A BIM ORIENTED MODEL TO A 3D INDOOR GIS FOR SPACE MANAGEMENT– A REQUIREMENT ANALYSIS

S N A Syed Mustorpha[1] and W M N Wan Mohd[1]
[1]Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning, and Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

Email :wmn@salam.uitm.edu.my

Abstract. Building Information Modeling (BIM) is a process concerning the formation of digital representations of the physical and functional features of built spaces. A significant increase of the BIM utilization in the Architecture, Engineering, and Construction (AEC) sector are becoming more accessible and functional. The BIM methodology was developed in order to provide an effective system for building management as well as to organize the collaboration between different parties. Industry Foundation Classes (IFC) is maintained by buildingSMART; enable an interoperable format for exchanging BIM data between different software platform which is capable of restoring both geometric information and rich semantic information of building components to support lifecycle data sharing. BIM provides a detailed 3D geometrical model with rich semantic data. In contrast, Geography Information Science (GIS) offers powerful spatial analytical tools. As the benefits brought by the integration of Building Information Modelling (BIM) and Geographic Information Systems (GIS) are being proved by many researchers, further spatial analysis can be applied that can benefit indoor-outdoor integrated applications. Recent research has mainly discussed the process required for data conversion from BIM to GIS. Thus, more specifics requirements on the functionalities of a 3D indoor applications need to be considered. In this study, the use of BIM IFC for 3D indoor GIS was reviewed, especially on the data conversation, data management, and 3D spatial analysis. The aim of this paper is to reveal the 3D indoor GIS requirements for space management. Therefore, the requirements were analyzed in four aspects: 1) data level integration; 2) data management; 3) 3D indoor GIS analysis; and 4) 3D space management. 3D space management was developed according to the requirement. Future research will be testing the conversion data in a GIS environment, the data structure for the 3D indoor GIS will be designed and a prototype will be developed to demonstrate the spatial analysis functionalities for 3D space management.

1. Introduction

Building Information Modelling (BIM) is one of the major technological advances in the Architecture, Engineering, and Construction (AEC) domains by providing detailed 3D building models, as it is letting stakeholders capture, manipulate, update and exchange information during the lifecycle of a building construction project [1]. This platform serves in bridging the gap of interoperability among industry players thus, boosting its popularity between stakeholders [2]. Specifically, Industry Foundation Classes (IFC) is the primary open data scheme developed by buildingSMART is used as an interoperable format for exchanging BIM data between different software platform [3][4]. The need for sophisticated analysis tools arises because different stakeholders use BIM for diverse purposes. Therefore, some attempts were made to design tools and systems to integrate building models into a GIS environment [5][6].

GIS is a powerful tool that can visualize and analyses location for archival and management of geospatial data by integrating different spatial and attribute data as well as allowing for spatial analysis and modeling operations [7]. BIM IFC contains many specific geometrical and semantic information on building components and can be treated as an ideal source of indoor spatial information and interpreted in GIS field studies, such as indoor modeling and mapping [8]. In precise, BIM IFC offers a standard data model, which can be selectively used for various purposes on GIS platforms such as location-based services (LBS) and navigation location [9][10], asset management [11][12], cultural heritage management [13][14] or hazard simulations [15]. In a building management relation, facility managers should play their roles for the translation of building models into geospatial context.

BIM and GIS interpret 3D modeling from two points of view which are BIM stresses detailed building components and project information from the architectural and construction point of view, while GIS is specific on the geographical information of buildings and their components from a geographical point of view [16]. Although traditionally, 2D GIS suffice to analyze data over a large area, the requirement of handling the insides of building drives to the development of a more detailed 3D GIS. Since IFC is one of the standard building formats, it is one of the interoperable tools for exchanging information from BIM to 3D GIS, enabling more complex analysis, visualization and documentation. BIM 's most important contribution to GIS would be the provision of detailed 3D building models for both geometry and semantic information, but it does not contain the surrounding information. In contrast, GIS provides a concise way of managing data through a geodatabase and offers plenty of tools for spatial analysis [17].

There are many researchers investigating the requirement of translation from BIM to GIS. Majority of the current studies were more focused on buildings, although tunnels, bridges, and other constructions are also vital. Isikdag et al. had proposed related conceptual requirements on a building model [18]. Although the integration of the IFC-based information model was investigated using various approaches, there were practical problems in solving the integration problem. For example, during the exchange of information between heterogeneous systems, which means more than two different software or commercial modeling software using IFCs, some information loss or changes have been reported [19]. In addition, a related study identified several issues relating to the integration of BIM and GIS [20].

A major barrier to achieve the integration of BIM-GIS is the nuts and bolts process for BIM data integration, often in the form of a variety of the proprietary file, web, and database-based information stores with GIS. Frequently, information from BIM is reused by engineers and facility managers in GIS analytical and visualization tools. The first step of this type of integration is getting BIM data into ArcGIS. By using ArcGIS Data Interoperability Extension, individual BIM elements are converted to GIS features depends on the level of details (LOD) of the building models.

However, specific requirements for GIS applications with data from BIM IFC should be clarified, such as how data converted from BIM IFC can be used, such as how BIM IFC converted data can be used, the level of detail I am looking for and the functionality of spatial analysis. For this application, a generic 3D indoor GIS was considered to provide modeling and analytical functionality for 3D space management. Although this research is in its early stages, this paper seeks to disclose the requirements of 3D indoor GIS for space management. Generally, this procedure was designed to incorporate a 3D building model with 3D spatial analysis. Therefore, BIM IFC is able to support this procedure in the following aspects: 1) data level integration; 2) data management; 3) 3D indoor GIS analysis, and 4) 3D space management such as space utilization optimization. Currently, there is no generic solution that can address the above topics completely. In this paper, a requirement analysis was carried out focusing on the four aspects and potential application scenarios explained with an example. The following sections will examine the four aspects of requirement analysis. Subsection 2.1 introduces the data level integration of BIM GIS; subsection 2.2 discusses the requirements on data management; subsection 2.3 presents the need for 3D indoor GIS analysis, and subsection 2.4 provides the requirements on 3D space management. Section 3 explains two case studies of large-scale facilities management and section 4 concludes this paper with some future work.

2. Requirement Analysis

This section presents an analysis of requirements regarding the development of a 3D building space management by using BIM IFC data. These requirements cover four main topics: 1) data level integration; 2) data management; 3) building management analysis, and 4) 3D space management based on BIM IFC data.

2.1. Data level integration

Data level integration of BIM and GIS was divided into two paths; geometry and semantic level [21]. The geometry level is the transformation of information related to geometry. Semantic level concentrates on full attribute information transfer. There are three approaches for 3D geometry representation of an object, which are boundary representation (b-rep), Sweep Solid (SS) and Constrictive Solid Geometry (CSG) [22][23]. IFC file uses one of b-rep, SS and or CGS or takes their combination to represent a 3D geometry. For complex shapes in IFC files, such as rectangular shapes, CSG is an efficient way to represent them. For example, IfcSpace represents an area or volume bounded with certain functions within a building, where space is often associated with a building storey and can potentially be used to manage space utilization inside buildings. For modeling physical parts of buildings, “IfcBuildingElement” entity is specialized into several subclass entities such as IfcDoor, IfcWall, IfcSlab and so on [24].

GIS adopt the use of only b-rep, like multipatch. Multipatch is the feature type used for storing 3D solid or surface features in ESRI systems [21]. Every space in the 3D building model has a unique ID which is used to specify the geometry location. While the requirements for information and level of detail (LOD) of the BIM objects in GIS environments depends on in which it is applied and should thus be taken into consideration in the integration.

Hence, Figure 1 and Figure 2 show the geometric information exported from Autodesk Revit software through IFC into multipatch features by using ESRI Data Interoperability Extention for developing ESRI geodatabase. Then, ESRI ArcGIS Pro was used to check the quality of the transformation. The quality of the transformation was evaluated by counting the number of features lost, by visual comparison, by checking that each transformed element could still be identified and then finally by testing whether the features were topologically closed. The ArcGIS Pro 3D scene was used to validate that a spatial query could be performed to find the 3D space where an object existed. Data level integration shows in Figure 1.

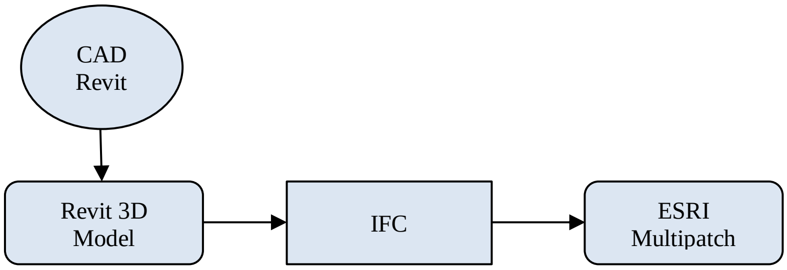

Figure 1. Data level integration

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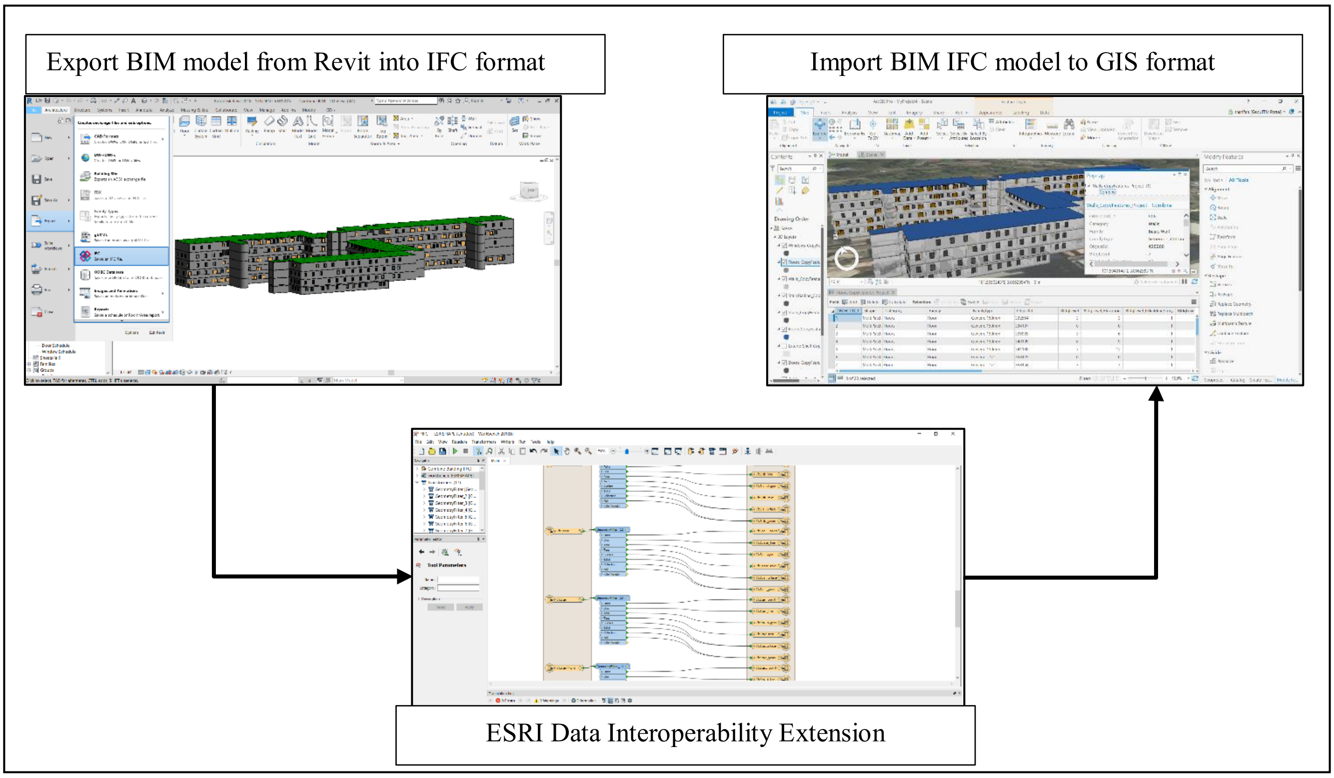

Figure 2. Example of BIM to GIS data conversion for 3D indoor GIS

Therefore, the requirements in regard to the integration of data levels for 3D indoor GIS are transforming CSG and Sweeping representations of IFC BIM into geometric representations in GIS which is fundamental for volume features in space management. Besides, the semantic data of the geometry must be preserved [18]. Thus, integrated geometry and semantic data must be separated based on specific standalone features. The transformations of BIM IFC data are validated in the GIS platform.

2.2. Data Management

The requirement to perform 3D indoor GIS data management is the geometric and semantic data need to be adequately organized in an effective way. Based on the functionalities of 3D indoor GIS, the enriches of data is an initiative to build focused GIS solutions for the facilities domain, enabling users to get up and running quickly and to be able to do their work more efficiently. The extension procedures can be added to absorb new information types from BIM IFC for the current implemented data models in GIS.

However, it may be considered insufficient as the building facilities are not reflected in the aspects of facility management (FM) in order to reduce the probability of failure because it is too extensive to build an entire FM system all at once in 3D. All data converted from BIM IFC must be managed properly. The data needed based on the functionalities queried to make better decision making includes detailed spatial data on the facility that satisfies 3D visualization and space search. Therefore, the geometry and semantic data were focused on space management and removed unnecessary information, making it easier to downsize files.

For instance, several BIM elements in IFC format that can be transformed into the 3D indoor GIS shows in Table 1. Therefore, the information from IFC data needs to be properly organized in 3D space management to keep their source correctly.

Table 1. Semantic data in IFC organized in GIS environment

BIM elements	GIS elements
IfcWall	Wall
IfcWindow	Window
IfcDoor	Door
IfcCovering	CeilingSurface
IfcSpace	Room

A developed 3D indoor GIS for space management facilitate the general users including FM managers to control the related work on the timetabling and space allocation problems, and so on because of object-oriented BIM modeling data. Besides, database is constructed according to space management and data would be managed by space, floor, and building unit.

All geometry and semantic data for spatial analysis stored in the 3D indoor GIS. The generic data model can be designed for different applications to maintain data integrity and independence. For example, 3D space with class schedule data can be stored and the room schedule can be analyzed and viewed in the 3D indoor GIS.

Figure 3 shows the conceptual data management of BIM information to the 3D indoor GIS. Four IFC data components, geometry, semantics, relationship classes, and properties of building elements are converted into the 3D indoor GIS [23]. The IFC geometry has been converted into boundary representation (b-rep), Sweep Solid (SS) and Constrictive Solid Geometry (CSG). The semantics of building elements and relationships between IFC classes could be transformed into the semantics in the GIS environment. Moreover, properties are converted to the attribution of geometric forms. At last, in GIS DBMS, geometry, associated semantics and attributes could be managed. In the implementation of the ESRI Geodatabase, all classes of the model are made up of polygons. The multipatch data type is used to populate objects in the implementation of Geodatabase.

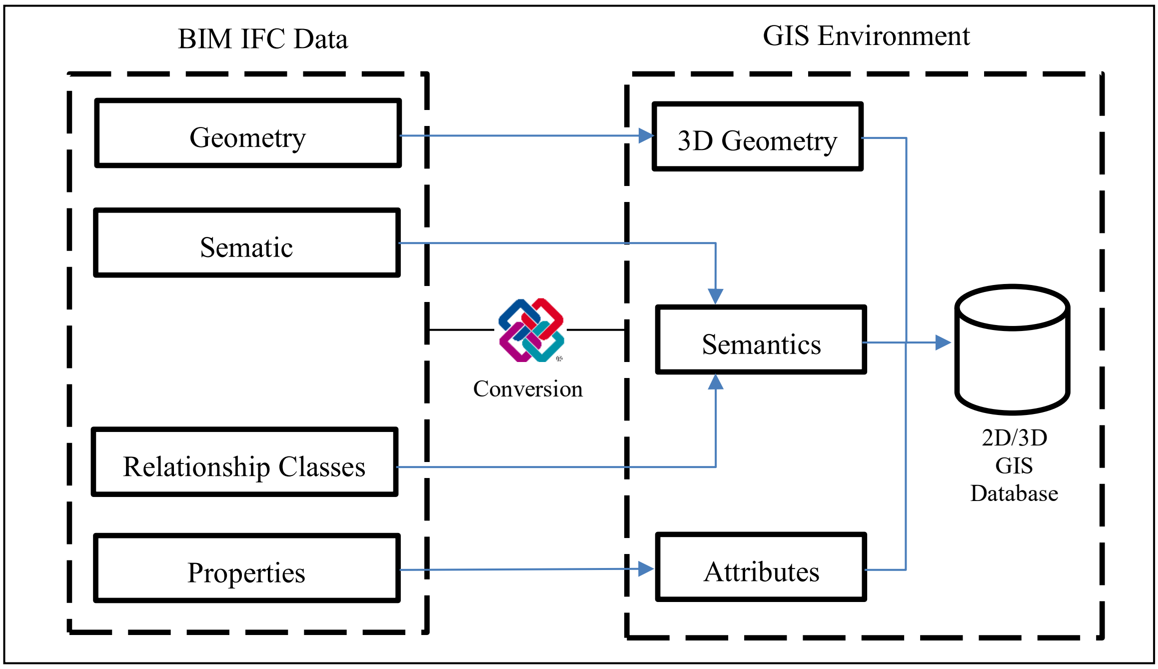

Figure 3. Conceptual data management of BIM IFC into a GIS environment

Therefore, the requirements on data management for BIM IFC information in the 3D indoor GIS are the original source from IFC models need to be kept and well organized with the model data of the generic 3D indoor GIS. Besides, four components of IFC data need to be linked to the corresponding parts in 3D indoor GIS to make the model more compact, and easy to find and search.

2.3. 3D indoor GIS analysis

BIM addresses details of individual buildings without the contextual geospatial information support. It will be insufficient and difficult to meet FM needs of a geographically dispersed, for instance, a wide range of building facilities such as campus buildings. Consequently, GIS is a technology that can offer FM scalable solutions far beyond the building perimeter if it is integrated with BIM and the myriad facilities management technologies. By integrating BIM and geospatial information, decision-makers can significantly build and evaluate various scenarios for moving planning, evaluate the current allocation of organizational space and determine overcrowded or underused facilities in real time. Moreover, coupled with the optimization algorithm, this procedure enabled the decision to optimize space utilization, can be quickly evaluated.

Building information that extracted from IFC provides highly structured and detailed information in a 3D or multidimensional format which is a lack in GIS. Thus, the data for space management incorporated with 3D building information that can use the spatial analysis for innovative, data-driven and performance-based solutions for strategic planning and decision-making. It should not only provide queries concerning single building elements, but also the whole building management environment involves. For example, room utilization can be analyzed and the room availability for an event can be checked using three-dimensional manage spaces that were formerly two-dimensionally managed with a spreadsheet and 2D CAD.

The blocks within the building that extracted from IFC represent the space of each room. Again, size is a proportional and relative position to the real-world location is preserved, where multiple floors of buildings delineated with shadow lines. There are many areas in a building, such as circulation areas, stairwells, bathrooms, and mechanical equipment rooms, which may not be germane to a space allocation problem thus, do not need to be included for analysis via the visualization tool.

The campus currently updates its drawing and data information on separate formats which requires a manual update in creating duplication of workload. For example, DWG floor plans which come in 2D representations and an MS Excel database. On the other hand, photographs scanned elevations and sections were also used to verify specific details from the original drawings' sheets. With the rapid development and changes in building utilization occurring year-round, it is dragging the full-time attention of a CAD technician. The lack of comprehensive, up-to-date, accurate, reliable and accessible information can seriously inhibit the improvement of space planning and management. The new transformation model has a rich set of spatial features and attributes. Thus, the data need to well-structured to be used for spatial analysis [25].

By properly designing data structure and modeling the building in 3D GIS model, it allows the function to automatically update the required schedules, elevations, 3D visuals, produce instant sections and generate drawing sheets, from a single program through the creation of geometric information and inclusion of specific building information [26]. This provides information that is currently not available to the facility management team and promotes instant efficiency gains as well as providing interactive information.

In summary, without losing the necessary details, the generic data structure is used to ensure that the geometries of the new 3D model are easily recognized and visualized. Besides, 3D geometric and semantic representation of a building must be validated and should have a structure that supports the data analysis requirement for the application. Thus, the data structure must be designed properly to meet the needs of the implemented spatial analysis.

2.4. 3D space management

The generic 3D space management needs to consider the computation of the space utilization optimization cases such as learning space usage rate based on the teaching and learning schedule (timetable). Timetabling represents room usage over time. BIM IFC data provides a 3D building model that can be used to visualize the room occupancy and exploring opportunities to use available data regarding room usage to match student need with available spaces. By utilizing this information, the simulation of space utilization can be performed and based on the optimization computation, it can support implicit cost saving.

Although there are studies on space utilization optimization [27], the computational functionalities can also be introduced to 3D space management. The core of the computational of space utilization optimization is the mathematical models that able to solve the complex space utilization optimization in an automatic and efficient manner. In addition, IFC data such as IfcSpace contains IfcLengthMeasure for room dimension. The computational of space utilization optimization can take the function of IfcLengthMeasurement into account. In this case, the 3D space management can provide computational and visualization of space utilization. It can also estimate the expenditure cost.

As mentioned before, up-to-date data collection in this 3D space management should be considered. In this instance, the up-to-date data can support the visualization of room usage over time. Space optimization calculation can be viewed as a variable which consists of several criteria. These criteria include used space, capacity, dimensions and so on. The visualization can be used to increase the efficiency of transition planning and management.

Therefore, to fulfill the requirement of 3D space management in the 3D indoor GIS, 3D building model development need to be incorporated with the timetables to schedule the room usage by assigning them to timeslots and places in a way that makes optimal use of the available resources. Besides, the 3D building model also needs to be integrated with the space utilization optimization computational functionality which is used to calculate the space usage and at the same time to save costs for the operational costs of the building.

3. Case Study

In recent years, various types of building information mostly CAD file has been integrated with GIS for asset and facilities management. Most efforts were focused on the management of facilities, in particular, space management. However, studies on these cases will gain some insight into the integrated GIS and BIM from a general perspective. This section provides an example of the case study in these implementations.

3.1. NASA, USA

Langley Research Center (LaRC) of the National Aeronautics and Space Administration (NASA) was implemented integrated spatial data management and decision-making system based on GIS [27]. The general scope of LaRC has been 800 acres and 400 buildings comprising 6,700 rooms totaling 3.7million square feet, with assets valued at approximately $3 billion. The facilities were designed to accommodate more than 4,000 employees.

LaRC has developed a move planning tools that allow space utilization managers to construct and evaluate various personnel move scenarios for both within buildings and between buildings. By consolidating space, LaRC able to reduce building dependence with uneffective operating costs while maintaining and improving the coherence of personnel distribution within each organization.

Web tools have been developed to make the analysis capabilities available to LaRC personnel with standard Web browsers. This approach will allow the user to access the data representations and minimizes the processing and requirements for plugins. The capabilities allow users to reuse additional conventional map views and building layouts with room details, increased analysis capability, uses any symbolization and labeling available, and easier integration with CAD. However, there are some useful capabilities include metadata access or linking, area measurement and statistical analysis has not been addressed in this system [27].

3.2. Korea Institute of Construction Technology (KICT)

Korea Institute of Construction Technology (KICT) was implemented a prototype system developed by utilizing the BIM/GIS-based for facility management. The databases were constructed based on existing managed documents and drawing. Thus, many information missing due to illegible handwriting. Furthermore, facilities management history data in terms of BIM objects were difficult to obtain. Therefore, historical data of facilities management were constructed based on space. The databases were integrated to the current system for information interoperability of the main building at the Korea Institute of Construction Technology (KICT), were Excel- based structures and the BIM objects were modeled using the Revit software.

The databases were divided into structural and facilities history data for space and managed in Excel files. According to each work based on field survey, databases were constructed, and FM data were managed by space, floor and building unit. This can systematically search and display data using the hierarchical order of the space-floor-building-area depending on the user's objective. Based on the existing KICT portal system, FM manager able to search, read, edit, and check with fundamental basic functions. FM manager can control a room schedule, history management of joint equipment, site navigation, remodeling plan of the institute, and so on because of object-oriented BIM modeling data [25]. The developed FM system was integrated with the KICT main system. Figure 5 shows the prototype system.

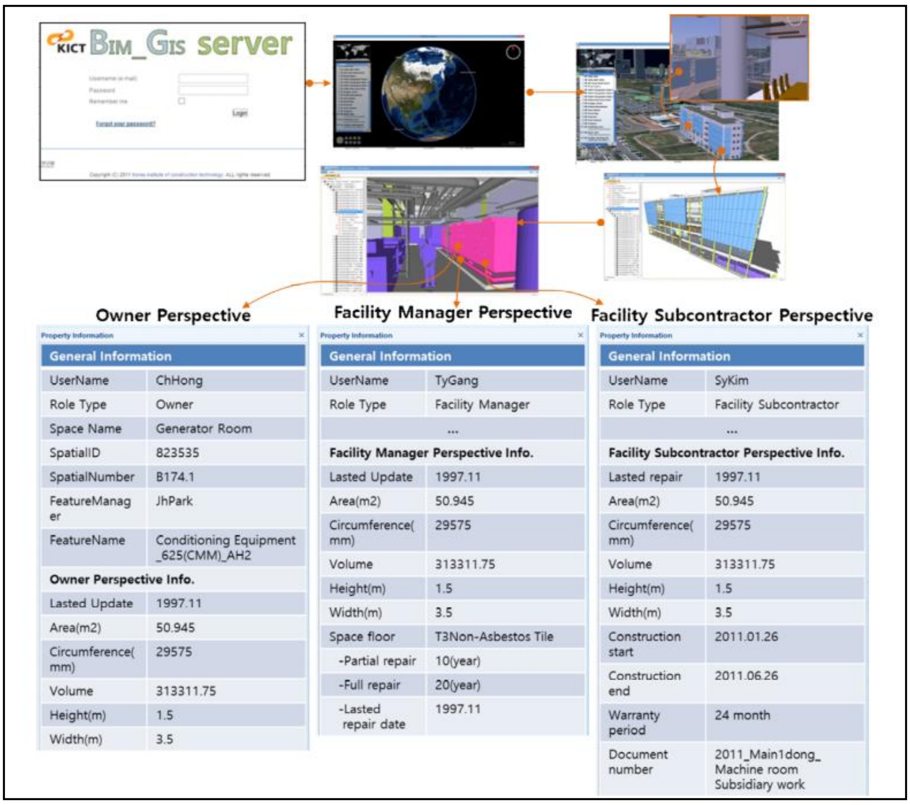

Figure 4. Prototype System for BIM/GIS-based FM software

4. Conclusion

A new approach to the integration of BIM and GIS allows managers to visualize the 3D model of the campus effectively. BIM IFC data provides information that can be refined to be used for spatial analysis in 3D indoor GIS. The aim of this paper is to reveal the 3D indoor GIS requirements for space management. The motivation behind this work is to facilitate the translation from BIM to the 3D indoor

GIS and to apply more suitable spatial analysis functionalities from the extracted 3D geometries and semantic information of BIM IFC.

Although this research is in the early stages, an analysis has been presented on the requirement for the possible development of 3D indoor GIS from BIM IFC. In specific, the requirements were analyzed in four aspects: 1) data level integration; 2) data management; 3) 3D indoor GIS, and 4) 3D space management based on BIM IFC data. Accordingly, the requirement for conducting 3D space management in 3D GIS environment are summarized as follows:

1. The conversion method to transform 3D geometry and semantics data in IFC and validation of the data.
2. The translation of the BIM IFC data component into the GIS environment and data storage management.
3. A generic data structure to facilitate the new 3D building model and data structure design that suit the spatial analysis implementation.
4. Timetabling data that relate to space usage and space utilization optimization computational functionality.

In the future, the feasibility integration of the BIM IFC into the 3D indoor GIS will be tested; the structure data model will be designed and implemented in GIS DBMS. Based on the structure data designed, the functionalities of spatial analysis for 3D space management will be established. After that, a demonstration prototype will be developed and presented.

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