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Introducing Building Indoor Topology Model (BITM) to Store Indoor Topology and Supporting Semantic Objects for Indoor Navigation

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Abstract

Indoor navigation models are a key part of indoor navigation systems, especially in microscale routing. Nowadays, indoor navigation approaches are using semantic information to extract indoor navigation graphs. However, the current algorithms suffer from a lack of detection of the semantics of indoor space. This paper proposes a Building Indoor Topology Model (BITM) for extracting indoor topology from BIM and storing the nodes and edges of the indoor navigation graph. BITM simplifies the complex indoor space by using Space and Portal classes and includes the geometric and semantic information required for the indoor navigation graph. BITM can support all indoor space objects. To clarify the structure and usage of BITM, a UML class diagram and a general approach to converting indoor topology to BITM using CityGML data model are provided. XMLSchema complexity comparison between BITM and three other standard navigation models proves the simplification influence of BITM. Hence, the proposed models can enhance the capability of current services for indoor navigation.

1. Introduction

Indoor navigation models are explicit representations of geometrical and topological information about the physical environments of buildings and the indoor navigation models, are a key part of indoor navigation systems (Fu et al, 2020). There are several types of indoor navigation models, and the most widely used are graph-based models result in less storage space and the inclusion of both geometric and semantic information about indoor space. Graph-based models are also called navigation graphs or route graphs, and the most essential thing to generating a navigation graph is the indoor topology of a building (Lin & Lin, 2018). Indoor space topology is a physical connection between indoor elements of a building, which are stored as nodes and edges in the navigation graph.

There are different approaches for extracting indoor topology, generating indoor navigation graphs, and storing the resulted indoor topology. In some research, the indoor topology and indoor navigation graph are generated by manually digitizing processes (Dimopoulou & Tsiliakou, 2016; Kim & Wilson, 2015). Often, prior to the indoor navigation extracting process, the complex 2D and 3D BIM datasets are generalized (simplified) by available software (Kim & Li, 2019; Tashakkori et al, 2015). The current software don't recognize building indoor space semantic objects and subsequently, during the simplification process, the useful semantic information is lost. Some other researchers are focused on methods in which indoor navigation graph generation is automatically implemented using computational geometric algorithms (Lewandowicz et al, 2019; Pang et al, 2019; Boguslawski et al, 2016; Tang et al, 2015; Yang & Worboys, 2015; Lee, 2004). BIM has a hierarchical structure and the geometric methods do not support indoor space topology. To overcome this, some other researchers proposed approaches using sub-space techniques for generating indoor navigation graphs semantically (Kruminaite & Zlatanova,2014; Diakite et al, 2017; Diakite & Zlatanova, 2017; Tekavec & Lisec, 2020). Semantic information is also used as a strategy in purely geometric graph production methods (Sadidi et al., 2021). Another model was introduced to simplify the CityGML model and support indoor navigation (Sun et al., 2020). The use of semantic information in indoor navigation research has a significant effect on increasing the efficiency, accuracy, and flexibility of the output (Afyouni et al, 2012).

As mentioned, indoor navigation approaches are moving towards the use of semantic information for extracting indoor navigation graphs. Without the use of semantic information, complete coverage of a building's indoor space by the indoor navigation graph is almost impossible. Hence, using semantic information provides a good strategy for generating indoor navigation graphs. In this paper, we proposed a Building Indoor Topology Model (BITM) for indoor navigation. BITM is designed to support extracted topology from Building Information Models (BIM) and describe the complex indoor environment in a simple hierarchy (the Space and the Portal classes) with semantic and geometric information required for the indoor navigation graph generation.

2. Methodology

2.1 Building Indoor Topology Model (BITM)

From the perspective of this paper, Building Indoor Environment Objects (BIEO) are either Space or Portal. In another word, from this point of view, the BIEOs are either space to stay or space to transmit. For example, rooms are generally a place to stay and settle, no matter what they are used for, and corridors or

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staircases are generally spaces for moving between rooms. Regarding this, different types of BIEOs are described using the general classes for generating an indoor navigation graph.

In order to add the ability to store the hierarchical topology of indoor space in BITM and its extendibility, BITM is designed based on XML (Extensible Markup Language). XML attributes are also used to describe the usage of Space (for example, office, conference room, or kitchen) and the type of Portal (for example, staircase, elevator, or corridor). The structure of BITM is shown in the Class UML diagram in Figure 1.

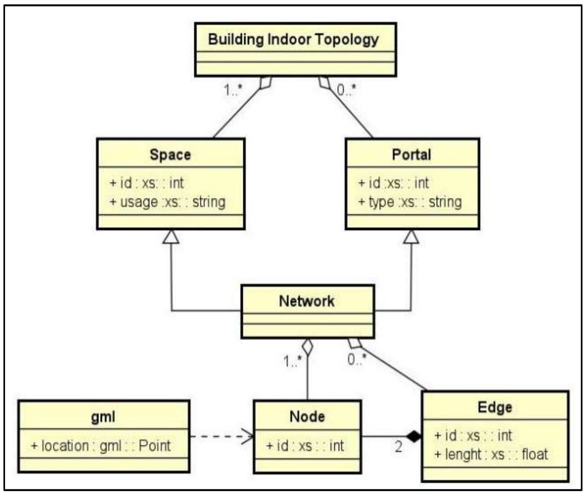

Figure 1. UML diagram of BITM structure.

To clarify the structure of BITM and assessment its application in indoor navigation, a general approach to converting indoor topology to BITM using a building information model has been implemented. The case study is performed by a CityGML dataset. BIEOs are converted to BITM and Finally, a database structure for storing BITM in a relational database is presented.

2.2 Indoor Topology Generation

Indoor topology in this study means whether BIEOs are related to each other or not. In CityGML, the horizontal connection of BIEOs (BIEOs that are located on a specific floor) is specified via XLink in the Opening Class (door, window, etc.) and the vertical connection of BIEOs in is specified using XLink in the Closure Surface Class, which is used for features which do not have a completely closed space such as stairs and elevators, etc. In fact, the Closure Surface Class is the hypothetical cross-section of this type of BIEOs. The topology extraction process is shown in Figure 2.

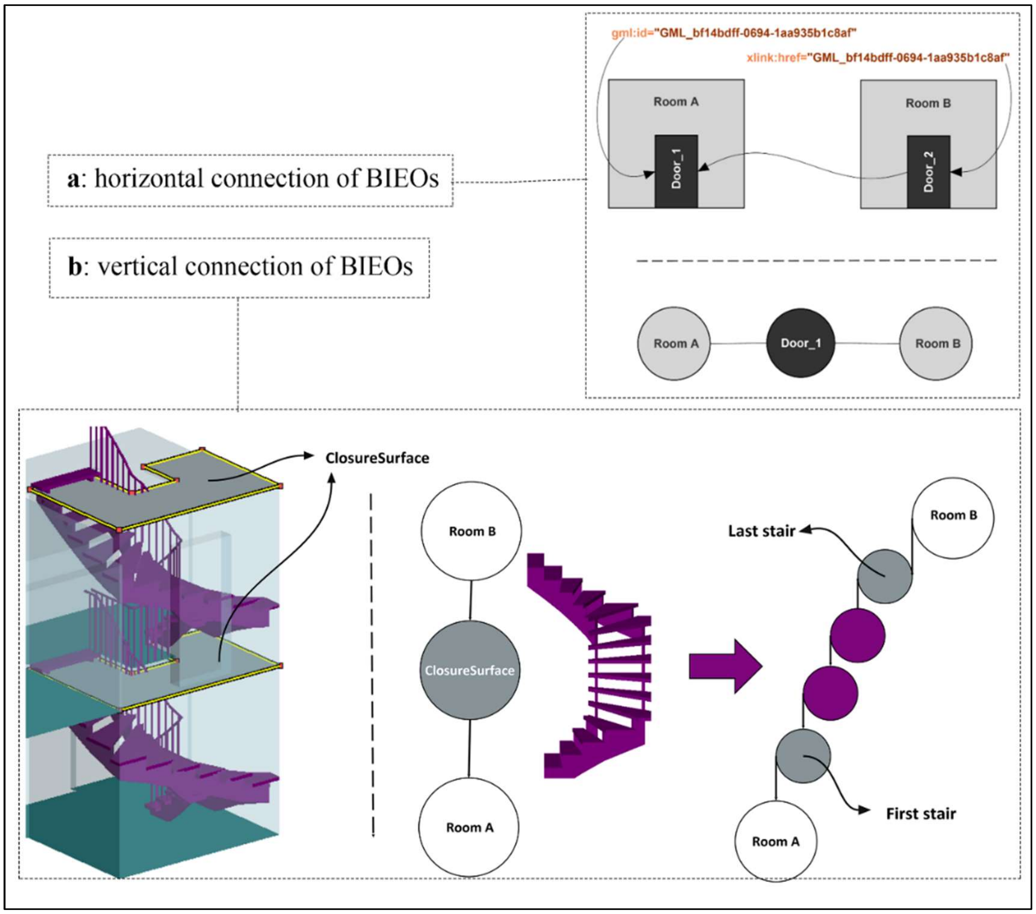

Figure 2. Hierarchical topology extraction from CityGML dataset.

2.3 Indoor Topology to BITM

As Figure 1 depicts, each object in BITM, whether Space or Portal, has a network of nodes and edges. The network can include only one node or a large network consisting of nodes and edges. This method allows for storing indoor navigation graphs with different levels of detail. For example, the space of a room can be added to BITM with just one node, or it can be stored as a network of paths. Usually, one of the challenging points in indoor navigation research is stairway navigation graph extraction. The navigable surface in the staircase is the horizontal surface of each step and in this study, each of the horizontal surfaces is used as a node in an indoor navigation graph. As shown in Figure 2b, each step of the staircase is extracted and sorted based on its elevation in the navigation graph.

It is notable that the current algorithms do not have the ability to detect the semantics of indoor space. Hence, here, the whole plan is not given as input to different types of computational geometry algorithms. But with the methodology presented in this research, the indoor navigation graph generation is done step by step according to the nature of BIEOs, and consequently, semantic information is not lost.

3. Results

In this research, the CityGML dataset is processed using citygml4j Java library for indoor topology extraction. The BITM of some typical BIEOs generated using the proposed approach is shown in Figures 3 and Figure 4.

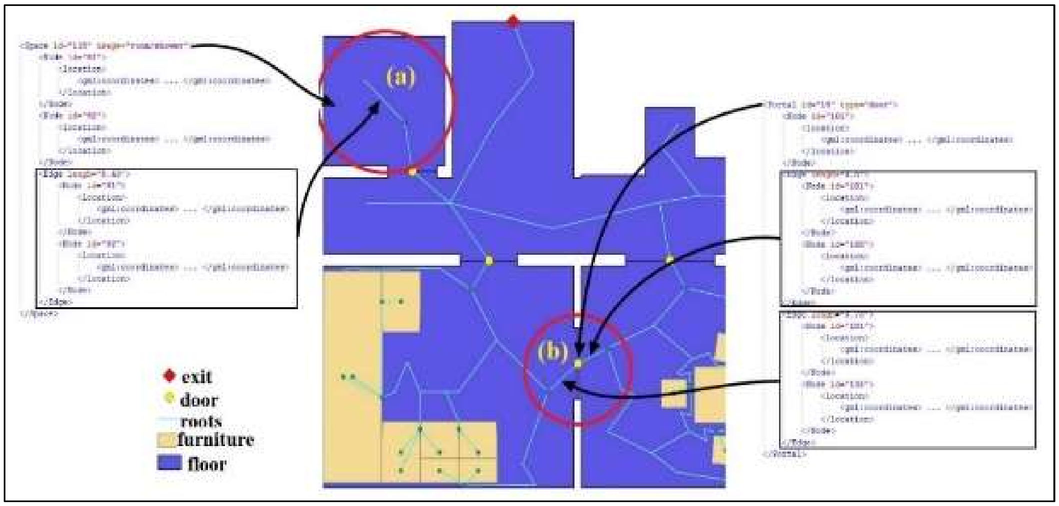

Figure 3. BITM dataset. (a) A room, (b) A door connects two adjacent rooms.

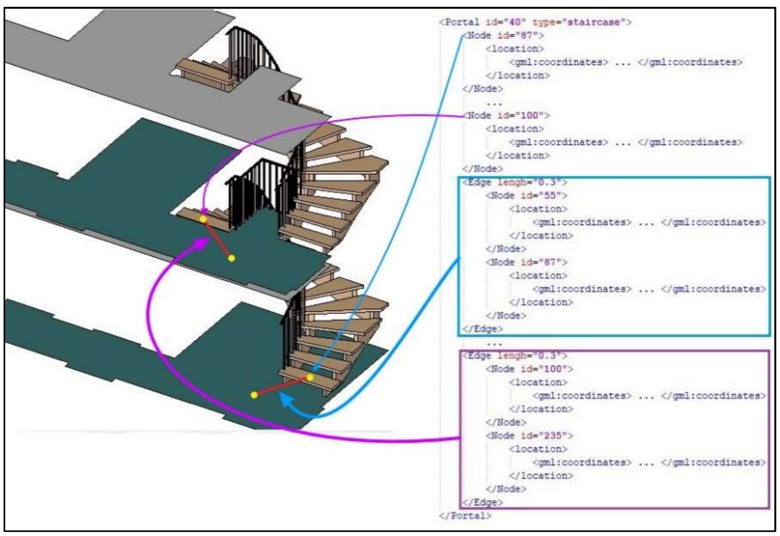

Figure 4. The BITM dataset of the stairway space.

The BIEOs converted to BITM in Figure 3 and Figure 4 show that usage of the Space is represented by "usage" attribute and the Portal type is represented by "type" attribute. The examples above also show how to convert the MAT (Chin et al, 1999) network produced for BIEOs to BITM format. With this method, the geometric indoor navigation route network is generated and stored semantically.

additionally, an RDBMS schema has been introduced for storing BITM in the database to store the resulted data. The proposed database structure is shown in Figure 5.

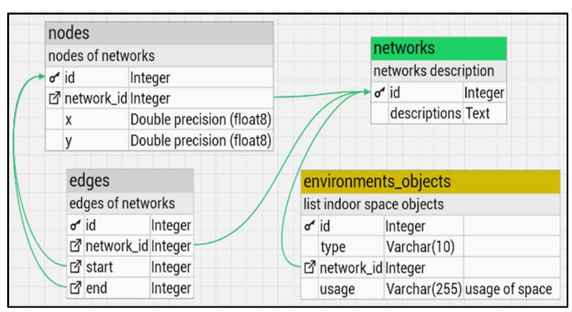

Figure 5. The database structure for BITM.

4. Conclusion

Regarding the importance of semantic information in indoor navigation as well as the strategic role of BIM hierarchical indoor topology for computational geometry algorithms, in this research, BITM is proposed to support indoor topology extraction and indoor navigation graph generation. The strategic role means that in the proposed method, the generation process of the indoor navigation graph has been done according to the usage and nature of BIEOs, which has not been considered in purely geometric methods.

In BITM the network of routes is segmented and each BIEO has its own network that is built based on the mentioned strategy. The graph generated with this method has a cellular space and also considers BIEOs as separate networks enabling the method for storing different levels of detail. CityGML has been used to extract indoor topology in this research, but any other BIM that supports indoor topology may be used by BITM.

To prove the efficiency of BITM compared to other standard navigation models, XML schema complexity criteria were used. XML Schema is a complicated language and the complexity of XML Schema and the difficulty of validation limit its use. Some of the XML Schema complexity analysis criteria are the Number of complex types (CT), Number of simple types (ST), and Number of global elements (EL) (Tamayo et al, 2012; Tamayo et al, 2011). Therefore, in this study, BITM is compared with some of the official navigation models based on XML Schema and the results for a particular case study are presented in Table 1.

Data Model	XML Schema Complexity Criteria		
	CT	ST	EL
CityGML Building module	27	-	40
BITM	3	-	4
IndoorGML core module	31	4	9
IndoorGML navigation module	18	-	13

Table 1. Comparison of some XML Schema complexity criteria between BITM and some standard navigation models.

As shown in table 1, the proposed model (BITM) significantly reduces the complexity in the all three criteria. Hence, BITM may be used to simplify the structure of the data can result in a lightweight database.

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