opening relationship, which is built by attaching an opening,
can represent the relation of a space and outdoor spaces such as the view and natural lighting (Figure 1.5).

![Diagram of topological relationships]

*Figure 1. Topological Relationships in Smart Topology.*

2.3. REPRESENTATION AND OPERATION OF SPATIAL GEOMETRY

Resolving topological conflicts in the spatial allocation, however, usually requires many geometric modifications such as altered shapes, dimensions, and relative positions. Since Smart Topology is based on SLG, the representation and operation of spaces still use the rectangular shape and grid system in SLG. The rectangular representation of a virtual space, as well as many other systems, is useful for simplifying shape and dimensional issues in the early design stage. Furthermore, Smart Topology also applies a grid system to reduce the dimensional and area decision-making.

The dimensional and area information of a space is more critical than its exact coordinates in the early stage of spatial allocation. Smart Topology therefore dynamically and immediately provides dimensional and area information while concealing the exact coordinates when a space is created or modified. Actually, many users are baffled by the coordinate system in most CAAD software such as AutoCAD when they first encounter it. Although it should be rather easy for an experienced architect to determine whether the dimensions and area of a given space are appropriate or not, more detailed decisions are still difficult and tedious in the early design stage. Smart Topology therefore applied an orthographic grid system, which is just like a graph paper or the grid system used by most CAAD software. Smart Topology has a 90cm-main grid system with three 30cm-sub-grids for the reasons of human factor engineering, practical applications, and local conventions in Taiwan. All dimensional and positional modifications of a space will be snapped on this grid system to reduce the burden on both users and computers.

2.4. INTERACTIONS BETWEEN SPATIAL TOPOLOGY AND GEOMETRY

Due to the ill-defined nature of spatial allocation problems, there is a mutually interacting process between the indicators of spatial topology which define
problems, and the modifications of spatial geometry, which search for solutions. Based on the previous study of SLG, Smart Topology provides an intuitive indicator, immediate response, and visual reminder to conflicts. It assists users to solve conflicts rather than automatically provides possible solutions.

Once an adjacent topology is indicated, SLG immediately modifies relevant spaces to be adjacent. However, SLG will not immediately move a space to the “right” position adjacent to another. SLG only checks one adjacent relation of a space at a time; then SLG simply moves it one grid along the X or Y dimension when a conflict occurs. Since this algorithm is very simple, overlapping and other conflicts often occur when SLG tries to modify the relative position of relevant spaces. To assist users solve conflicts, every spatial topology needs to be translated into spatial geometry for both human reading and computer processing. Smart Topology thus models essential geometric constraints on each spatial topology into its SLG-based algorithm.

For example, the connecting topology requires that the minimal overlapping length of two adjacent spaces must be at least 90 cm to create a normal access; the combining topology requires that the minimal overlapping length of two adjacent spaces must be at least half of the shorter edge of the two spaces; and the opening topology requires that the opening of a space cannot be adjacent with other spaces. Once a topology is specified or a geometric feature of a space is modified, Smart Topology will try to modify the relative positions of relevant spaces in order to satisfy those constraints.

3. Implementation of Smart Topology

The prototype of SLG was developed under the open source software named “Processing.” Processing is a simplified programming environment developed by MIT for teaching fundamentals of computer programming in the visual art and design education (Reas and Fry, 2007). By applying Java-based object-oriented programming techniques, Smart Topology extends the class within SLG to more topological indicators and intuitive manipulations.

3.1. INTERFACE OF SMART TOPOLOGY

Since Processing focuses on producing images, animations, and interactions, it lacks the complete APIs for complex GUIs such as dialog windows, text fields, and other data input forms, unless users try to call the complex APIs of original Java language such as AWT or Swing. Consequently, all Smart Topology manipulations are restricted to the mouse or keyboard and do not involve complex parameters in a dialog window like other CAAD.
The topological indicator of SLG applies a node within the center of a space and their linking networks to manipulate and display adjacent topology. The network diagram of spatial node applied in SLG is a good visualization for simple adjacent topology but is not enough for indicating and representing other spatial topology. Hence, Smart Topology expands the indicators from adjacent node of SLG to connective boundary for connecting topology, combining boundary for combining topology, and opening icon for opening topology. (Figure 2)

For geometric manipulations, Smart Topology still inherits the interface of SLG, which includes the delete and resize icon, the dimensional and area information attached on a modifying space, and the direct click-and-move operation for modifying spatial positions. However, Smart Topology extends the simple topological manipulation of SLG from linking adjacent nodes to sensitive boundary for intuitive manipulations. The boundary of a space in Smart Topology becomes the sensor for topological manipulations.

3.2. INTUITIVE AND INTERACTIVE MANIPULATIONS

Users must click the node within the center of a space then links to the node of another space for specifying an adjacent topology in SLG. However, Smart Topology provides more intuitive operation for the adjacent topology. When the boundary of a modified space is sensed adjacent with another space, Smart Topology will ask users whether to build an adjacent topology or not. Once two spaces have been indicated as an adjacent topology, users can switch the
topology of two spaces among adjacency, connective, and combination by clicking adjacent boundaries of two spaces. Even though two spaces are not adjacent, users can click the boundary of one space and then link to another by specifying a connecting topology. Linkages among spatial nodes are only applied to cancel the spatial topology between two spaces for now.

However, the SLG-based algorithm will not immediately move a space to the “right” position where all constraints are met. Smart Topology only checks one spatial topology and then tries to modify the position of one relevant space along one grid of X or Y dimension at a time. Obviously, this algorithm is too simple to solve conflicts, but the interactive processes between the spatial topology and geometry and visual cues provided by Smart Topology’s interface may still stimulate users to find out possible solutions.

3.3. PRELIMINARY EVALUATION ON SMART TOPOLOGY

Although efforts were made to develop Smart Topology, the following issues still require further studies: (1) a simple interface for users to sort the prosecuting sequence of different spatial topologies; (2) a intuitive interface for modeling multiple-spatial topology and geometry such as the group, alignment, and zoning; (3) an effective interface for tracking and rolling back spatial allocation processes.

Even though Smart Topology tried to avoid the effect of execution sequences, different orders of executing spatial topologies still cause different interactive behaviors among spaces in Smart Topology. Therefore, an interface for users to sort the execution sequence of spatial topologies should help users solve conflicts and find out possible solutions.

Multi-spatial topology and geometry usually are applied in large and complex projects to reduce complexities of design problems. Although it is possible to extend our approach to the containing topology, which allows a super-space as a group or a zone to contain other sub-spaces, at present, we are more interested in developing a simple yet intuitive tool for solving basic spatial allocation problems such as a small house project. However, we will try to integrate functions required in a complete and complex assisting environment into our next and more advanced version of Smart Topology.

Since Smart Topology has been tested to connect with a MySQL database for recording the history of a user’s manipulations in details, it is possible to store the final result as well as to track and then roll back the whole processes of spatial allocation. However, the efficiency of data retrieval and visualization becomes a programming challenge. It still needs more studies on developing an effective interface for the applying database technology to assist users in solving spatial allocation problems.
4. Discussions

4.1. SMART VS. SMOOTH CAAD TOOLS

As technology developed, the present CAAD tools have integrated more information technologies than ever and provide assistance to the AEC industry. However, the assistance seems to aim at applications of the engineering and construction industries while neglecting the needs of architectural design and education.

As a reviewer argued that a smart phone contains built-in stupid software (Manes, 2005), smart design tools usually implies not so smart manipulations such as the tedious inputs of parameters within a small but annoying dialogue window. The premise of a smart tool is to understand the intention of designers and then provide the right assistance at the right time (Do, 1998). However, the translation between design intentions and drawings is not so easy; and unconcerned manipulations usually interrupt the thinking and design processes. Especially for the early and conceptual design stage, an architect actually needs a simple but smooth tool to explore possibilities, rather than the exquisite but tedious equipment for detailed drawing. Therefore, although Smart Topology is named “smart”, we attempted to make its interface smooth in topological manipulation rather than smart in geometric arrangement.

4.2. SPATIAL TOPOLOGY VS. PHYSICAL GEOMETRY

Lao Tzu, a wisdom philosopher of ancient China, wrote in Tao Te Ching that “Doors and windows are cut out (from the walls) to form a room. Because of the vacancies of the doors, windows and space, the room is functional.”

Although physical components form the actual spaces of a building, it is the vacancies of spaces and opening that make a building really functional. The present CAAD tools have paid too much attention to coordinating the physical geometry of architectural components, with insufficient concern on recognizing and organizing the spatial topology of architectural spaces. Therefore, architects cannot even check two spaces within a building project whether those are adjacent or accessible by the CAAD tools.

The spatial topology and physical geometry of architectural design is actually like the two sides of a coin. For different design stages, architect may translate from spatial topology to physical geometry back and forth. Therefore, the translating device between the spatial topology and physical geometry and data models for storing their correlations should be the lost piece of the present CAAD tools, which connects the architectural design with engineering and construction industries.
4.3. SIMPLICITY VS. COMPLEXITY OF ARCHITECTURE

“Smart Geometry” is a new technology supported by Bentley using computing rules to generate complex architectural components, which are difficult to produce and control by traditional methods. It sheds lights on the title and approach of our research and intents to handle complexity by simple algorithm and programming codes.

We do not attempt to challenge the achievements of “Smart Geometry” but try to learn the concept of the minimal abstraction with most expression and extensibility (Aish, 2008). Through the simplicity of spatial topology and its basic geometric constrain, Smart Topology can assist users to handle complexities of spatial allocation.

5. Conclusions

Smart Topology moves toward additional manipulations of more topological relations and geometric properties compared to the SLG. As the topological relations and geometric properties limit and affect each other, Smart Topology has built simple algorithms extended from SLG to translate and check conflicts between the two. However, since the SLG-based algorithms of Smart Topology are too simple to generate solutions satisfying all constraints, the designers’ main task is to solve the conflict between the two during the spatial allocation. Currently, Smart Topology can maintain relative positions of spatial allocation so as to satisfy the defined topology relations during the design process and suggest the designer where the conflicts are. Visual hints provided by Smart Topology allow the designer to focus on the construction and modifications of the topological relations and then solve the conflict, which thereby avoids complicated drafting, modeling, or parametric inputs. Hence, we expect the introduction of more AI technology in the future to make Smart Topology smarter than now, for example, to point out possible solutions when conflict occurs or to learn available solution approaches from the user’s manipulations.

References


