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A study on software architecture for effective BIM/GIS-based facility management data integration

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ABSTRACT

In this study, we propose software architecture for the effective integration of building information modeling (BIM) into a geographic information system (GIS)-based facilities management (FM) system. This requires the acquisition of data from various sources followed by the transformation of these data into an appropriate format. The integration and representation of heterogeneous data in a GIS are very important for use cases involving both BIM and GIS data, such as in the management of municipal facilities. We propose a BIM/GIS-based information Extract, Transform, and Load (BG-ETL) architecture that separates geometrical information from that related to the relevant properties. The property required for each use-case perspective is extracted and transformed from information for the BIM with FM to GIS using the ETL concept. In consideration of the viewpoint of geometry, the surface model for several representations in the GIS, we designed BG-ETL, developed a prototype, and verified the results through interviews. The results show that BG-ETL considering BIM/GIS integration issue has benefits such as reusability and extensibility.

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1. Introduction

The integration of data through geographic information system (GIS)-based building information modeling (BIM) has recently emerged as an important area of research. Several studies have investigated the benefits of the effective integration of BIM and GIS [10,11].

This process generally involves the extraction and transformation of information required by each stakeholder in the relevant project. GIS and BIM are similar in that they both model spatial information — the former is used for outdoor modeling and the latter for indoor modeling — and have common use cases, such as location-based municipal facilities information queries and management. In order to realize use cases based on BIM and GIS, effective interoperability between GIS and BIM should be supported by an appropriate platform.

To facilitate information interoperability in the construction sector, buildingSMART has developed and standardized the Industry Foundation Class (IFC) data model in a significant effort to accommodate industry requirements. IFC is an integrated model schema that describes construction information. It uses an object-oriented method to integrate information required by the relevant stakeholders in a project.

Attempts to integrate information models using IFC have aimed to achieve the relevant objectives. However, there are practical issues in solving the integration problem. For example, during information exchange between heterogeneous systems or commercial modeling software using IFCs, some loss or change of information has been reported [1]. Furthermore, a related study has pointed out various issues associated with the integration of BIM and GIS [12].

In particular, a facilities management system that has accumulated data over a long period tends to lack IFC compatibility and fails to support the creation of an IFC model. In general, the formats that a facility management (FM) system supports for import and export are text, spreadsheet, and relational database file, and the data in these are heterogeneous [35]. Managing a BIM-based facility initially requires the integration of heterogeneous data with a BIM object. Only following integration can the GIS effectively utilize the BIM containing facility management data. The manual integration of heterogeneous data can incur a substantial cost and cause incorrect data entries, thus hindering correct decision making.

For these reasons, integration between heterogeneous datasets related to FM, and the BIM and GIS models should be automated. Moreover, the data integration process should be adjustable according to the use case at hand, and each phase of integration should be testable.

This study approaches problems related to BIM-based data integration from a practical perspective. To integrate heterogeneous data, such as BIM, GIS, and FM data, we propose a method to map FM data from BIM to GIS by using a BIM/GIS-based information Extract, Transform, and Load (BG-ETL) method. To verify the effectiveness of the proposed architecture, we develop a prototype system and conduct interviews with experts.

Abbreviations: BIM, building information modeling; FM, facilities management; GIS, geographic information system; IFC, Industry Foundation Class; LOD, Level of Detail

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In this study, the data to be integrated is divided into two categories:

1. Geometrical information representation based on BG-ETL: The geometry of the BIM object presented to a GIS viewer for a client should be a surface model. This is represented by accounting for the levels of details (LOD) 1, 2, and LOD4, as specified in CityGML LOD schema.
2. Property information exchange based on BG-ETL: Properties desired by the user will be displayed when a specific facility is selected in the BIM viewer, taking into consideration the perspective of the project's stakeholders and the convenience of the relevant information.

2. Research objective

Our purpose in this study is to propose BG-ETL architecture for the effective integration of BIM, GIS, and FM data. We design BG-ETL workflow in order to define each phase to map BIM objects to GIS objects in a CityGML model after integrating external, heterogeneous data into the attributes of the BIM object. For BIM object shaping, LODs are obtained through an LOD extraction algorithm and mapped to the LOD of the relevant GIS object. Accordingly, we also propose an architecture that effectively integrates the properties and shapes of the BIM object into GIS and displays them, as this is required by the user.

In this study, we design the ETL concept for the proposed BG-ETL architecture to effectively integrate BIM, GIS, and FM data, and provide object mapping that transforms the BIM model — IFC — into the GIS model, CityGML. BG-ETL includes heterogeneous data extraction, data integration with the BIM object, a workflow transforming the BIM object to the GIS object, and mapping rules.

To test the usefulness of the proposed architecture, we implement simple facility management use cases. We extracted and processed information stored in the BIM facility management database of the Korea Institute of Construction Technology to check the information using the GIS through the BIM model. The model uploaded to the GIS is a surface-based model that simplifies the BIM model, which has a large capacity, and contains information of a degree of detail between LOD1 and LOD2. We can upload the BIM model to an additional viewer in order to check details beyond LOD3. When a facility object included in the BIM model is selected, the FM information can be viewed. Through this architecture, the information required according to each use-case perspective is defined, processed, and extracted through BG-ETL. Thus, heterogeneous systems are cost-effectively interrelated to form a data warehouse that can be utilized for information mining. BG-ETL provides various data sources and facilitates function expansion. The object geometry information of BIM can be quickly visualized by the simplified surface model.

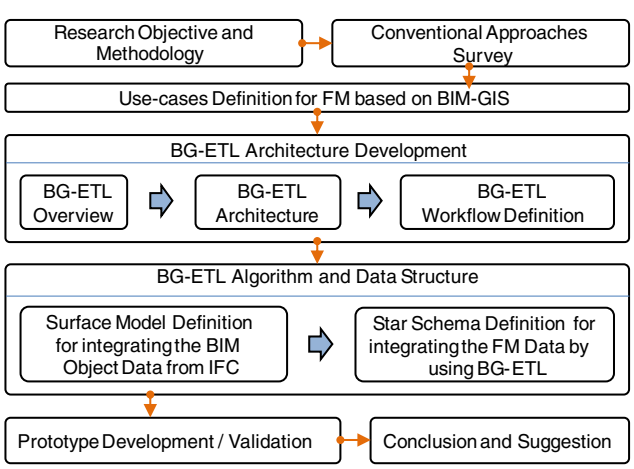

Fig. 1. BG-ETL research flow.

The rest of this paper is organized as follows (Fig. 1): in Section 3, we review recent research on the interoperability of BIM and GIS. This includes use cases and the BG-ETL architecture. Section 4 contains a description of the BG-ETL architecture designed based on information from the previous section. The architecture is designed to support the proposed use cases. We develop a system by referring to the architecture design, and use a simple prototype to show the implementation of FM use cases of the Korea Institute of Construction Technology. Further, to test the BG-ETL architecture, we create a prototype, conduct case studies, and evaluate the utility of the proposed architecture through expert interviews. The final section presents our conclusions and considers avenues for future research.

3. Conventional approaches

3.1. Overview

Although it is difficult to precisely categorize studies on BIM and GIS data integration, we classify them into groups based on similar subject keywords and categorization trends in recent research as follows:

1. Schema-based approaches: The purpose of schema-based data integration is to integrate heterogeneous schema models and facilitate the exchange of information among them. Schema-based approaches expand schema structures, develop a common schema, or define mapping rules for a schema model.
2. Service-based approaches: Service-based approaches perform services that can request and extract information from each heterogeneous model for the integration and conversion of heterogeneous data.
3. Ontology-based approaches: Ontology-based approaches extract information from heterogeneous models and generate a common ontology model using a general ontology model, such as the resource description framework (RDF). They also apply data mapping rules between two heterogeneous models using ontology operators.
4. Process-based approaches: This class of approaches offers modeling guidelines or specifications to integrate heterogeneous data into a standard model, such as IFC. It assists in modeling operations and provides a method to confirm modeling results. However, the modeling for data integration is mostly carried out manually.
5 System-based approaches: These approaches embrace the above approaches and propose a systematic architecture for the integration of heterogeneous data. Such approaches make full use of open libraries, components, and commercial software tools, and implement data integration architecture.

3.2. Schema-based approaches

3.2.1. Schema-based application domain extensions approaches

Hijazi et al. [2] proposed a mapping methodology to extract utility information through CityGML application domain extensions. The integration of BIM into GIS was considered in a study on GeoBIM to extend GIS data using CityGML and an open source-based BIM server [3].

Sebastian et al. proposed a method that expands BIM using an application domain extension to support interoperability between BIM and a GIS in relation to a bridge construction plan [13]. Furthermore, in order to implement a GIS-based use case, such as land selection or fire management in the construction industry, Isikdag et al. proposed a method to integrate BIM information into GIS [14]. The relevant study developed a persistent schema-level model view schema in order to convert IFC data into an Environmental Systems Research Institute (ESRI) schema. It also proposed a method that converts these data into transient temporary object model data, integrates them with a GIS geographic data model, and saves the final data in ESRI's shape file and geodatabase structures [15,16]. Expert interviews were used to confirm the results of this study in terms of quality according to ISO 9126-1.

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