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Ontology- and freeware-based platform for rapid development of BIM applications with reasoning support

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ABSTRACT

In the Architecture, Engineering and Construction (AEC) area, a prominent tendency is to use Building Information Modeling (BIM) data to perform analyses and calculations based on specified rules in regulations or standards so that BIM applications with reasoning support (BIM-R applications) are necessary. The current method is to develop BIM-R applications separately and represent the rules by coding or using proprietary formats, which has the problems of cost and efficiency. To solve these problems, a new method is proposed: to use a platform to rapidly develop BIM-R applications (BIM-R platform) based on ontology and freeware components. Thus, a BIM-R platform must be developed. This study establishes: 1) the functional requirements of the BIM-R platform, 2) the mechanism to transform BIM data into ontology data, and 3) the architecture of the BIM-R platform. This study also selects freeware components to develop the BIM-R platform. A BIM-R platform is implemented accordingly and applied to develop a prototype BIM-R application for the as-bid cost estimation of buildings for illustration. It is concluded that the proposed platform can help reduce the cost and improve the efficiency for the development of BIM-R applications and can be used by both researchers and developers.

1. Introduction

In the past decade, Building Information Modeling (BIM) has become widely used in the AEC (Architecture, Engineering and Construction) area, and a prominent tendency is to use BIM data to perform various analyses and calculations such as design check and cost estimation. Since such analysis and calculation must always be based on specified rules in regulations or standards, BIM applications with reasoning support (BIM-R applications) are necessary to use the BIM data and execute the specified rules [1]. Currently, there are several such commercial BIM-R applications, e.g., Navisworks [2] and Vico Quantities [3]. Existing BIM-R applications were separately developed, but they share many similarities in development, and the related rules have been represented by coding or proprietary formats in the applications, and therefore it is difficult for the users to maintain, update and reuse the rules. Thus, the current method to develop BIM-R applications has the problems of both cost and efficiency. However, if there is a rapid development platform that provides common components to facilitate the development of BIM-R applications, the speed and quality to develop BIM-R applications can be significantly improved, and the cost can be reduced. In addition, if such a BIM-R platform can use currently available freeware components, the cost of development can be further reduced.

At present, Solibri Model Checker [4] and FORNAX [5] are the only two available BIM-R platforms. The courthouse design circulation check system for the GSA [6] was implemented based on Solibri Model Checker, whereas the e-PlanCheck system in the CORENET project [7] was implemented based on FORNAX. In both cases, instead of ontology, proprietary formats were used to represent the rules, making it difficult to maintain and reuse rules within them, which hampers wider adoption. Ontology is one of the semantic web technologies to represent, exchange and reuse domain concepts, relations between concepts, and rules. Ontology has begun to be used in the AEC area for knowledge representation, information interoperation and rule-based reasoning due to its better adaptability and efficiency [8] [9]. Thus, a platform for rapid development of BIM-R applications (BIM-R platform) can use ontology to represent the rules for easy manipulation and reuse.

Although studies on ontology-based BIM-R platforms have not been reported, this is not the case for ontology-based BIM-R applications for specific domain problems. Hyunjoo and Francois [9] proposed a method to analyze possible conflicts of design BIM data by transforming the data into ontology data and checking the consistency of the ontology using the existing reasoning machine. The prototype tool of the study implemented the basic functions of the BIM-R application, but the data transformation in the tool was developed only for the domain problem in the study, which was difficult to reuse. Pauwels et al. [11]

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proposed a method to analyze the acoustic performance of buildings by translating the design BIM data into ontology data and performing reasoning according to ontology-based rules. The data translation in the study was generalized, but its reasoning results were represented only in text form with building component IDs. Because there are hundreds of building components with complex spatial relations in actual projects, the post-process for reasoning results, such as visualization and statistic, is necessary. Zhang et al. [12] developed a BIM-R application based on a commercial BIM modeling tool, i.e. Tekla Structures, to analyze the design BIM data for construction safety and suggest proper safety measures, but the application was limited to the projects where Tekla Structures [13] was used. Lee et al. [14] developed a BIM-R application to consistently infer cost items for building components via reasoning, but the rules were limited to tiling work, which hampered the application in terms of practical use.

To improve the efficiency and reduce the cost for the development of BIM-R applications, a new method is proposed: to use a BIM-R platform implemented based on ontology and freeware components. Before this platform is designed and implemented, studies regarding the functional requirements of a BIM-R platform and the way to implement the requirements should be answered. First, by analyzing existing BIM-R applications, the functional requirements of the BIM-R platform are summarized, and a mechanism to transform BIM data into ontology data is established. Second, based on the result, freeware components are surveyed and selected for the import, calculation and visualization of BIM data and the reasoning and query of ontology data. Then, the architecture of the BIM-R platform is formulated. Finally, an ontology- and freeware-based BIM-R platform is implemented accordingly and used to develop a prototype BIM-R application for the as-bid cost estimation of buildings as a case study of the platform.

2. Functional requirements of the BIM-R platform

As a premise, the rules in the BIM-R platform are assumed to be represented in terms of a domain ontology. Domain ontology is a form of representation of concepts, relations and rules in a specific domain so that information in the domain can be well stored, searched and shared. In addition, for better extensibility and reusability, the BIM data are assumed to be stored in files that conform to the Industry Foundation Classes (IFC) standards (IFC files). The BIM-R platform should provide the common functions that the BIM-R applications share. Thus, by analyzing the existing ontology-based BIM-R applications for different domain problems [10–12] [14], five functional requirements are obtained, as summarized in Table 1.

As assumed, the platform should support domain ontology and BIM data so that reading, parsing and writing ontology and BIM data in mainstream formats are necessary functional requirements. In addition, because reasoning is assumed to be conducted using ontology data, the functions of transforming BIM data to ontology data, reasoning and querying are required. According to the analyzed applications, visualization and query results can improve the user experience significantly because it is difficult and unintuitive for normal users to understand text-based query results. In this regard, highlighting and hiding building components as well as showing some tips around the building components are enough to satisfy the requirements, and the functions for complex 3D interaction, such as changing 3D shapes, are unnecessary.

Note that the domain ontology and BIM data can be created and modified using existing third-party tools, and relevant functions are not included in the BIM-R platform for simplicity.

3. Mechanism to transform BIM data into ontology data

When ontology is used to represent the rules, implicit data must be inferred from explicit data in the domain ontology by reasoning according to ontology-based rules to answer a certain domain question, where both explicit and implicit data are represented as instances of concepts and relations between instances. The BIM data must also be transformed into ontology data to obtain the explicit data to prepare for the reasoning.

As shown in Fig. 1, when BIM data are transformed into explicit ontology data, based on the analysis of the specified domain problem, not all BIM data are required for reasoning; thus, the unnecessary data should be filtered out (e.g., data A), and other data should be changed into another format to represent the same information (e.g., data B). Note that not all implicit data must be obtained by reasoning. Some data, such as the volume for complex building components and collision among building components, should be calculated through coding for the transformation (e.g., data C). Notably, compared to reasoning through hard coding using BIM data, reasoning through a reasoning machine using ontology is less efficient but has higher reusability and extensibility. In addition, filtering unnecessary data can improve the efficiency of reasoning and querying.

The method to translate BIM data into ontology data is affected by the format and structure of both BIM data and ontology data. As stated in Section 2, the IFC format is selected to input BIM data. Regarding the ontology, the Resource Description Framework (RDF) [15] is a well-used framework that provides the necessary data model, syntax and basic vocabulary for the semantic web. The Web Ontology Language (OWL) [16] is a recommended language that follows the RDF syntax and extends the data model and vocabulary to represent concepts, relations and instances of concepts in ontology. Since the ontology represented in OWL (OWL ontology) is compatible to the RDF syntax, it can be stored in various RDF formats such as Turtle (TTL) [17]. Thus, OWL is selected as the language to represent ontology data in the BIM-R platform.

One of the principles for building the domain ontology is to reuse existing basic ontologies. Although there are few basic ontologies in the AEC area, IfcOWL [18] is the only recommendation from buildingSMART International Ltd., a major no-profit organization providing the standards for BIM data. Both IfcOWL data and IFC data are semantically structured, which enables direct translation between them by simply changing the syntax. For simplicity, it is also assumed that the domain ontology on the BIM-R platform is built on IfcOWL, so that an existing open-source freeware component (IFC-to-RDF-converter [19]) to translate BIM data stored in IFC files into ontology data stored as RDF file [18] can be used. Thus, the mechanism of transformation based on IfcOWL consists of three steps, as shown in Fig. 1:

1) Calculate the implicit data required in the reasoning based on the

Table 1
Functional requirements of the BIM-R platform.

No.	Functional requirement	Detailed description
1	Handling of domain ontology	Read, parse and write domain ontology, supporting mainstream ontology formats.
2	Handling of BIM data	Read, parse and write BIM data in the IFC files, supporting mainstream formats of IFC files.
3	Transformation from BIM data into ontology data	Transform BIM data (both geometric and non-geometric) into ontology data, filtering unnecessary BIM data.
4	Reasoning and query using ontology data	Conduct expressive rule-based reasoning and query, supporting mainstream ontology formats.
5	Visualization of BIM models and query results	Highlight and hide building components and support basic 3D interaction