Ontology-based Facility Maintenance Information Integration Model using IFC-based BIM data

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Abstract: Many construction projects have used the building information modeling (BIM) extensively considering data interoperability throughout the projects' lifecycles. However, the current approach, which is to collect the data required to support facility maintenance system (FMS) has a significant shortcoming in that there are various individual pieces of information to represent the performance of the facility and the condition of each of the elements of the facility. Since a heterogeneous external database could be used to manage a construction project, all of the conditions related to the building cannot be included in an integrated BIM-based building model for data exchange. In this paper, we proposed an ontology-based facility maintenance information model to integrate multiple, related pieces of information on the construction project using industry foundation classes-based (IFC-based) BIM data. The proposed process will enable the engineers who are responsible for facility management to use a BIM-based model directly in the FMS-based work process without having to do additional data input. The proposed process can help ensure that the management of FMS information is more accurate and reliable.

Keywords: Facility maintenance, Integration model, BIM, Ontology

I. INTRODUCTION

Because the construction industry differs from the manufacturing industry, facility maintenance in the construction industry must be managed considering the following differences [1], i.e., 1) almost all construction projects are unique, 2) each construction site has different constraints, 3) the lifecycle of construction projects are much longer, 4) construction projects usually are evaluated subjectively, 5) the owner directly influences production, and 6) there are various stakeholders in construction projects.

In addition, building information modeling (BIM) has been used extensively in the entire lifecycle of buildings to manage their physical and functional characteristics. Since BIM technology can provide object-based parameter management [2], various engineering analyses of the construction project's phases, such as energy analysis, structural analysis, estimation, and scheduling, have been conducted using BIM technology. BIM technology derives integrated information from the Industry Foundation Classes (IFC) considering semantic relationships between concepts [3], meaning that BIM-based building models provide automatic and systematic management procedures on the entire lifecycle of buildings.

In this regard, many researchers have evaluated the potential benefits of BIM by focusing on both the technical and procedural perspectives [4]. According to recent surveys, in which less than 10% of the respondents were facility managers, owners or deconstructors, these trends do not necessarily reflect the current use of BIM in existing buildings [5]. For this reason, research and case studies related to facility maintenance (FM) are not conducted very often, and, even when they are muchless detailed than the other design and construction phases of a building's lifecycle [6].

Focusing on the use of BIM in FM, there is a growing interest in coordinated, consistent, and computable building information or knowledge management through the design, construction, operation, and maintenance phases. In this regard, the information collected through a BIM process is stored in a heterogeneous database based on various information management systems for a variety of FM practices, such as commissioning and closeout, quality control and assurance, energy management, maintenance and repair, and space management [7]. Since these information management systems for FM support the practices individually, the required data are fragmented between the systems. Moreover, when the databases of these systems are filled by facility managers, the data are entered manually after hand-over of a building by 2D-based as-built drawings, even if the data were managed using the BIM-based information management system's form design and construction phases. In addition, on the most current cases in the FM phase, because the plan of using BIM in FM information system is unclear to the stakeholders of FM, including the owner and the facility manager, the definitions of the required data for BIM-based FM practices are vague. In this regard, an international standard is being developed to exchange facility information during design and construction phases through the construction operation building information exchange (COBie). Using the COBie sheet for data exchange, however, the required data

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should be managed by the integrated BIM-based building model with some external data. When an information manager wants to collect FM data using COBie, he or she must consider external data, for instance, product data using specifiers properties information exchange (SPie) library, which provides buildingSMART by a middleware to apply the SPie library on the COBie sheet.

To collect the information required for FM, in this paper, we proposed an ontology-based facility maintenance information model to integrate multiple related information pieces on the construction project using IFC-based BIM data. To that end, we analyzed the exchange requirements for FM according to the buildingSMART alliance. Then, we developed an ontological conceptual integration model to relate the data semantically with applying process.

II. RELATED WORKS

A. IFC-based BIM data

The IFC data model is intended to describe building and construction industry data [3]. The format of the IFC file was developed by the international alliance for interoperability (IAI) to facilitate interoperability, and it is an open data-exchange format that is used by model-based applications to exchange building information [8]. The IFC model consists of tangible components such as walls, doors, beams, and furniture, as well as the more abstract concepts, such as space, geometry, materials, finishes, and activities.

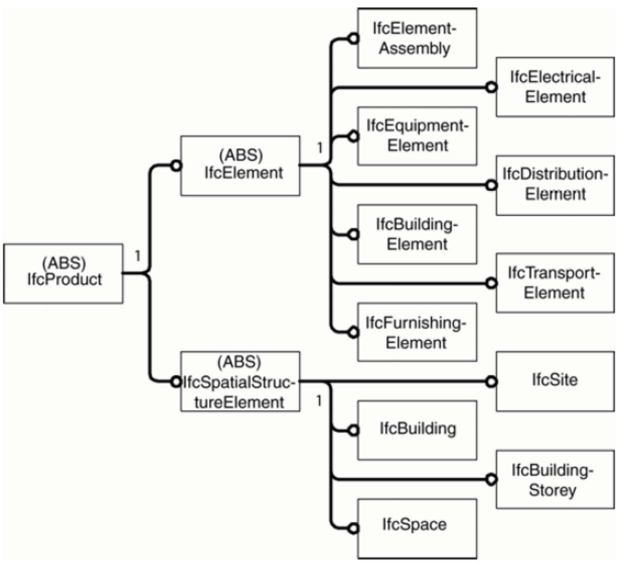

FIGURE I. SUBCLASSES OF "IFCOBJECT" IN IFC SCHEMA 2X [9]

In the current state, there are two major international candidates for core ontologies common to the FM sector, i.e., IFC and ISO 12006-2 [9]. ISO 12006-2 is an international standard that represents a classification system for construction work by ISO/TC 59 in 2001. This classification system contains 17 tables to categorize the construction information by four facets: 1) construction result, 2) construction process, 3) construction resource, and 4) property/characteristic. These facets are related to each other with semantic relationships, as shown in Figure 2 [10].

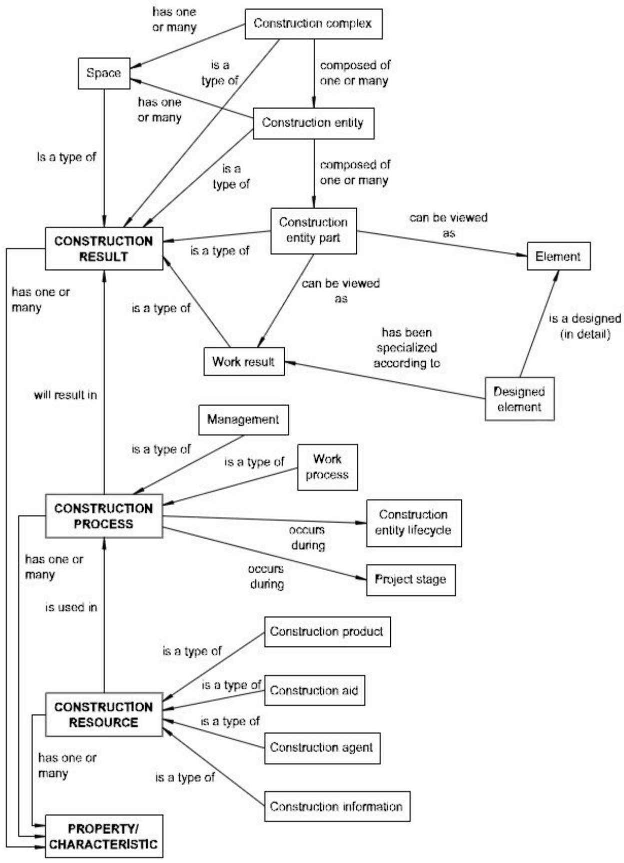

FIGURE 2. SEMANTIC RELATIONSHIPS IN ISO 12006-2 [10]

The format of the IFC file was developed by building SMART international in 1997 as an international standard file format to represent a building model. In 2014, the latest version of IFC, i.e., IFC4, was adopted by most BIM-based design programs, such as Revit, ArchiCAD, Allplan, and DigitalProject. However, the EXPRESS general purpose information modeling language and encoding rules are complex and difficult to parse and recognize without STEP technology [11]. Since the IFC-based BIM data are well organized by semantic relationships in the IFC schema, recently, the buildingSMART International Institute has been developing IFC web ontology language (IFCOWL) which can be used to conceptualize the terms and relationships in various domains [12].

B. Exchange Requirements for FM

In 2009, the buildingSMART alliance defined the general requirements for design applications to enable the handover of facility management information [13]. These requirements describe the common data by the exchange requirements needed between the planning and design process at the start of the maintenance and operation phase. The exchange requirements are given in detail for all objects and attributes needed for the handover of the facility, but they are still neutral to the actual format of the exchange. There are three categories in the exchange

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requirements, including project information in Figure 3. The model structure category contains two sub-categories by spatial containment, which defines by site, building, building storey, and space, and then groups those that define a set of spaces as a zone. The architecture category contains building elements, which are defined as window, door, covering, furniture, fixture and equipment, and furnishing. The MEP category contains MEP elements and systems.

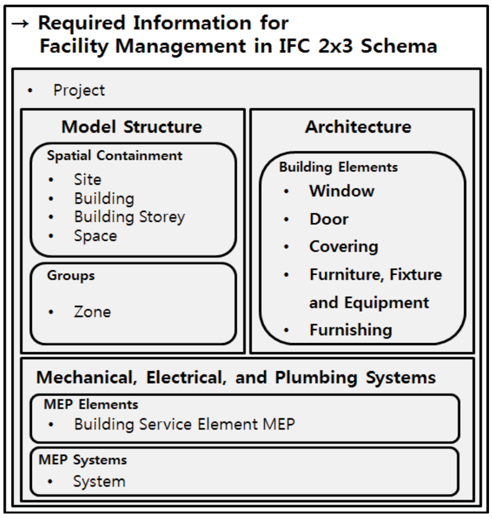

FIGURE 3. EXCHANGE REQUIREMENTS FOR FM [13]

III. ONTOLOGY-BASED INTEGRATION MODEL

A. Conceptual Integration Model

In general, various sources of information are required by the FMS throughout a building's lifecycle. However, since the information exchanged is not complete enough from the design and construction phases to the operation and maintenance phases, the exchange requirements for FM may be very difficult to collect or create with a project management information system (PMIS) based on a BIM-based information management system. Moreover, collected information, such as design information extracted from the BIM-based building model, construction information from the PMIS, and the property/characteristic information managed, heterogeneous external database must be integrated comprehensively to use the FM process. In this regard, ontology technology can be used to automatically and systematically integrate the semantic exchange requirements for FM, as shown in Figure 4.

In the conceptual integration model, the integrated exchange requirements have five subclasses: 1) project class with site information from PMIS database, 2) building class with physical and logical boundaries, such as storeys and spaces, 3) architectural elements class with window, door, covering, furniture, fixture and equipment, and furnishing subclasses to use as a subject item in FM work using FMS, 4) property/characteristic class with detailed product specification from heterogeneous external database, and 5) system class with MEP elements of the facility.

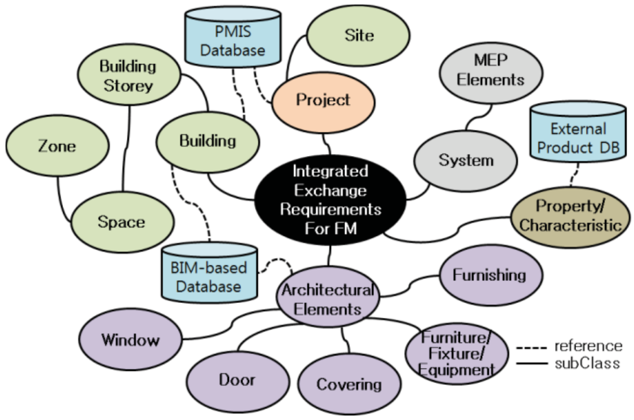

FIGURE 4. CONCEPTUAL INTEGRATION MODEL

B. Process of using the Integration Model

There are two major sources to integrate exchange requirements for FM using the semantic reasoning method. The BIM-based building model has been exchanged from the design phase to the construction phase, and, after that, the as-built building model is updated based on the BIM-based building model in the construction phase. In this regard, the as-built model contains many types of facility objects, including architectural and MEP elements, by the IFC file format. Then, in the BIM data extraction layer, the IFC data can be extracted to convert the resource description framework (RDF) [14] format to bind with PMIS data on the reasoning layer. In addition, the project and building information, which has been generated on the site during the construction phase, also is loaded from PMIS to convert the RDF format. Both sets of converted RDF data are bound with both spatial and architectural ontologies in ontology manager. The spatial ontology defines the classes of the physical and logical boundaries of a building to describe the placement of architectural elements as a facility object on the architectural ontology. The inferred knowledge and RDF data can be managed on the knowledge base as a database of the information integration model. With the knowledge base, users can query the inferred knowledge, with specific query language such as SPAQL, when they want to get any information for FM works using FMS [15]. Figure 5 shows the process of applying the integration model.

IV. Conclusions

In last decade, BIM-based project management methodologies have been studied actively and developed from various perspectives. However, in the facility maintenance sector, there is still limited use of BIM in FM works using FMS, including data input and information management processes. Therefore, in this paper, we proposed an ontology-based facility maintenance information model to integrate multiple related information pieces on the construction project from the design and through construction phases using IFC-based BIM data. We analyzed the IFC-based

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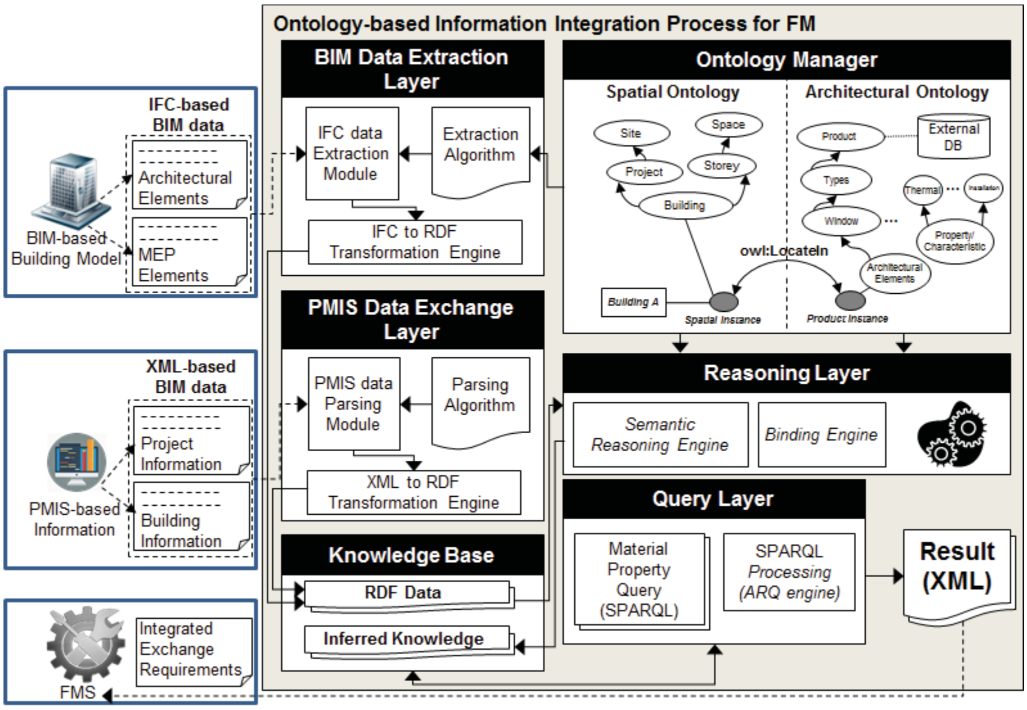

FIGURE 5. PROCESS OF APPLYING THE ONTOLOGICAL INTEGRATION MODEL

exchange requirements developed by buildingSMART alliance in 2009 to handover a building for FM. After that, we defined the conceptual information integration model within BIM, PMIS, and external product databases. Moreover, we developed the process of using the integration model based on ontological reasoning process.

This integration model enables owners or facility managers to use the BIM-based FM information considering the exchange requirements related to the BIM-based as-built model and PMIS data. In addition, since the data input process of exchange requirements into FMS is automated systematically, using the ontological reasoning method, the effectiveness and efficiency of the data input for FM can be increased dramatically.

Future research should pursue further validation of the integration model and the process of its application. In addition, the proposed model should be developed further to support FM practices in real world cases involving specific uses.

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