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Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison

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A B S T R A C T

The Building Information Modeling (BIM) domain and the Geographic Information System (GIS) domain share a mutual need for information from each other. Information from GIS can facilitate BIM applications such as site selection and onsite material layout, while BIM models could help generate detailed models in GIS and achieve better utility management. The mapping between the key schemas in the BIM domain and the GIS domain is the most critical step towards interoperability between the two domains. In this study, Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML) were chosen as the key schemas due to their wide applications in the BIM domain and the GIS domain, respectively. We used an instance-based method to generate the mapping rules between IFC and CityGML based on the inspection of entities representing the same component in the same model. It ensures accurate mapping between the two schemas. The transformation of coordinate systems and geometry are two major issues addressed in the instance-based method. Considering the difference in schema structure and information richness between the two schemas, a reference ontology called Semantic City Model was developed and an instance-based method was adopted. The Semantic City Model captures all the relevant information from BIM models and GIS models during the mapping process. Since CityGML is defined in five levels of detail (LoD), the harmonization among LoDs in CityGML was also developed in order to complete the mapping. The test results show that the developed framework can achieve automatic data mapping between IFC and CityGML in different LoDs. Furthermore, the developed Semantic City Model is extensible and can be the basis for other schema mappings between the BIM domain and the GIS domain.

1. Introduction

The architecture, engineering, and construction (AEC) industry is fragmented and yet information intensive [1]. Information sharing between stakeholders in the AEC industry is critical for collaboration during the construction process. Building Information Modeling (BIM) provides a solution for the interoperability in the AEC industry by providing an information backbone throughout the building life cycle. BIM is the process to create, store, and manage the information related to buildings throughout their whole life cycle [2]. Using BIM, different parties involved in the building process can work on a common platform, where the cost of information sharing is much less. While BIM aims to solve the problem of interoperability between stakeholders within the AEC industry, the integration of BIM with other systems, such as Geographic Information System (GIS), is becoming increasingly important. In the AEC industry, it has been reported that more than 80% of information could be referenced from geographical information [3]. Thus, the integration between BIM and GIS could further enhance information sharing.

GIS is a system to capture, store, manipulate, analyze, manage, and present all types of geographical data [4]. Traditionally, GIS is based on 2D maps, in which objects are assigned 2D references such as longitude and latitude. Currently, 3D GIS is also emerging. 3D GIS schemas such as KML [5], COLLADA [6] and Geography Markup Language (GML) [7] are able to store 3D attributes of objects in GIS, which enhances the functionality of GIS. There have been several studies concerning the application of GIS in the AEC industry. Su et al. [8] reported a GIS-based dynamic construction site material layout evaluation for building projects. Simão et al. [9] used a web-based GIS for collaborative planning and public participation in the planing of wind farm sites. Isikdag et al. [10] investigated the application of GIS to support site selection and fire response for BIM models. Anumba [11] developed a GIS-based approach to labor market planning in consruction. A comprehensive review about the application of GIS in construction activities was presented in [12]. BIM models are also rich information sources for GIS for certain applications. Benner et al. [13] presents a framework to generate

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semantic 3D buildings using BIM models. Hijazi et al. [14] introduced their initial investigations for modeling interior utilities in 3D GIS buildings from BIM models. Some applications also require collaboration between the GIS and BIM models. For example, Strzalka et al. [15] presented an urban scale heating energy demand forecasting system by combining information from GIS and BIM models. Thiis and Hjelseth [16] tried to use BIM and GIS to enable climatic adaptations of buildings.

It has been shown in previous studies that the BIM domain and the GIS domain have mutual need of information from each other. For example, when designing a building in a crowded urban environment, noise could be a concern for designers. By using data from GIS on neighborhood buildings and surrounding infrastructure, designers could have a much better understanding about the noise sources and take necessary measures in the design process in BIM. This kind of design process uses data from both BIM and GIS, and a seamless data integration between BIM and GIS should be achieved. The automatic data mapping between data schemas in the BIM models and GIS models must be achieved first in order to exchange data seamlessly.

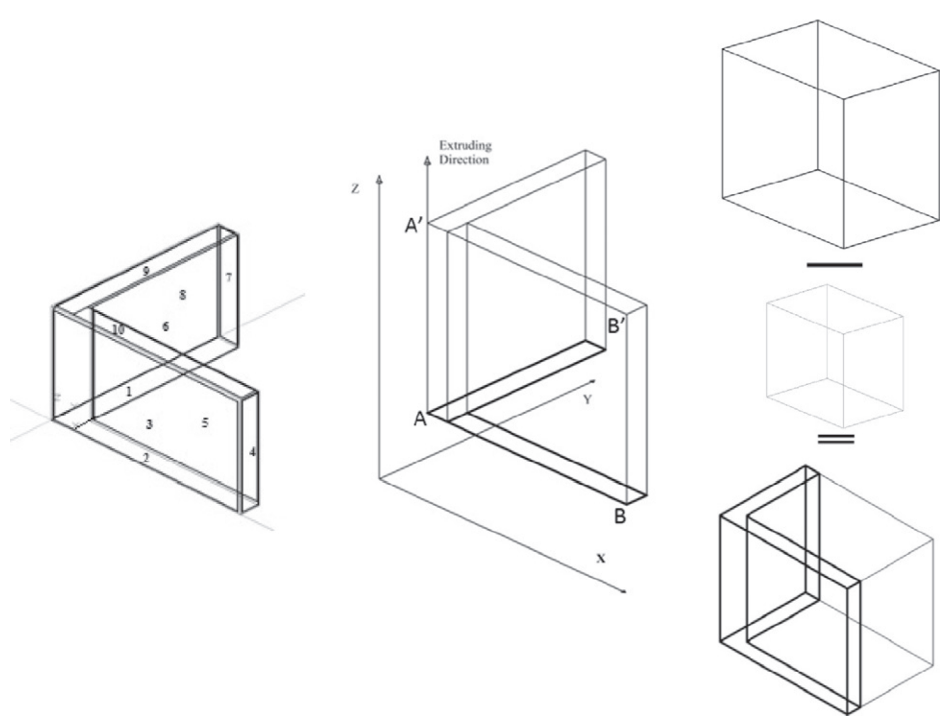
In this study, the Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML) are chosen as the representative schemas for the BIM domain and the GIS domain, respectively. IFC is an EXPRESS-based open data standard initiated by buildingSMART (formerly the International Alliance for Interoperability) in 1994. Supported by most of the BIM software in the AEC industry, IFC is believed to be the most popular BIM standard. On the other hand, CityGML is a GIS standard developed by SIG3D (Special Interest Group 3D). It was adopted as an official OGC (Open Geospatial Consortium) standard in 2008 by OGC members. It is a semantic-rich data standard which supports five levels of detail (multi-resolution) modeling of city objects. The data mapping between IFC and CityGML could be challenging due to the fact that the two schemas are proposed for completely different purposes. IFC tries to capture all the information relevant to a building, such as detailed geometry of building components and semantic information such as cost, scheduling, and utility information. CityGML models are usually used to capture demographic information with reference to a map or the geometry of buildings. IFC is EXPRESS-based, in which the entities are refered to each other by line number, while CityGML is an XML-based schema which uses the XML Schema Definition (XSD) to define the relationships between entities. Since there are a large number of entities in both schemas and the stucture of the two schemas are different, an instance-based inspection of entities in both schemas is desirable. Furthermore, due to the fact that IFC contains much more information than CityGML, a seamless information exchange will require the extension of the CityGML schema, for which a reference ontology is proposed to store all the relavant information from IFC models and CityGML models.

In this paper, we propose a mapping framework between IFC and CityGML which consists of four components:

- Transformation of geometry among BRep, Swept Solid, and Constructive Solid Geometry
- Transformation of coordinate system
- Schema mediation using reference ontology for different sets of terminology from IFC and CityGML, and
- Transformation among different LoDs in CityGML

Different components in IFC and CityGML from the building models will be extracted and compared to generate the mapping rules. The reference ontology is developed based on the attributes in these two schemas. Special attention is given to the inverse-attributes in the schemas of IFC and CityGML, which have not been covered by previous studies.

The remainder of the paper is structured as follows: Section 2 introduces the two data schemas and reviews previous methodology proposed to achieve the mapping between IFC and CityGML. Section 3 presents our proposed methodology framework utilized for the mapping. Section 4 discusses the transformation between LoDs in



(a) Boundary Representation (BRep)   (b) Swept Solid   (c) Constructive Solid Geometry (CSG)

Fig. 1. BRep, Swept Solid. and CSG.