THE ARCHITECTURE DEVELOPMENT FOR THE INTEROPERABILITY BETWEEN BIM AND GIS

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ABSTRACT: *The purpose of this study is to propose a scalable architecture that can be supported via the BIM (Building Information Modeling) on a GIS (Geographic Information System) platform for information interoperability between various heterogeneous systems such as BIM, GIS, and FM (Facility Management). This platform requires the acquisition of information from various data sources such as IFC (Industry Foundation Classes) and DBMS (Database Management System) if a use case for facility management, energy management, and design evaluation needs to be implemented, followed by a transformation of the information into appropriate information that can represent the perspective suitable for the use case.*

IFC may be considered a method for information interoperability, but it has a limitation in representing information in the perspectives of the use cases. Unlike the support of information interoperability based on the existing IFC, we would like to approach the problem of GIS- and BIM-based information interoperability by separating the problem in terms of geometry and property information. The geometry information is transformed into a simplified surface model from the IFC geometry information for that visualization of a number of objects represented in the GIS. The information required for the use case perspective is extracted and transformed from the property information by utilizing ETL (Extraction, Transform, and Load). ETL is a technology that extracts, transforms, and loads information from a variety of data sources and has been used for OLAP (Online Analytical Processing) function implementation via data mining in the management engineering arena to represent perspective-oriented information. In this study, we have applied ETL from the perspective of BIM.

For this purpose, we have reviewed the related study trends and derived a general use case of BIM on a GIS platform. Further, component architecture is designed to implement the use case as well as a Star Schema to represent information according to the perspective for the development of a data warehouse. On the basis of these, BGP architecture is proposed for implementing the ETL concept using BIM on a GIS platform. Furthermore, a use case for the facility management of Korea Institute of Construction Technology is implemented as a prototype to show the usefulness of the proposed architecture. Thus, in this study, we demonstrate that information required from the perspective of project stakeholders can be interoperated effectively.

KEYWORDS: *BIM, GIS, integration, interoperability, perspective representation, ETL*

1. INTRODUCTION

Interoperability recently performed by extracting and transforming required information from the perspective of each project stakeholder through GIS-based BIM has emerged as a big issue. GIS and BIM are similar in terms of modeling space information (one is for the outdoors, and the other for the indoors) as well as have common use cases for each system. For example, location-based information query and object management or path finding, which have been the traditional use cases in GIS, have also been utilized conceptually in the case of BIM. In particular, if each system's use cases can be operated in an integrated manner, effective urban facility management can be possible. For integrated use case implementation, effective interoperability between GIS, BIM, and FM should be supported at the platform level.

In order to facilitate seamless information operability in the construction sector, the BuildingSMART Association has developed and standardized the IFC and put in a significant amount of effort to accept requirements from the industry. IFC is an integrated model schema for construction information designed by an

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object-oriented method to integrate all the information required by project stakeholders from the big BIM perspective.

Through the information model integration attempts via this IFC, we have ultimately tried to achieve the required objectives. However, issues have arisen while solving the interoperability problem in practice. For example, during the information exchange between heterogeneous systems or commercial modeling software using IFC, some information loss or change has been reported (Lim Jae-In, 2008.6).

In order to support interoperability via the IFC, there should be no problem in parsing the IFC model and interpreting the meaning for information extraction and loading followed by the information exchange. To achieve this, IFC should accept the integration of information models managed and modeled by heterogeneous systems and there should be no confusion while exchanging information via IFC in terms of the semantic points of views. Currently, the IFC model is a building-oriented information model, which is on the way to improvement and advancement. IFC may accept general information. However, it is not easy for IFC to support a system's information models for specialized purpose utilization. Moreover, the information models created by some commercial modeler software were developed for a commercial purpose to keep their formats closed to the public, which makes IFC difficult to accept. Further, the development philosophy of these models for the information model schema was different from that of the IFC, which makes IFC compatibility relatively difficult.

The purpose of this study is to approach to the BIM-based information interoperability problem from a practical viewpoint unlike the direction of supporting the information interoperability based on the existing IFC. To this end, the ETL concept, which was widely utilized in the field of management engineering, was applied, thereby implementing a supporting architecture for effective information interoperability between heterogeneous systems such as BIM, GIS, and FM, and developing the prototype. Through such heterogeneous systems, in this study, we demonstrated effective interoperability of the required information from the perspectives of the project stakeholders.

In this study, information to be interoperated is divided into two categories:

1. Geometry information representation: When a user logs in to a GIS server, the BIM object geometry that is represented to the GIS viewer for a client should be a surface model, which is represented between LOD (Level Of Detail) 100 and LOD 200 specified in the AIA (The American Institute of Architects), taking the performance into consideration.

2. Property information exchange: Properties required only by the logged account from the user's viewpoint shall be displayed when a specific facility is selected in the BIM viewer, taking into consideration the perspective seen by the project stakeholders and information convenience.

2. RESEARCH OBJECTIVE

In this study, an architecture in which data were extracted from different heterogeneous systems such as BIM, GIS, and FM database using ETL was designed, and its prototype was developed. The extracted data were transformed into the required forms before being presented to a user. To this end, scalable information interoperability supported by the BIM-GIS-based architecture model was presented.

This architecture used the ETL solution for extracting and processing the required information from various heterogeneous systems. To validate the usefulness of the proposed architecture, simple facility management use cases were implemented. Information stored in the BIM facility management database of Korea Institute of Construction Technology was extracted and processed using ETL so that the information could be checked by GIS via the BIM model. The model uploaded in the GIS was a surface-based model, which simplified a large-capacity BIM model and had an information detail degree between LOD 100 and LOD 200 specified by the AIA. By double clicking, we uploaded the BIM model to the additional viewer so that information details of more than LOD 300 could be checked. When a facility object included in the model was selected, the information extracted via ETL could be viewed.

Through this architecture, required information according to each use-case perspective was defined, processed, and extracted via ETL; thus, heterogeneous systems were interrelated cost effectively to form a data warehouse that could be utilized for information mining. ETL could provide various data sources and facilitated function expansion. The BIM object geometry information could be visualized quickly by the simplified surface model.

The rest of this paper is organized as follows: Section 3 reviews the current study on the interoperability of BIM and GIS. This includes the use cases and platform architecture as well as ETL. In Section 4, we described the system architecture designed on the basis of the information given in the previous section. The architecture is designed to support the proposed use cases. A system is developed by referring to the architecture design, and a simple prototype program is demonstrated to show the implementation of the facility management use cases of Korea Institute of Construction Technology. The last section presents the conclusion and future research.

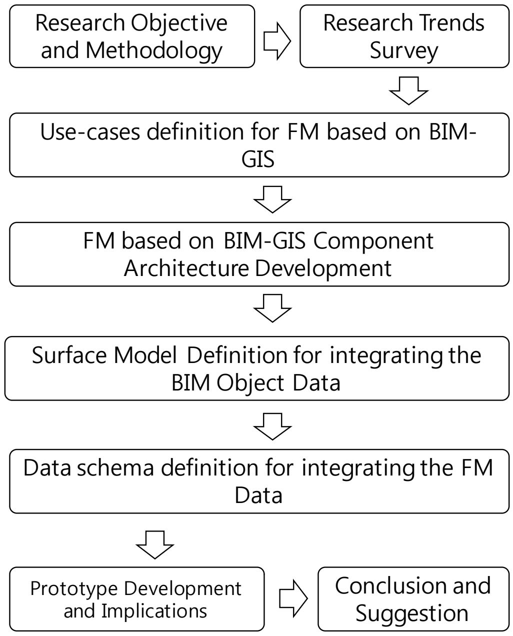

Fig. 1: Research Flow

3. CONVENTIONAL APPROACHES

3.1 CityGML Domain Extensions and Web service-based approaches

Hijazi proposed the mapping methodology to extract the utility the information by using CityGML Application Domain Extensions (Hijazi I, 2011). As a study about the integration between BIM and GIS, there was a study of the GeoBIM to extend GIS data by using CityGML and Open source-based BIM server (Laat R. D, 2010.11).

As the another approach to integrate the data, there was the web service-based integration study to manage the urban data management by using CityGML, WFS (Web Feature Service) and 3D Viewer(Lapierre A, 2007). Döllner researched the integration method to integrate the urban information of GIS, CAD and BIM by using web service supported by ONUMA system (Döllner, 2007). Burcu studied the ontology structure and navigation method to resolve the use-cases between CAD and GIS (Burcu A, 2008.3).

As described above, most of the studies used the CityGML Application Domain Extensions or Web Service to import IFC or CAD data and the research to integrate the external data for the special purpose such as FM information related to GIS-based BIM is not enough.

3.2 Spatial Data Warehouse and ETL-based approaches

SDW (Spatial Data Warehouse) is a system that adds a 3D model of the required information from the user-case perspective to the existing data warehouse system. SDW has been studied for a long time consistently in the area of GIS. It supports analysis and decision making by storing non-volatile data that have the integration and temporal property according to a topic-centered space information and non-space property information (S. Chaudhuri, 1997). SDW is constructed on the basis of the space data extracted from heterogeneous systems such as the GIS and the Asset Management System. BIM is also focused on the re-utilization of the object information over a space and can be utilized effectively from the perspective of BIM interoperability. The SDW can be created and renewed in a topic-oriented manner via ETL.

ETL for the data managed in the FM can support extraction, transformation, and loading processes with respect to the data, such as manufacturer, manufacturing date, maintenance strategy, and maintenance date data, from the heterogeneous systems effectively. While loading the data, even if the numeric data are the same at the time of loading, they can have different meaning or representation methods depending on the project stakeholder's or the user's perspective.

During DW (Data Warehouse) construction, it is important to load only the required information by extracting file data used as the sources that were created from the heterogeneous DBMS or software used by the project stakeholders. The types of extracted data are space data such as geometry and non-space data such as properties. The figure given below shows the ETL process, which extracts, transforms, and loads data from various data sources. The spatial ETL plays the role of loading data, which were created in the data cleansing and transformation steps with respect to various sets of space data obtained from the heterogeneous systems, to the DW.

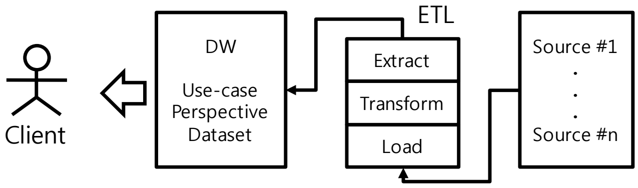

Fig. 2: ETL Process Concept Diagram

From the BIM perspective, space data, which were extracted and loaded through an ETL process from the data sources of various heterogeneous systems, should have a structure to assist the data analysis requirement with respect to the DW (Krivoruchko K, 2003).

For recent studies on ETL for buildings, a case study of the energy management system using ETL to perform extraction, transformation, and loading of data by Gökçe can be found (Gökçe H. U, 2011). Their study showed that a single integration information model was not suitable for the environment where each project stakeholder used a different database. This study proposed architecture in which the building information was extracted from data sources and sensor data including multi-dimensional data in order to avoid the abovementioned problem. The information was extracted from a wireless sensor network or CAD and managed in the data warehouse.

As described above, the SDW study, which was started in the GIS area, accounts for most of the DW and ETL-related studies. Although a study on ETL for buildings has been conducted recently, few studies have been performed on information interoperability in conjunction with the GIS.

4. SYSTEM DESIGN AND DEVELOPMENT

4.1 Use cases between BIM and GIS

When a system user wants to view specific information about any object, if unnecessary information is shown to the user other than FM information, the user may feel discomfort. Therefore, it is required to extract only the required data and present them to the user. In the situation wherein information, document files, and sensor information are managed additionally by the system databases, only the information required by a user should be viewed via the DW in which the required information is loaded, by interworking with a server. For example, when a facility administrator is logged in, he may check the status of facilities. On the other hand, a subcontractor of facility maintenance may want to view building structure information or maintenance history information. Data required from the user's perspective should be queried to the DW, which holds the data beforehand via ETL, and displayed to the user. Information required from the user's perspective should be defined beforehand by Star Schema.

The present study is focused on a method for an effective information exchange assuming that FM is a use case in order to support information interoperability between heterogeneous systems using GIS-based BIM. The utilized FM system assumes that information is managed by heterogeneous database systems or file-based systems. Taking this into consideration, the GIS-BIM architecture for FM should support the user's information perspective. The use case scenario is as follows:

1. A user runs the GIS Client Program.

2. The user logs in to the GIS server. According to the login account, the information perspective is determined.

3. From the GIS server, the objects of GIS and BIM are loaded into the GIS Client Program.

4. The user selects a BIM object. The BIM viewer is run.

5. The user selects a specific facility object in the BIM viewer. Information regarding the login account perspective is acquired via a query to the DW. At this time, the DW stores the FM data that were constructed beforehand by Star Schema.

6. In the BIM viewer, the queried BIM object information is shown.

The following use-case diagram represented by the UML shows the above scenario:

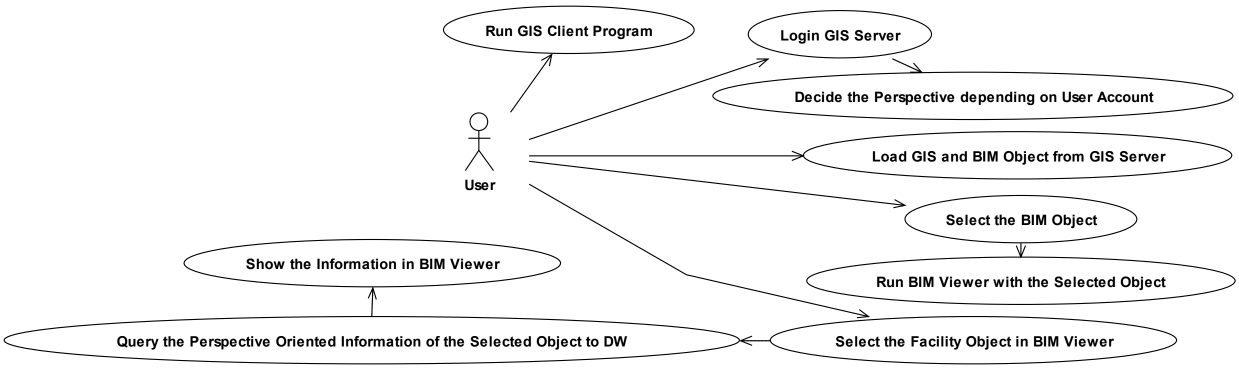

Fig. 3: Use-Case Diagram (UML)

Information types and levels from the user's perspective are defined below:

Table 1: Perspective-Oriented Information depending on FM User Account

No.	User Perspective	Information
1	Owner	Facility manager general, Space general information including space name, ID
2	Facility Manager	General management information, Space including structure/electric/mechanic element general information
3	Facility Subcontractor	Space general information, Space maintenance history

It was assumed that a user checks the information regarding the utilization of FM general information and space area mainly, while a facility management manager accesses the general management information and space, and general information regarding the MEP elements included in the space. On the other hand, it was assumed that a subcontractor for facility management will want to access the general information of the maintenance space and the history information of maintenance.

4.2 Component architecture with open source

The system architecture should consider the scalability and flexibility of the information exchange method in order to support interoperability. Taking this into consideration, the component architecture for supporting the BIM-GIS-based FM was designed using UML. To design a sustainable and cost-effective architecture, frequently used open sources were applied. In order to support fast visualization and search numerous BIM objects in three-dimensional space, our own BIM viewer was developed. In order to extract, process, and load the required data in the BIM data warehouse from the external FM DBMS, ETL open source Talend was used, and the transformation part was designed. The related component architecture is as follows:

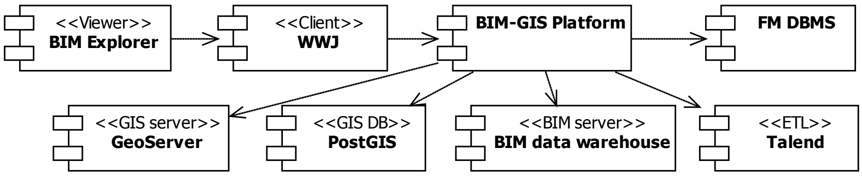

Fig. 4: BIM-GIS-based FM Component Architecture (UML)

The role of each component in the component architecture is as follows:

Table 2: BIM-GIS-based FM Component Description

No.	Stereo type	Component	Description
1	Client	WWJ (World Wind Java)	Java-based client program developed by the NASA and supports Google Earth-like UI and functions.
2	Viewer	BIM Explorer	Independently developed BIM viewer to visualize the object geometry using the light mesh-based surface model file by which IFC was transformed beforehand.
3	Platform	BIM-GIS Platform	Using GIS server, BIM server, and ETL module, it supports information interoperability between heterogeneous systems.
4	GIS Server	Geoserver	Open-source-based topography server that supports topography image or vector information streaming when WWJ client program is run.
5	GIS DB	PostGIS	Open-source program to support GIS-based space query when performing SQL query.
6	BIM Server	BIM Data Warehouse	BIM object-oriented extracted and loaded database of required information from the external heterogeneous systems, in which Star Schema was designed and placed beforehand according to a topic.
7	ETL	Talend	Required information is extracted and transformed from the external heterogeneous systems according to user's perspective and loaded into the BIM DW.
8	FM DBMS	KICT FM DB	Excel-based database used for this study and created by Korea Institute of Construction Technology for FM.

4.3 Surface model for geometry representation

The IFC file, which is used as a BIM neutral file, is a flexible and scalable structure, but it has a problem that the file format itself is a heavy and complex structure. This problem is partly due to the fact that IFC contains phase information between objects as well as B-Rep geometry parameter information for geometry modeling. However, geometry information utilized over the GIS does not normally require geometry modeling, and a fast representation of numerous object geometry pieces of information is considerably important; hence, modeling-related information is not necessary. It is important for the GIS to represent geometry rapidly and appropriately in a three-dimensional space according to the distance of an observer view, by creating the LOD of objects beforehand.

Because of these reasons, in the present study, we converted mashes before they are used according to LOD in the B-REP geometry model included in the IFC. These files are managed in the server, and when the GIS client program requests this information, it is transferred to the client. The figure given below represents the structure of the surface model as a UML.

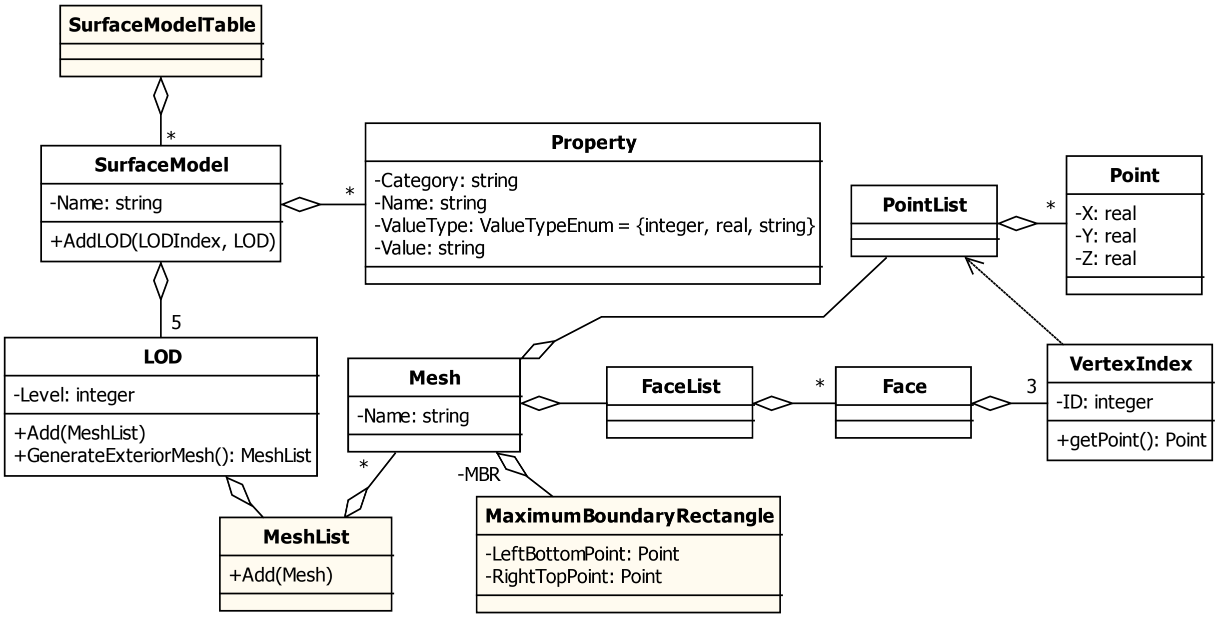

Fig. 5: Surface Model Structure for Geometry Representation in GIS

In order to create the surface model structure, using the developed IFC converter, five LOD levels were converted as a semi-automatic mode to meet the CityGML LOD level. LOD contains a number of meshes. A mesh consists of PointList, which manages the X, Y, and Z coordinates; FaceList, which manages Face consisting Mesh; and VertexIndex consisting Face. VertexIndex manages the corresponding Point ID in PointList.

Property manages the information category, property name, property value type, and property value. Property is extracted via the IFC converter from the BIM object after the store process.

The below describes the sequence diagram to create the mesh about LOD-2. To extract the exterior surfaces of the LOD-2 from the mesh, the screen buffer which is similar to the Z-buffer was used. The other LODs are created manually.

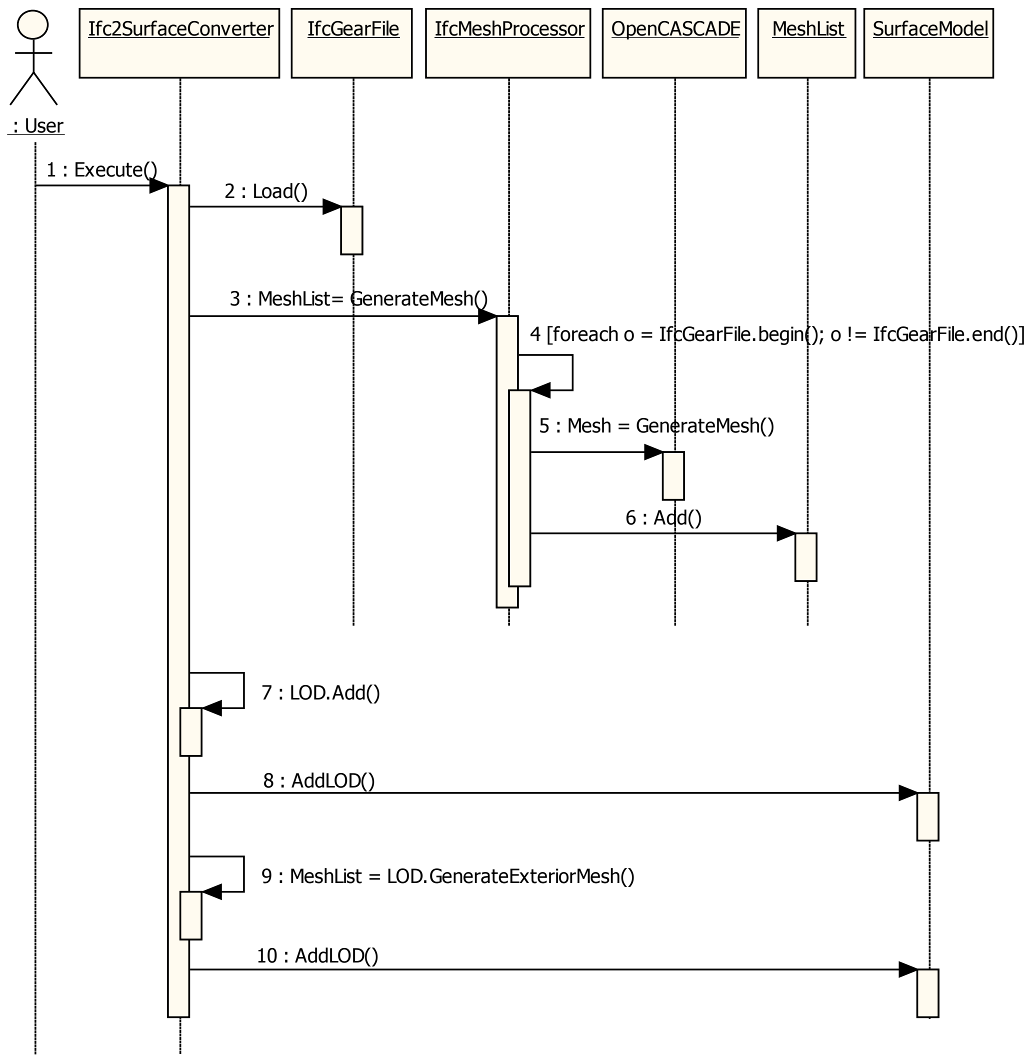

Fig. 6: Sequence diagram to create the Surface Model

4.4 Star Schema for properties exchange

Star Schema was developed for FM to support topic-based queries. Once the elements required for FM were analyzed, a dimension table and a fact table were designed on the basis of the DW components. Further, DW was constructed via BIM ETL so that the information required from the project stakeholder's perspective could be queried. As shown in the figure given below, five dimension tables and one fact table, according to the Star Schema format, were represented including the table name and the field names.

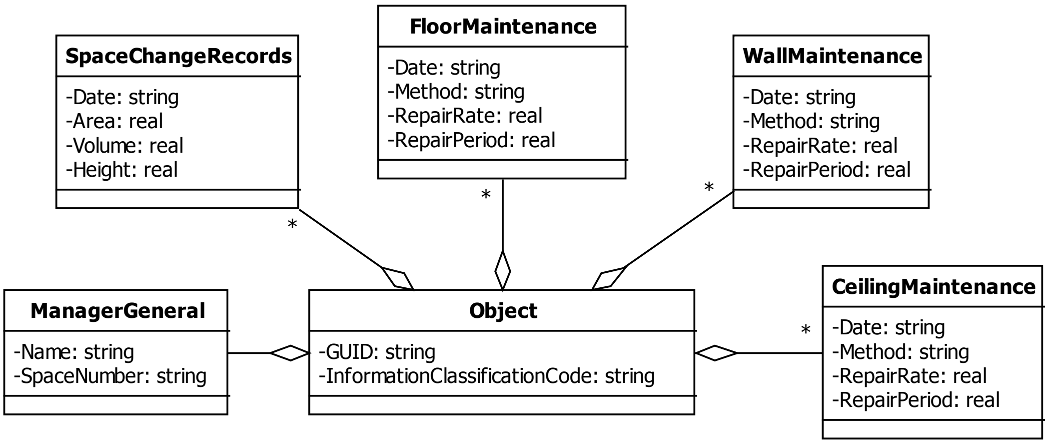

Fig. 7: Example of Table Design (Dimension Tables and Fact Table)

In order to process FM on the basis of BIM, we need to extract the facility management data stored in the dispersed databases followed by transformation into an easy format and store. This process is performed in ETL. Thus, property data extracted via data extraction, data transformation, and data load into the DW from various topography space data can help extract or analyze information from a project stakeholder's perspective. In this study, Talend open-source ETL software was used for the ETL engine. For data sources, files, databases, and open APIs were allowed to be used for extracting information.

4.5 System development

The process of system development is as follows.

1. Data Warehouse Star Schema Design and Development

2. FM Dataset Setting

3. ETL Process Development by using ETL with Talend

4. Set Information Perspective depending on User Account

5. Query Development of Perspective-Oriented Information about BIM Object

No. 1 is to define the Data Warehouse Star Schema, thereby creating a space to contain information so that OLAP can be performed to extract information by perspectives. In the Star Schema, the fact table should include the GUID of BIM objects, and on the basis of the GUID, information can be divided into many sets of information. If the information required by the user is the modification date and the maintenance details of an object among the past history of the object, the required information can only be queried to show the result to the user.

No. 2 is a step to set the required data source from the user's perspective to obtain the FM dataset.

No. 3 is a step to develop an ETL process to interwork with the BIM/GIS server and the FM dataset.

No. 4 is a step to set the information perspective according to user accounts.

No. 5 is a step to develop a perspective-oriented information query based on a BIM object when an object is selected.

5. CASE STUDY: BIM-GIS-Based KICT Facility Management System

A prototype system was developed by utilizing the BIM-GIS FM architecture designed in Section 4. The databases, which were interoperated with the present system for information interoperability, were Excel-based databases constructed for BIM-based FM located in Section 1 of the main building and the BIM objects modeled by Revit. The databases were constructed by referring to the existing managed documents. Note that Section 1 in the main building was an old building constructed in 2004; thus, maintenance history was managed by documents and drawings shown in the figure below, thereby having many pieces of missing information due to illegible handwriting. Further, it was difficult to obtain the maintenance history information according to a BIM object. Therefore, the facility maintenance history information was constructed on the basis of space.

Fig. 8: Documents and Drawing related to KICT FM

The database constructed in Korea Institute of Construction Technology for the FM was constructed within two months, a short period; therefore, it was primarily divided into structure data and maintenance history data for space and managed in Excel files. The classification code system for the facility object information was defined by referring to the construction information classification system published in 2006 by the Ministry of Construction and Transportation.

Table 3: KICT FM Space Data Item Description

No.	Item	Description
1	Information classification code	Space classification based on facility and configured as two-digit numbers
2	Space actual name	Actual space name
3	Space ID	Revit's Zone object ID and unique ID
4	Manager	Name of manager
5	Space number	To manage space room, facility manager assigned the number additionally
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

The above FM data were extracted, transformed, and loaded into the DW by the ETL process, and information was represented from the user's perspective.

The following figure shows the prototype system implemented.

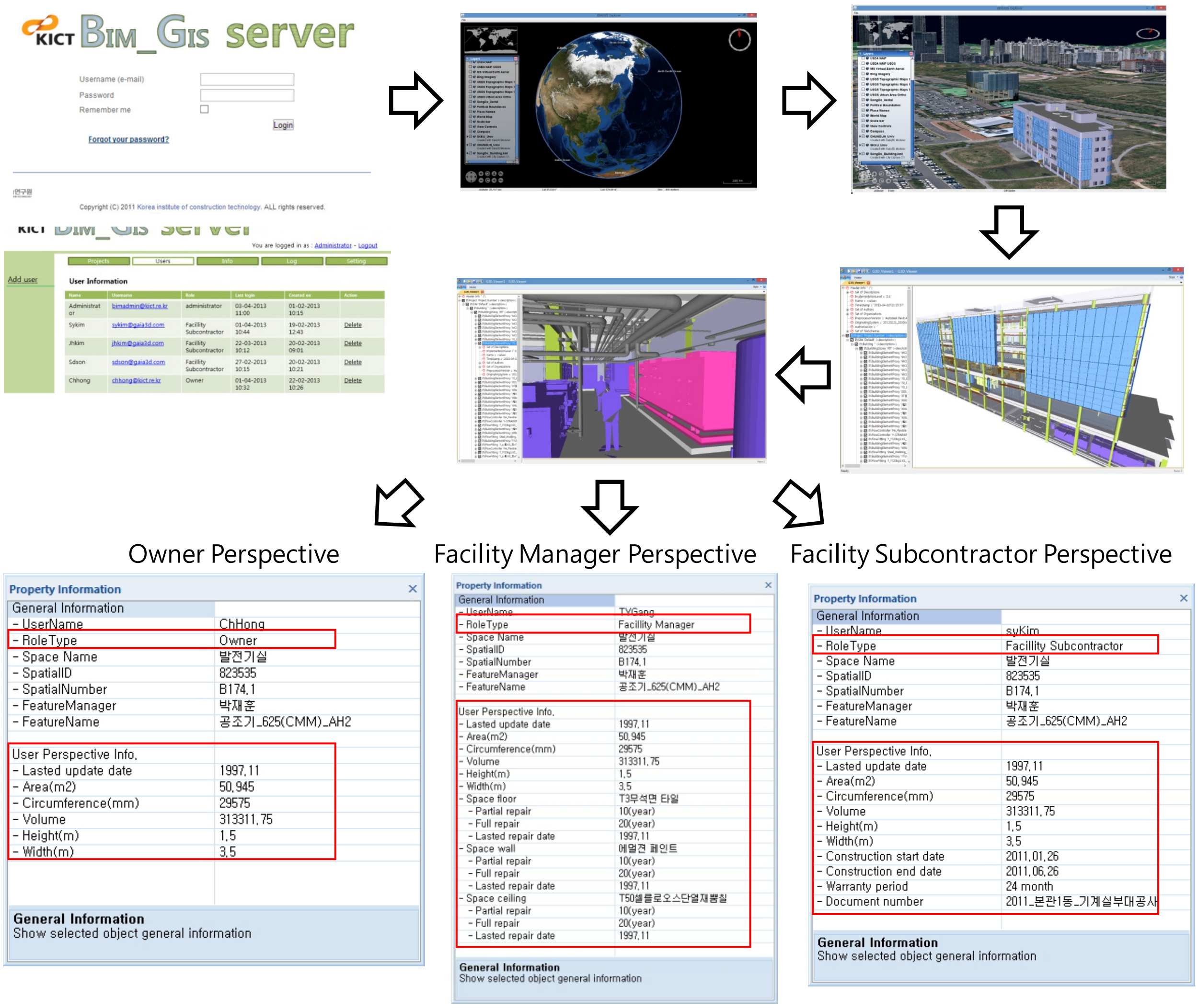

Fig. 9: FM Prototype System based on BIM-GIS Platform

6. CONCLUSION

In this paper, we proposed a scalable architecture for supporting interoperability between heterogeneous systems of BIM, GIS, and FM.

From the practical viewpoints of information interoperability, data were divided into geometry and property information so that the problem of GIS- and BIM-based information interoperability could be addressed. In order to visualize numerous objects represented over the GIS, from the IFC geometry information, a simplified surface model was converted while the property information was extracted and transformed to be utilized for obtaining the required information from the use-case perspective by utilizing ETL. Applying the open-source ETL (Extract, Transform, Load) solution, we designed an effective information interoperability supported architecture between heterogeneous systems of BIM, GIS, and FM and developed a prototype that implemented the FM use cases. Through them, the effective interoperability of required information from the project stakeholder's perspective could be verified.

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

7. ACKNOWLEDGEMENTS

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