SMART TOPOLOGICAL GEOMETRY
An Interactive Tool for Coordination of Spatial Topology and Geometry

CHIEH-JEN LIN
Department of Interior Design, Tainan University of Technology, Taiwan

ABSTRACT: This paper describes a prototype of an interactive tool named Smart Topology Geometry (STG) for coordination between spatial topology and geometry in the early design phase. STG focuses on the manipulations of virtual spaces and can manipulate the topological relations among them by instantly modifying the geometric properties of spaces so as to comply with the topological relation defined by the user.

KEYWORDS: Spatial allocation, spatial topology, interactive manipulation and design representation

RÉSUMÉ: Cet article décrit un prototype d’un outil interactif appelé Smart Topologie Géométrie (STG) pour la coordination entre la topologie et la géométrie spatiales, au début la phase de conception. Le STG se concentre sur la manipulation des espaces virtuels et rend possible la manipulation de relations topologiques entre eux en modifiant de façon immédiate les propriétés géométriques des espaces, dans le but de les rendre conformes à la relation topologique définie par l’utilisateur.

MOTS-CLÉS: Répartition spatiale, topologie spatiale, manipulation interactive, représentation du design
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 from the initial design phase of a building project, especially the engineering and construction process.

However, the nature of architectural design is to appropriately create and arrange topological and geometric relations between vacant spaces and physical components of a building. In the early design phase, an architect usually first considers the “topological relationship” among vacant spaces of a building program, rather than detailed geometric properties of physical components. For example, an architect may consider the adjacency among relevant rooms, the circulation formed by the connections of accesses and corridors among rooms, and directions of views formed by the opening, etc.

To an experienced architect, the topological relation among spaces not only presents what the design problems are, but also how s/he solves those problems. To a beginning student, the topological relation among spaces is the important but implicit design knowledge that s/he has to acquire and then represent when arranging all spaces within a building program. Hence, the topological relation among spaces is not only the key to allocate spaces within a building program, but also the guide to geometric relations among physical components within the building that shape those spaces. However, BIM usually only focuses on the geometric properties of physical components within a building and ignores the construction and maintenance of the topological relations among vacant spaces within the building. Hence, BIM can satisfy engineering and construction applications of a building project; but, it is not suitable for the application of architectural design tasks, especially in the early design phase.

2. THE SMART TOPOLOGICAL GEOMETRY APPROACH

This paper describes a prototype of an interactive tool named Smart Topological Geometry (STG), which coordinates the spatial topology and geometry in the early design phase. In the early architectural design phase, one of the major tasks is spatial allocation. The design objectives of spatial allocation can be summarized into two basic properties: topological and geometric (Arvin and House 2002). Topological objectives are those related to the relative positions and correlations among spaces; while geometric objectives are related to
the size and shape of spaces. The two types of design objectives reflect the architect’s intentions and the requirements for the building program.

Unlike BIM-based CAAD tools, which focus on the geometric properties of the physical components, STG focuses on manipulations of topological relations among vacant spaces. However, spatial topology and geometry objectives are actually two different representations of a same design problem or solution to the spatial allocation. Each objective needs to be translated into the other in the process of design problem solving. Through surveying spatial topology and its geometric representations, STG therefore modelled interactive behaviours between topological and geometrical manipulations of architectural spaces, in order to help architects solve the spatial allocation problems.

2.1. Survey on the Spatial Topology

The data model, which represents and reasons topological relationships among spatial features, is an important issue in geographic information system (GIS), but it is usually ignored in CAAD research. Basic topological relationships within GIS include adjacency, overlapping, disjointness, inclusion, etc. (Rigaux, Scholl and Voisard 2002). However, topological relationships of GIS are applied to represent important geographic features of open spaces; the goal is for computer to automatically reason correlations among spaces, such as the traffic connection. Therefore, not all GIS topologies are useful for architectural design, such as overlapping and inclusion. GIS may lose some important spatial features for architectural design, such as the accessibility of human circulation, which is formed by accesses between interior spaces in a building (Hillier 1996).

Therefore, topological relationships other than GIS are necessary for a CAAD tool. As a result, STG modelled four manipulatable and one detectable spatial topology for solving the spatial allocation. The four manipulatable spatial topologies in STG are: (1) adjacency, (2) connection, (3) combination and (4) opening. The detectable spatial topology is spatial orientation.

2.2. Graphic Representations of Spatial Topologies

Tedious constraint setting and annoying generation-testing procedures are common drawbacks of automatic generating systems. BIM-based systems do not seem to avoid the defect of complicated parameter-inputs. Therefore, the graphic representations of spatial topologies are necessary for intuitive manipulation within an interactive spatial allocation tool. Equations are left justified from the paragraph indent with a space before and after and equation number at right-hand margin.

Spatial topology can be expressed in four forms: an adjacency matrix, a network diagram, a bubble diagram, and a schematic plan (Ruch 1978; White 1986) (Figure 1). Although those representations have been developed for a
long time, due to technical constraints, there were no CAAD tools, which could integrate multi-representations of spatial topologies into a manipulatible object within a CAAD system.

**FIGURE 1. FOUR LEVELS OF GRAPHIC REPRESENTATIONS OF SPATIAL TOPOLOGIES.(RUCH 1978; WHITE 1986).**

In the previous study, we have modelled the Boolean adjacent topology of rectangular spaces in SLG (Lin 2005). The Boolean adjacent relationship means that two spaces must be adjacent when assigned an adjacent topology between them; it could be adjacent even without any assigned topological linkages. It is quite obvious that the Boolean adjacent topology is not enough to represent all important design issues of spatial allocation, such as the interior circulation. Therefore, STG extends adjacent topology of SLG to the connection, combination, opening, and orientation, for representing important design issues in spatial allocation (Figure 2).

The connective topology, which is built by an access connecting two adjacent spaces, can represent the interior circulation (Figure 2.2). The combining topology, 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 2.3). The opening topology, which is built by attaching an opening, can represent the relation of an interior space with outdoor spaces for the view and natural lighting (Figure 2.4). The orientating topology, which is determined by relative positions of two adjacent spaces, can represent the functional requirements such as a response to the climate or context of the site (Figure 2.5). However, to avoid complicated inputs in assigning spatial topology, only the first four topologies are manipulatible in STG. The orientating topology could only be detected.

**FIGURE 2. FIVE SPATIAL TOPOLOGIES IN STG.**
2.3. Manipulations of Spatial Geometry

Spatial allocation in architectural design is a process of solving conflicts between spatial topology and geometry. However, since spatial topologies can represent an architect’s intention or requirements of a building’s program. The manipulations of spatial geometry, such as altered shapes, dimensions, and relative positions, become the major means to solve design conflicts.

The spatial geometry manipulations in STG are based on SLG; therefore, the representation and operation of spaces in STG still apply rectangular space and 30/90cm grid system of SLG. The rectangular representation of a vacant space, as well as many other systems such as SEED (Flemming & Chien 1995), is useful for simplifying shape and dimensional issues in the early design stage. Furthermore, STG also applies a grid system to reduce the dimensional and area decision-making.

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. STG therefore applied an orthographic grid system, which is just like a graph paper or the grid system used by most CAAD software. STG has a 90cm-main grid system with three 30cm-sub-grids. The design of this grid system is based on 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.

The dimensional and area information of a space is more critical than its exact coordinates in the early stage of spatial allocation. STG therefore provides dimensional and area information dynamically and immediately, 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 when they first encounter it. The simplified information is helpful for users to concentrate on problem-solving rather than graph-drawing.

2.4. Interactions between Spatial Topology and Geometry

Due to the ill-defined nature of spatial allocation problems, there is a mutually interactive process between the indicators of spatial topology, which define design problems or present designer’s intention, and the modifications of spatial geometry, which search for conflict solutions or present requirements of the building’s program. Based on the interface and simple algorithm of SLG, STG provides an intuitive indicator, immediate response, and visual reminder to conflicts (Figure 3).
3.1 Assign an adjacent topology by user. 3.2 Modified relative positions by STG.

Once an adjacent topology is indicated, STG immediately modifies relevant spaces to be adjacent. Since STG models every space as a rigid body and does not allow two spaces to overlap, overlapping and other conflicts caused by the simple algorithm of STG still occur frequently. To assist users solve conflicts, every spatial topology needs to be translated into spatial geometry for both human reading and computer processing. STG thus models essential geometric constraints on each spatial topology into its algorithm.

For example, the connecting topology requires the minimal overlapping boundaries of two adjacent spaces to be at least 90 cm to create a normal access; the combining topology requires the minimal overlapping boundaries of two adjacent spaces to be at least 90 cm or half the shorter edge of the two spaces; and the opening topology requires the opening of a space not to be adjacent with any other spaces. Once a topology is specified or a geometric feature of a space is modified, STG will try to modify the relative positions of relevant spaces in order to satisfy those constraints. Even though the SLG-based algorithm is very simple and the shape and dimension usually involve with design’s intention or requirements of the building’s program, however, STG will not automatically modify the shape and dimension of a space for now.

3. IMPLEMENTATION OF SMART TOPOLOGICAL GEOMETRY

The prototype of STG 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, STG extends the methods and properties of the “space” class within SLG to more topological indicators, the intuitive manipulations and modifying algorithms.
3.1. Interface of STG

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 the original Java language, such as AWT or Swing. Consequently, all STG manipulations are restricted to the mouse or keyboard and do not involve complex parameters in a dialog window like BIM-based CAAD.

In the previous study, the original indicator of SLG applies a node within the centre of a space and their linking networks to manipulate and display adjacent topology. The network diagram of spatial node applied in SLG is an intuitive visualization for simple adjacent topology. This is not enough to indicate and represent other spatial topology of STG. Hence, STG expands the indicators from the adjacent node to the connective boundary for connecting topology, combining boundary for combining topology, and opening icon for opening topology (Figure 4).

**FIGURE 4. THE INTERFACE OF SMART TOPOLOGICAL GEOMETRY.**

For geometric manipulations, STG 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, STG extends the simple topological manipulation of SLG from linking adjacent nodes to sensitive boundary for intuitive manipulations. The boundary of a space in STG becomes the sensor for topological manipulations.

3.2. Interactive Manipulations

The indicator of an adjacent topology in STG is similar to SLG, where users can click the node within the center of a space, which then links to the node of another space for specifying an adjacent topology. However, STG provides even more intuitive operation for the adjacent topology. When the boundary of a modifying space is sensed adjacent with another space, STG 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 on the overlapping boundaries of two spaces. Even though the two spaces may not be adjacent yet, users can click the boundary of one space and then link to another for specifying a connecting topology. User can also link two linked spatial nodes again so as to cancel all the spatial topology between two spaces.

However, since the objective of SLG-based algorithm is to assist users to solve conflicts but not to automatically generate possible solutions, STG will not immediately move a space to the “right” position where all constraints are met. The SLG-based algorithm of STG 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 SLG-based algorithm is too simple to solve all conflicts, but the interactive processes between the spatial topology and geometry and visual cues provided by STG’s interface could still stimulate users to find out possible solutions.

3.3. Preliminary Evaluation on STG

Although some efforts were made to develop STG, the following issues still require further studies: (1) a simple interface for users to sort the prosecuting sequence of different spatial topologies; (2) an 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 STG tried to avoid the effect of prosecuting sequences, different orders of prosecuting space and their spatial topologies still cause different interactive behaviors among spaces in STG. Therefore, an interface for users to sort the prosecuting sequence of spatial topologies would be helpful for users to understand the interactive behaviors between spaces and to solve conflicts and find out possible solutions.

Multi-spatial topology and geometry are usually 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 such as a group or a zone to contain other sub-spaces, at present, we are more interested in developing a simple yet interactive tool for solving basic spatial allocation problems like a small house project. Still, we will try to integrate functions required in a complete and complex assisting environment into our next and more advanced version of STG.

Since STG has been tested to connect with a MySQL database to record a user’s manipulation history in details, it is possible to store the final result as well as to tack and then roll back the whole processes of spatial allocation. However, the efficiency of data retrieval and a visualizing interface become a
programming challenge in the Processing IDE. We need more studies to develop an effective interface for the applying database technology to assist users solve spatial allocation problems.

4. DISCUSSIONS

4.1. Smart vs. Smooth Tools

As technology develops, the present CAAD tools have integrated more information technologies than ever and provide much more assistance to the AEC industry. However, the assistance seems to aim on applications of the engineering and construction industries in the final constructing phase while neglecting the needs of architectural design and education in the early design phase. Consequently, an architect may feel like a draftsman or constructor more than a designer when s/he applies smart tools within CAAD software to draft or build a virtual building, rather than designing an ideal architecture.

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 parameter inputs within a small but annoying dialogue window. The premise of a smart tool should be able to understand the designer’s intention and then provide the right assistance at the right time (Do 1998). However, the translation between design intentions and software’s operation is not so easy; unconcerned manipulations and over detailed setting of smart tools usually interrupt the thinking and design processes. Especially in the early and conceptual design stage, an architect actually needs a simple but smooth tool to explore possibilities, but not the exquisite yet tedious equipment for detailed drawing. Therefore, although STG is named by “smart”, we attempted to make its interface simple and smooth in topological and geometric manipulation; we do not want a smart but complicated tool in generating possible solutions.

4.2. Spatial Topology vs. Physical Geometry

Lao Tzu, a wise philosopher in 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.” Hillier also proposed that the accessibility of human circulation should be the key to the social functions of a building or a city (Hillier 1996).

Although physical components form the actual spaces of a building, it is the vacancy of space and opening of walls 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, even though architects can apply CAAD tools to create impressive 3D models or to accomplish large and complex projects for now, they cannot even check whether two spaces within a building project are adjacent or accessible by their CAAD tools.

The spatial topology and physical geometry of architectural design are actually like the two sides of a coin. For different design stages, an architect may translate from spatial topology to physical geometry forwards and backwards. Therefore, the translating device between the spatial topology and physical geometry and data models for storing spatial topology is lost piece of the present CAAD tools, which connects the early architectural design to the final engineering and construction industries.

4.3. Simplicity vs. Complexity of Architecture

“Smart Geometry”, a new technology supported by Bentley applies computing rules to generating complex geometric components. It sheds lights on the title and approach of this paper. By developing a “generative component” and extensive programming environment within “Smart Geometry”, designers can create and edit complex 3D models, which are difficult to produce and control by traditional methods or other CAAD tools. The feature of “Smart Geometry”, which can handle complexity by simple programming codes, gives designers a powerful tool to explore possibilities of the architectural form.

However, we do not attempt to challenge the achievements of “Smart Geometry.” we try to learn the concept of developing a “generative component”, i.e. the minimal abstraction of design with most expression and extensibility (Aish 2008). Although the STG algorithms may not be smart enough to generate spatial allocation which met all constrains automatically, the STG visual prompts, such as interactive behaviors of relevant spaces as well as the changing colors and highlighting linkages of nodes and other topological icons, could still stimulate users to notice and then solve conflicts by themselves. Therefore, through the simplicities of spatial topology, STG can assist users to handle complexities of spatial allocation.

5. CONCLUSIONS

While we try to implement the SLG’s manipulations as easy as intuitive hand drawing on papers, STG also moves toward simplifying the manipulations of more topological relations and geometric properties. As topological relations and geometric properties limit and affect one another, STG has built simple algorithms extended from SLG to translate and check conflicts between the two. However, since SLG-base algorithms in STG are too simple to generate solutions satisfying all constraints, designer’s main task is to solve the conflicts
between the two during the spatial allocation. Currently, STG can maintain relative positions of spatial allocation to satisfy the defined spatial topology and their geometric constrains during the design process and hints the designer where the conflicts are. It does not solve conflicts automatically for the users. However, visual hints provided by STG allow the designer to focus on the construction and modifications of spatial topologies and then to solve the conflict, which thereby avoids complicated drafting, modeling, or parametric inputs. Hence, we expect the introduction of more AI technologies in the future will make STG smarter than now, for example, to point out possible solutions when a conflict occurs or automatically learn available solving approaches from the user’s manipulations.

REFERENCES