A Topology Deduction System for the Design and Construction of Buildings

By

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Abstract: Constructed facilities or buildings are comprised of many components, each of which is usually represented in product data models by their spatial information including three dimensional (3-D) geometry and topology. Geometrical data describes the facility components' dimensions and locations, whereas topological data represents information about spatial relationships (e.g. connectivity, adjacency, containment, etc.) between the facility components. In A/E/C (Architecture, Engineering, and Construction) area, information about topological relations are essential. This paper describes a computerized building data framework being developed in a solid modeling environment, which is capable of automatically extracting topological information of building components to support various aspects in building design such as constructability analysis, construction planning, and building code compliance checking.

Keywords: topological relations, building design, information representation, product data models, solid modeling, computer-aided design.

INTRODUCTION

In the context of building design, topological relations between building components are conventionally modeled directly in building product data models. Previous work on computerized building product data models [Eastman, 1990; Ford, 1994; Hakim, 1994; Ito, 1990; Tzanev, 1995; and Ikeda, 1996] has indicated complexities in explicitly representing all building information in general and topological information in particular because it often involves a large volume of building data.

Therefore, most of computerized building design systems that have been recently developed do not have sufficient capabilities to model 3D geometric and topological data of building elements [Ito, 1996]. The emergence of solid modelers has offered solutions for the representation of 3D geometric and topological information of design objects as well as provided support for the addition of semantic attributes describing the design objects [Zamanian, 1992].

This research concentrates mainly on specific information about the spatial relationships between building components to be designed at the preliminary stage. The research objective is to provide a computerized building data framework using geometric solid modeling techniques, from which topological information of building components can be automatically generated and extracted to support various aspects in building design such as constructability analysis, construction planning, and building code compliance checking. Typical examples of the applications of topological information to building design and construction include the following:

- Structural engineers require information about *connections* between individual structural elements for structural performance analysis or constructability evaluation,

- architects are more concerned about the *adjacency* and *intersection* between building spaces and their boundaries for creation of building shapes and space layouts,

- construction planners need information about the *vicinity* among construction zones for determining the interdependencies of construction activities to be performed in various spaces, and

- HVAC engineers use topological relations between spaces and their enclosing structures for heat-loss calculations and thermal analysis.

TOPOLOGICAL INFORMATION

A constructed facility or a building comprises of a large number of components among which the topological information (or spatial relations) are varied and complex to be represented in product data models. Also, different design tasks may require different types of spatial relations; for example, constructibility evaluation for a structural frame needs information about the *connectivity* between the frame's members; whereas space layout for a building requires information about the *adjacency* relations among the building's spaces. Furthermore, in the same discipline, designers may describe topological relationships, such as *adjacent-to*, *connected-to*, or *contained-in*, in different ways. For example, to express the adjacency between two building spaces, architects may refer to the relation where one space is either *next-to*, *right-to*, or *left-to* the other; and structural engineers may model the *connection* between a column and a beam as either a *supported-by* or *connected-to* relation. Also, many concepts about spatial relationships needed in the building design domain, especially building code compliance checking, are quite abstract and ambiguous to be directly represented in a computer data model. For example, a building regulation reads "the vestibule shall be *separated* from the remainder of the level of exit discharge by self-closing doors and the equivalent of ¼ in thick wired glass in steel frame" [BOCA, 1993], implying a requirement about the spatial relationship (i.e. *separation*) between the vestibule and the remainder of the level of exit discharge. Another example of abstract spatial relationships is found in some rules used in architectural design such as “the master room should be *behind* the central lines of the house, i.e., *away from* the main entrance, in order to provide the owner with more privacy and quietness” or “entrance to room should be *visible* from bed”.

A classification of the variety of spatial relations commonly used throughout the building design and construction process could be based upon identifiable physical relationships between two building components or systems, which have been described in [Rush, 1986], including *remote, touching, connected, meshed,* and *unified* (Figure 1).

The first relation refers to the case where two systems are *remote* from each other, i.e. they do not physically touch. The second relation involves contact without a permanent connection between the systems. The third category applies when two systems are permanently attached. The meshed category refers to systems that interpenetrate and occupy the same space. Finally, the unified case occurs when two systems are no longer distinct.

Following the classification of these physical relationships, various topological relations between building components can be correspondingly grouped into five main categories: *separation, adjacency, connectivity, intersection,* and *containment*, which have been found to be commonly used in various AEC disciplinary applications (see Figures 2 - 5).

TOPOLOGICAL DEDUCTION

The methodology to deduce topological information is analogous to the methodology to detect feature interactions between parts in mechanical engineering design, which has been described in [Talwar, 1994]. The methodology provides algorithms to generate quickly and accurately spatial relationships between design objects such as building components. The building components are represented as solid modeling objects in CAD environments. The information that an algorithm needs for deducing the spatial relationships can be obtained from the B-rep model of the solids and consists of vertex, edge, face, cell, and loop information. Basically, the determination of various spatial relationships between building components requires the relationships between vertices and faces of those components. There are three possible relationships between a vertex and a face, i.e. the vertex could lies on the face, to the right or above, or to the left or below the face.

The procedure for the deduction of various topological relationships between two building objects can be summarized as follows: an algorithm initially extracts B-rep geometric data from the CAD system and then checks for conditions of topological relationships, i.e. *adjacency, containment, separation, intersection,* and *connectivity*.

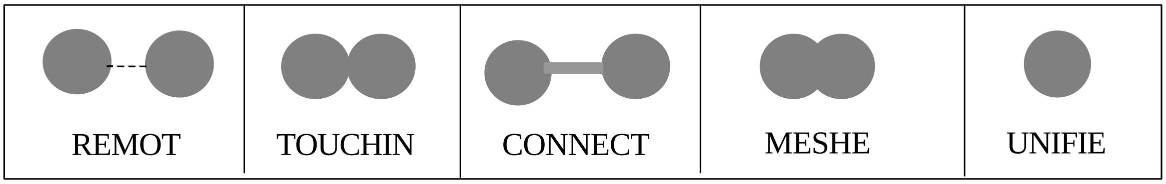

Figure 1 : Five Physical Relationships between Two Systems

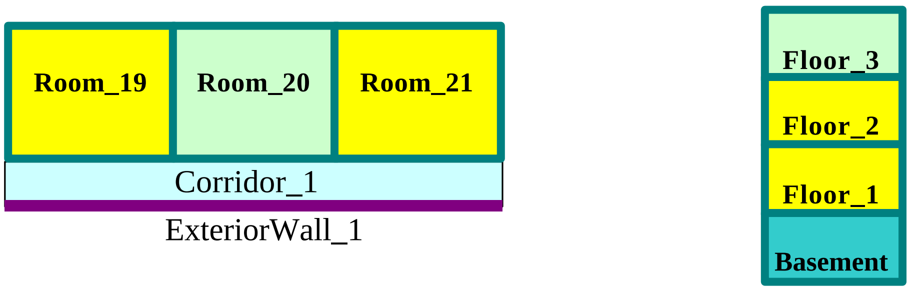

Figure 2 : Examples of Adjacency Relations

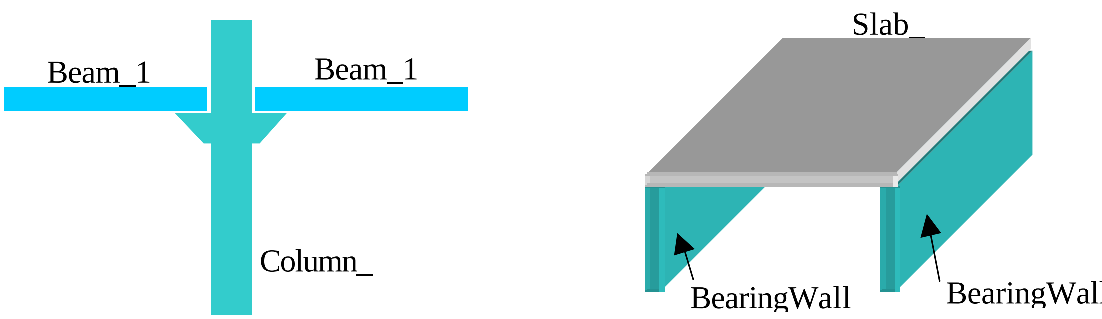

Figure 3 : Examples of Connectivity Relations

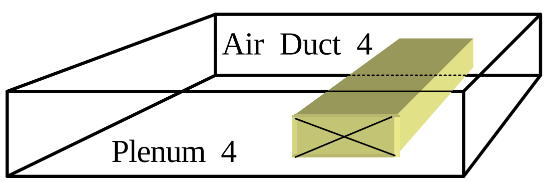

Figure 4 : Examples of Containment Relations

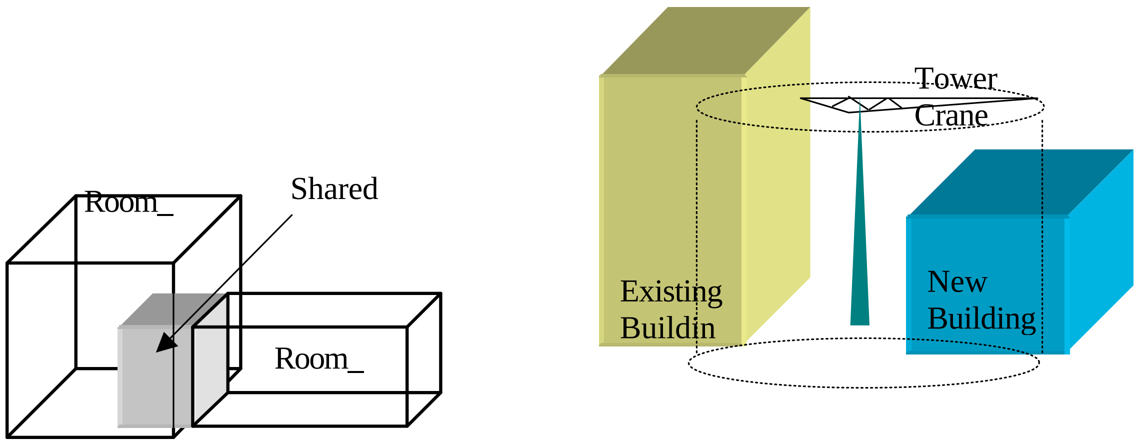

Figure 5 : Examples of Intersection Relations

CONCLUSIONS & FUTURE RESEARCH

This paper provides a classification of different topological information necessary for various AEC disciplinary applications and a description of a standard computer-based building design framework capable of automatically deducing the topological information to support different aspects of building design. The primary objective is to provide a formal methodology to deduce various categories of topological relationships among building components. The implementation of a prototype system has demonstrated the feasibility and practicality of the integration of a generation engine into the building design system for deducing complex information such as topological relations.

Recently, two important developments towards the standardization of building object models have been reported. The first effort is STEP/AP-225 by ISO, and the second development is the Industry Foundation Classes (IFC) developed by the International Alliance for Interoperability (IAI). These models however, are not fully capable of developing sufficient topological information needed by the various players in the AEC arena.

For future work, CAD systems need to be able to "deduce" the existence of "Spaces" from surrounding spatial elements. Furthermore, these systems should be capable of "splitting" and "aggregating" various building objects as needed, and later develop a "complete" topological model from this information. This is an important capability as for example some construction processes such as concrete pouring may require "splitting" an object in several "pieces" that will be poured separately.

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