BIM/GIS-based Data Integration Framework for Facility Management

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***Abstract*— In this study, we propose a software architecture for the effective integration of building information modeling (BIM) into a geographic information system (GIS)-based facilities management (FM) system related to smart city service. This requires the acquisition of data from various sources followed by the transformation of this 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 Data Integration Framework (DI) that separates geometrical information from that related to the relevant properties. For a GIS based facility management, the property information is extracted from BIM models and transformed using the ETL (extract, transform, and load) concept. In consideration of the viewpoint of geometry, the surface model for several representations in the GIS, we designed BG (BIM/GIS)-DI, developed a prototype, and verified the results through interviews. The results show that BG-DI and BIM/GIS integration has benefits such as reusability and extensibility.**

Keywords-BIM; GIS; FM; integration; surface model; BG-DI

I. INTRODUCTION

The integration of data through geographic information system (GIS)-based building information modeling (BIM) has recently emerged as an important area of research related to developing smart city services. Several studies have investigated the benefits of the effective integration of BIM and GIS [1][2].

This integration process generally involves the extraction and transformation of information required by each domain in a single project. GIS and BIM are similar in that both are used to 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, etc. In order to implement some 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, the buildingSMART, which is the worldwide authority driving transformation of the built environment through creation & adoption of open, international standards, has developed and standardized the Industry Foundation Classes (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.

Even though the IFC based information model integration was researched using various methods, there were practical issues in solving the integration problem. For example, during information exchange among heterogeneous systems, which means more than two different software, or commercial modeling software using IFCs, some loss or change of information has been reported [3]. Furthermore, a related study has pointed out various issues associated with the integration of BIM and GIS [4].

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 [5]. Managing a BIM-based facility initially requires the integration of heterogeneous data with a BIM object. By integrating GIS and BIM, the BIM model including the facility management data can be utilized effectively based on GIS 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 among 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-DI) method. To verify the effectiveness of the proposed the architecture, we developed a prototype system and conducted interviews with experts.

The rest of the paper is structured as follows. In Section II, we present the research objective of this study. Section III describes other conventional approaches from related literature. In Section IV, we describe our BG data integration framework and, in Section V, we discuss some case studies. We conclude in Section VI.

II. RESEARCH OBJECTIVE

Our purpose in this study is to propose BG-DI architecture for the effective integration of BIM, GIS, and FM data. We design BG-DI 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-DI 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-DI 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-DI. Thus, heterogeneous systems are cost-effectively interrelated to form a data warehouse that can be utilized for information mining. BG-DI provides various data sources and facilitates function expansion. The object geometry information of BIM can be quickly visualized by the simplified surface model.

III. CONVENTIONAL APPROACHES

Hijazi et al [6] 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 [7].

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 [8]. 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 [9]. 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 this 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 [10][11]. Expert interviews were used to confirm the results of this study in terms of quality according to ISO 9126-1.

Moreover, a few researchers attempted to solve problems arising from the difference between BIM and GIS schemas by developing a new common schema. This unified building model (UBM) analyzed IFC and CityGML schema structures and proposed a new schema [12][13].

BIM data can be converted into another schema model depending on its structure. Such conversion is considered a mapping-based process that, in general, consists of several mapping conditions and rules.

In relation to this approach, Nour partially utilized a model in order to use IFC in a cooperative team work environment [14]. He pointed out that schema-based modeling tools, such as Standard for the Exchange of Product Model Data (STEP) tools and Express Data Management (EDM), are complex and inconvenient for the user.

LaPierre and Cote [15] proposed another approach to integrate data that considers a web service-based solution for city data management using CityGML, Web Feature Service (WFS), and 3D Viewer. Döllner and Hagedorn [16] researched the integration of city information from GIS, computer-aided design (CAD), and BIM using a web service supported by the Onuma system, and Akinci et al. [17] proposed an ontology structure and a navigation method to resolve the CAD and GIS use cases.

A Spatial Data Warehouse (SDW) is a system that adds a 3D model of the required information from the use-case perspective to the existing data warehouse system. SDW has long been studied in the field of GIS. It supports analysis and decision making by storing non-volatile data that have integrative and temporal properties according to the relevant topic-centered spatial and non-spatial information regarding properties [18]. SDWs are constructed based on spatial data extracted from heterogeneous systems, such as a GIS and asset management systems. BIM also focuses on the re-utilization of object information over a certain space and can be effectively utilized from the perspective of BIM interoperability. An SDW can be created and renewed in a topic-oriented manner through ETL.

For data managed using FM, ETL supports effective extraction, transformation, and loading processes from heterogeneous systems. Even if numeric data are the same at the time of loading, they can have a different meaning or representation depending on the perspective of the project stakeholder or the user.

During the construction of a data warehouse (DW), it is important to load only the required information by extracting source data from the heterogeneous database management system (DBMS) or the software used by the relevant project's stakeholders. The extracted data may include geometrical spatial data, as well as non-spatial data, such as properties. From the BIM perspective, spatial data extracted and loaded through an ETL process should have a structure that assists the data analysis requirement with respect to the DW [19].

A recent study by Gökçe and Gökçe on ETL for buildings centered on a case study of the energy management system used to perform extraction, transformation, and data loading [20]. They showed that a single integration information model is not suitable for an environment where each project stakeholder uses a different database. They proposed an architecture where building information was extracted from data sources and sensor data, including multi-dimensional data, to avoid the above-mentioned problem. Information was extracted using a wireless sensor network or CAD and was managed in the DW.

As described above, SDWs are the focus of most DW- and ETL-related studies. Few studies have considered data integration in conjunction with a GIS.

Of the aforementioned studies on heterogeneous data integration, the service- and system-based approaches may be more effective than others in terms of system performance, but are disadvantageous because the programming code for system development can limit the element mapping process, in which heterogeneous data are integrated, of the relevant models. These approaches hinder the flexibility and extendibility of a system, and require extensively specialized problem-solving methods.

IV. BG-Data Integration Framework

A. *Overview for semantic data integration between*

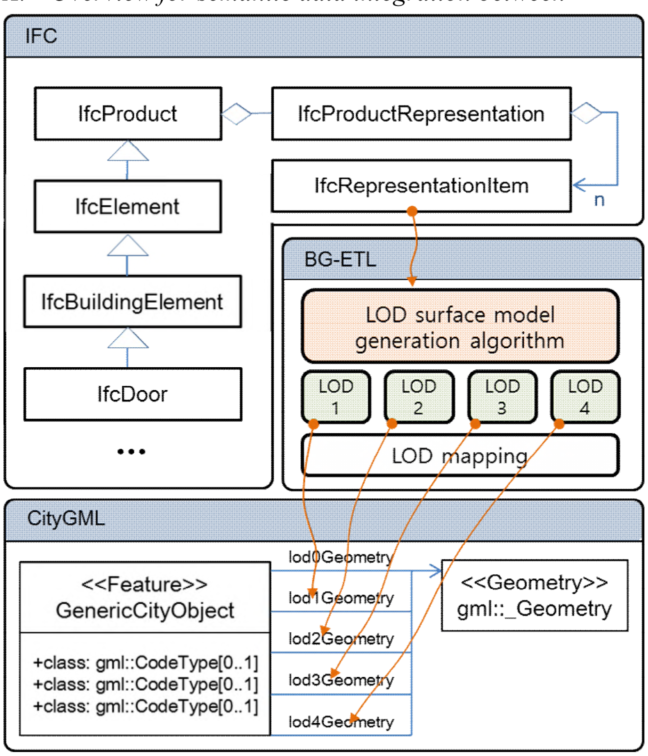

Figure 1. Data Integration Process between IFC and CityGML

For data integration between heterogeneous data models, mapping rules appropriate for a use-case are needed. Further, if an element is missing when mapping from the data source to the target information model, an algorithm that generates the necessary element using the data source needs to be executed prior to executing the mapping rules. Figure 1 shows such a process.

B. *Data Integration Framework Design*

The BG-DI architecture should consider the scalability and flexibility of the data integration method in order to support interoperability. Taking this into consideration, the architecture for supporting BIM/GIS-based FM is designed as shown in Figure 2. The BIM/GIS middleware consists of an IFC converter to represent GIS model, which is suggested, BG-DI to extract the external data related to FM. Following its extraction from the heterogeneous system, such as the excel file, external data is stored in the DW DB. The DW storage phase normalizes heterogeneous data in the form of a table. Following this, the datasets stored in each table of the DW are connected to the BIM object of IFC. To link the BIM object and external data, such as maintenance records stored in the excel file, the Primary Key (PK), such as the Globally Unique Identifier (GUID), is used as the primary key in the data schema of our database. The BIM objects are mapped in the form of CityGML to be represented in GIS format. Moreover, for prompt visualization, building facility objects in the GIS are converted to a lightweight surface format. The facility objects are represented as LOD1, LOD2, etc., in GIS, and the shape of an object at a high level, such as LOD4, is verified through a separate viewer.

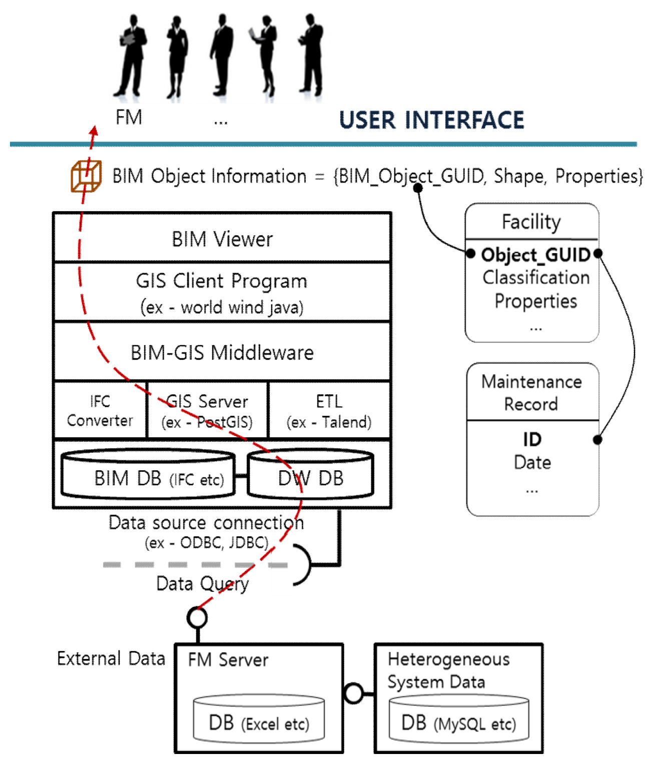

Figure 2. BG-Data Integration Workflow

C. *BG-DI workflow and data mapping rule set*

If connecting heterogeneous facility data and the BIM object, and representing the data and object in the GIS are not automated, the data modelers and FM staff need to perform additional tasks for data integration and manual conversion. Such manual tasks can cause side effects, including data entry errors, and the integrity of the integrated data can be compromised, thus generating unproductive results. Therefore, if possible, the workflow where the elements between set of heterogeneous data models are mapped needs to be automated, and a standard method is needed to verify the integrity of the data during mapping. A BG-DI workflow is defined to standardize such data integration. The BG-DI workflow is applied using the ETL concept and, as shown in Figure 3, mapping the elements of the data model between two heterogeneous systems is completely automated.

The definition of the BG-DI workflow consists of the following elements:

1. Extraction: Heterogeneous datasets are extracted and stored in the form of a relational database. The necessary data from the perspective of each use case are extracted; the data structure is similar to a star schema, which is built in the DW. The relationship of the table of each dataset forming the schema should be set around the PK, as with the object GUID, in order to connect it to the BIM object.

2. Transform: This process comprises two steps:

1) D2B_Binding: The dataset is integrated by linking it to the relevant BIM object. The dataset is extracted from the table stored in the DW during the extraction phase. The parameter for setting the PK needed for the data source stored in the DW and binding is defined as the "DataRecord" element. The parameter is used to bind the BIM object and the dataset of the DW through the PK field, which is designated in the "Object" element. The "category" parameter is used to distinguish the attribute categories, and any name that is designated here is saved as "("+"categoryname" + ")" + "attributename" during CityGML's attribute mapping.

2) B2G_MappingRuleset: The mapping rules are defined to semantically map the integrated BIM object to the GIS object. The mapping rules are classified into "Object," which is an object attribute mapping rule, and "Geometry," which is a shape mapping rule. Mapping a shape requires the execution of a separate algorithm to generate the LODs. Thus, an algorithm implementation module can be set to the "algorithm" parameter. The mapping source is designated as "source" and the mapping target as "destination."

3. Load: The format mapped to a GIS object is represented in CityGML and, for effective visualization of the actual building facility objects when they are loaded in the GIS, data integration post-processing may be needed. That is, the data can be converted to a lightweight format optimized for visualization. Such post-processing requires an additional algorithm.

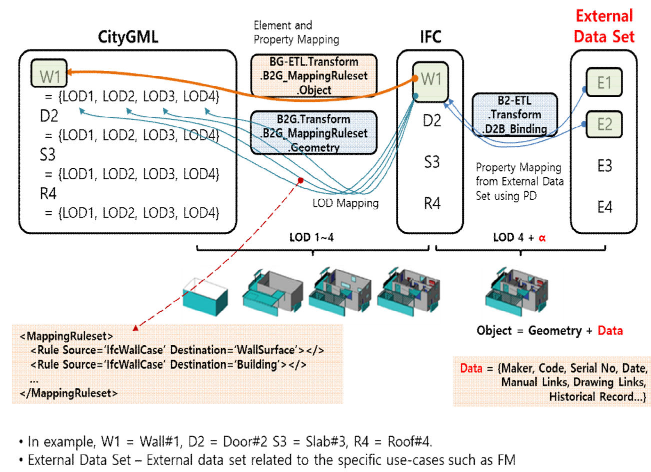

Figure 3. BG-Data Integration Workflow

BG-DI defines a mapping rule table for semantic mapping from the BIM model to the GIS model. The mapping tables are classified into two types, attribute mapping and shape mapping, and is defined. Attribute mapping is defined by naming the source and target object, where the attribute tag "TYPE" is used to store the type of the source object in the corresponding target object because 1:1 mapping is difficult. For shape mapping, the LOD unavailable in the BIM model needs to be obtained through an LOD generation algorithm and then properly mapped to the LOD of an object, as shown in Figure 4.

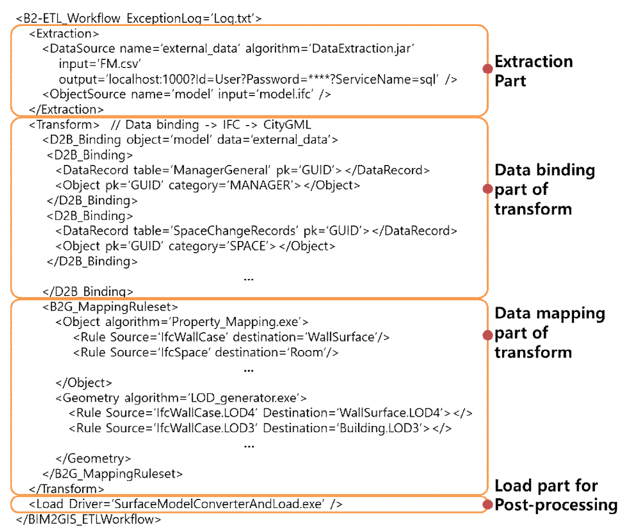

Figure 4. BG-Data Integration Workflow

V. CASE STUDY

We developed a prototype system by utilizing the BIM/GIS-based FM software architecture described in Section 4. The databases, which were integrated with the current system for information interoperability, were Excel-based structures constructed for the BIM-based FM of the main building at the Korea Institute of Construction

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Technology (KICT), and the BIM objects were modeled using the Revit software. The databases were constructed according to existing managed documents. Thus, its maintenance history was managed through documents and drawings. Many items of information were hence unavailable because of illegible handwriting. Furthermore, it was difficult to obtain maintenance history data in terms of BIM objects. Therefore, the facility maintenance historical data was constructed on the basis of space.

The FM database for KICT was constructed in only two months. Therefore, it was primarily divided into structural data and maintenance history data for the space, and was managed in Excel files. The classification code system for the facility object information was defined according to the construction information classification system published in 2006 by the Ministry of Land, Infrastructure, and Transport (Table 1).

TABLE I. FACILITY DATA ITEM (KICT).

No	Item	Description
1	Information classification code	Space classification based on facility and configured as two-digit numbers
2	Actual space name	Actual space name
3	Space ID	Revit's zone object ID
4	Manager	Name of manager
5	Space number	To manage room space, facility managers are assigned this additional number
6	Space modification history information	Maintenance history information, such as space modified date, space area, space perimeter, space volume, space ceiling height, and the number of occupants
7	Floor maintenance history information	Maintenance history information, such as space floor finish, partial repair, repair rate, total repair, and final repair date
8	Wall maintenance history information	Maintenance history information, such as space wall finish, partial repair, repair rate, total repair, and final repair date
9	Ceiling maintenance history information	Maintenance history information, such as space ceiling finish, partial repair, repair rate, total repair, and final repair date

This table was extracted from the excel file and included space, floor, wall, and ceiling management information developed to manage KICT building and facilities

The FM data were extracted, transformed, and loaded into the DW by the ETL process, and each property was represented from the user's perspective. From the viewpoint of geometrical representation performance, the Surface Model format was about 13.6 times faster than IFC format in terms of the data loading time for sample data with 643,279,768 vertices. Figure 5 shows our prototype system.

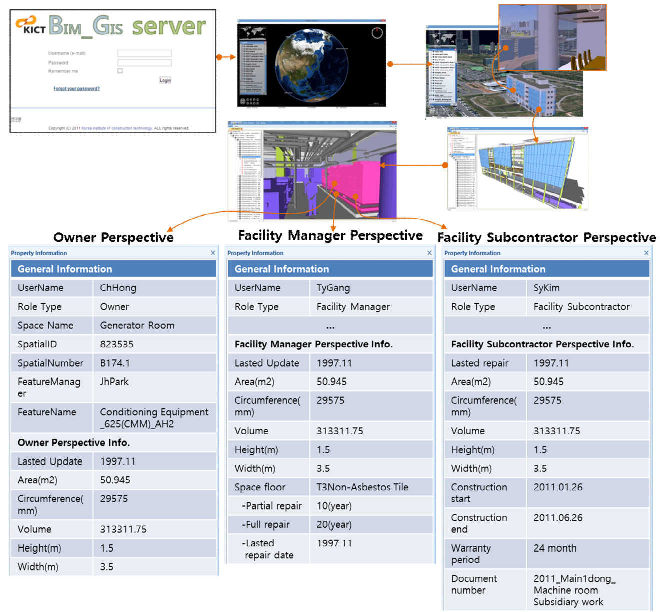

Figure 5. Prototype System for BIM/GIS-based FM software

VI. CONCLUSIONS

In this paper, we proposed a BG-DI architecture for the effective integration of data from heterogeneous systems of BIM, GIS, and FM.

From the practical viewpoint of data integration, data were divided according to their geometry and property information, allowing the problem of GIS- and BIM-based information interoperability to be addressed. Property information was extracted and transformed to obtain the required information from a use-case perspective by utilizing BG-DI. Applying BG-DI, we designed an effective architecture for the support of information interoperability between heterogeneous BIM, GIS, and FM systems, and developed a prototype that implemented FM use cases. Thus, we verified the effective integration of the required data from the project stakeholder's perspective.

In future work, we intend to analyze the spatial data of a topic on the basis of the proposed architecture, and study the effect on datasets using linkage analysis between the previously analyzed spatial data and other spatial data. We also intend to obtain query information required for decision making through data mining based on BIM.

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