PROCESS OF BIM AND ONTOLOGY-BASED AUTOMATION FOR ESTIMATION OF BUILDING REPAIR AND REPLACEMENT COSTS

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Abstract- It is important to consider initial construction costs and also maintenance cost, operation cost, and end-of-life costs, which together are called the life cycle cost (LCC). LCC analysis is compulsory in Korea per various regulations and systems. Increasingly, the construction industry must deal with a large amount of information and building information modeling (BIM) is now being implemented to address this issue. Therefore, it is inevitable that the use of BIM in construction and LCC analysis in the pre-construction phase will inevitably need to be brought together. This research proposes an ontological approach to automatic BIM-based estimation of repair and replacement costs. This will overcome current problems in cost estimation of repair and replacement. Such estimates are currently done thru a manual process that lends toward inefficiency and subjectivity.

The proposed methodology of the study is as follows. First, analyze repair and replacement criteria currently applied overseas and in Korea. Second, define the route of extraction IFC (Industry Foundation Classes) data from the BIM model that describes each of the required elements for estimating repair and replacement costs. Finally, suggest a process of automation to estimate repair and replacement costs thru an Initial Construction Cost Estimation Ontology (ICCEO) that recommends the most adequate work item in order to map with cost information and the Repair and Replacement Cost Estimation Ontology (RRCEO) that refers to initial construction costs as recommended by ICCEO. Using the proposed process is more objective and accurate for obtaining estimated R&R costs. The use of IFC is more accurate and it is more consistent to infer appropriate R&R criteria and information based on ontology technology.

Index Terms- BIM, LCC, Repair and Replacement(R&R) cost estimation, Semantic Web, Ontology, Automation system

I. INTRODUCTION

A. Background and Objective

The portion for maintenance cost in terms of overall construction project cost is tremendous because the service life of a building is quite long. Therefore, it is important to consider not only initial construction cost, but also maintenance cost, operation cost, and end-of-life. Together, these costs comprise the life cycle cost (LCC) of a building. The life cycle cost is the total cost of building or its parts of life, and includes cost of design, planning, operation, maintenance and disposal cost [1]. According to BS ISO 15686-5, LCC is composed of construction cost, operation cost, maintenance cost and end-of-life [2]. For Korea, according to the Construction Technology Management Act of Article 75, all construction projects with a construction cost over 10 billion won should review value engineering (VE) in the design phase. In this VE process, it is mandatory to contain LCC analysis. Additionally, in accordance with Ministry of Land, Infrastructure, and Transport Instruction Article 371, bidding documentation should include documentation for an economic analysis of design in the design-build project and an alternative tender project. This documentation includes LCC analysis, initial construction cost, repair and replacement cost, energy cost, and disposal costs. Meanwhile, dealing with the large amount of information in the construction industry is increasingly important. Building Information Modeling (BIM) has been adopted as the solution for this problem. BIM is a technology and a paradigm of providing and managing facilities or building information from the initial planning phase to facility management. In Korea since 2012, turnkey and design competition construction projects that are over than 50 billion won must apply BIM design in all projects for the Korea Public Procurement Service. This requirement also extends to all projects and guidelines apply BIM depending on construction scale.

Therefore, it is inevitable to bring together the paradigm of BIM in the construction industry and LCC analysis in the pre-construction phase. To date, however, the study of BIM-based LCC analysis is insufficient and in particular the study of repair and replacement cost as one element of maintenance cost has garnered only a very low level of interest.

This research proposes an ontological approach to BIM-based automated estimation of repair and replacement cost. It will overcome the problems of cost estimation for repair and replacement. Currently, this activity is part of LCC estimation, and completely manual, and as such, the results can be subjective and inefficient. Furthermore, costs can vary depending on who is estimating the cost. As any estimate requires consistency and reliability, [3] it is necessary to further investigate effective estimation methodologies.

B. Scope and Methodology

The ultimate goal of this research is to develop BIM-based automation when estimating LCC by an ontological approach. This study is limited to only repair and replacement cost estimations of maintenance cost. The methodology of the study is as follows. Firstly analyze repair and replacement criteria overseas such as in Belgium, England, Japan and Korea. Then we obtained the requirements to estimate repair and replacement cost in buildings as a result. Second, define the route for extraction of IFC (Industry Foundation Classes) data from the BIM model that describes each of the requirements for estimating repair and replacement costs. Finally, suggest an automation process for estimating repair and replacement cost by ontology. To obtain the final result, initial construction cost is automatically inferred from the Initial Construction Cost Estimation Ontology (ICCEO) which recommends the most adequate work item in order to map to cost information. In addition to estimating repair and replacement cost, we suggest a Repair and Replacement Cost Estimation Ontology (RRCEO) by referring to initial construction costs as recommended by ICCEO [5].

Table 1 Comparison between Housing Act and Education Office R&R criteria

	Target object	Repair cycle (Year)	Repair rate (%)	Replacement Cycle (year)
Housing Act	Internal-Aluminum Window	20	10	25
Chungnam Education Office	Window Construction-Aluminum Window	17	6.4	34

II. OVERVIEW OF REPAIR & REPLACEMENT (R&R) CRITERIA

A. Analysis of repair & replacement (R&R) criteria

A-1. Overseas

Building repair & replacement (R&R) criteria exist outside of Korea, but vary from country to country. In Japan, companies specialize in managing different criteria such as external painting, external rust preventative painting, waterproof asphalt repair items such as space, and this is divided by building elements.

There are various standards in European countries, but the content is similar. Repairs and replacement items are separated by spaces and areas, as in the case of Japan, it is set to the repair cycle, repair rate, and replacement cycle. For example, the content of Belgian training standards are categorized by areas such as the inner forming member and window frames, interior partition walls, windows, and window frames. A unique approach is that Belgium separates the building into four applications such as homes, offices, hospitals and schools, and each have a classification system based on space and building elements. The United Kingdom has standard repair and replacement criteria for a larger range of classification systems, such as interior materials or exterior materials.

A-2. Korea

There are several criteria for repair & replacement (R&R) in Korea, but there are no standard or official criteria to estimate consistent cost. The long-term maintenance plan of the Housing Act, Education Office of the province, and service life of Korea Public Procurement Service (PPS) are the most commonly used criteria for maintenance cost. They are used by different projects and situations according to an engineer's preferences.

The Housing Act for long-term repair plan is classified as a building exterior, interior, etc. It further classifies items as roofing, external, ceilings, interior wall, floor, etc. PPS useful life by item serial number is used to distinguish the items and are classified in the Daejeon/Chungnam Education Office repair & replacement standard building construction guidelines and civil engineering construction and plastering are classified as a sub-classification system, such as for waterproofing, tile construction, etc [4].

B. Requirements for estimating repair & replacement cost in a building

A review of the criteria needed to estimate R&R cost found the following items: repair cycle, repair rate, and replacement cycle. This information depends on external or internal information about a building, building element, and material information. Moreover, although an object may have the same building element and same material, R&R information is different depending on R&R criteria. For example, an internal aluminum window's R&R information is totally different when complying with the Housing Act versus the Chungnam Education Office criteria. This comes about because building

usage may be different and the purpose of the criteria is different for each system. As such, a perfect fit does not exist for every building criteria and regulatory requirement. As such, it is necessary to estimate R&R cost by selecting one of the existing criteria for a particular system. The Housing Act requires data on repair cycle, repair rate, replacement cycle as 20 years, 10%, 25 years. In comparison, the Chungnam Education Office creates a specification of 17 years, 6.4%, 34 years. (Table 1)

Therefore, the requirements for estimating R&R cost in a building includes space of building, building element, and material type of building element [4]. Furthermore, there are differences among the R&R criteria that exist overseas and Korea and an estimator should select the most appropriate criteria for the project purpose.

III. PROCESS OF BIM-BASED R&R COST ESTIMATION BY ONTOLOGY

A. Overall process of BIM-based R&R cost estimation by ontology

This study proposes an automated process for determining BIM-based repair & replacement (R&R) cost estimation by semantic web. The semantic web based ontology infers the most appropriate R&R criteria and R&R information that best fits each project condition. This advanced process can solve the problems that exist in the present process of estimating R&R costs. Estimators currently first estimate the initial construction cost and map this with several R&R criteria based on their own opinions. As such, the results are often subjective and inconsistent and items that should be contained to better determine costs are often missed.

The overall process of this study is depicted in Fig. 1. This process is divided into two main parts, one is an initial construction cost estimation part and the other is a repair & replacement (R&R) cost estimation part. To begin, IFC data for estimating initial construction cost and R&R cost is parsed from a BIM model such as *ifcSpace*, *ifcBuildingElement*, etc. Then, those items that are recognized as a design condition become the input data for the Initial Construction Cost Estimation Ontology (ICCEO). It is necessary to convert data from IFCXML to RDF for automated inference of work items, size, thickness of finish, thickness of waterproofing, etc. Finally, ICCEO provides the most appropriate item in standard unit cost using both kinds of IFC data from BIM and inferred data from ICCEO.

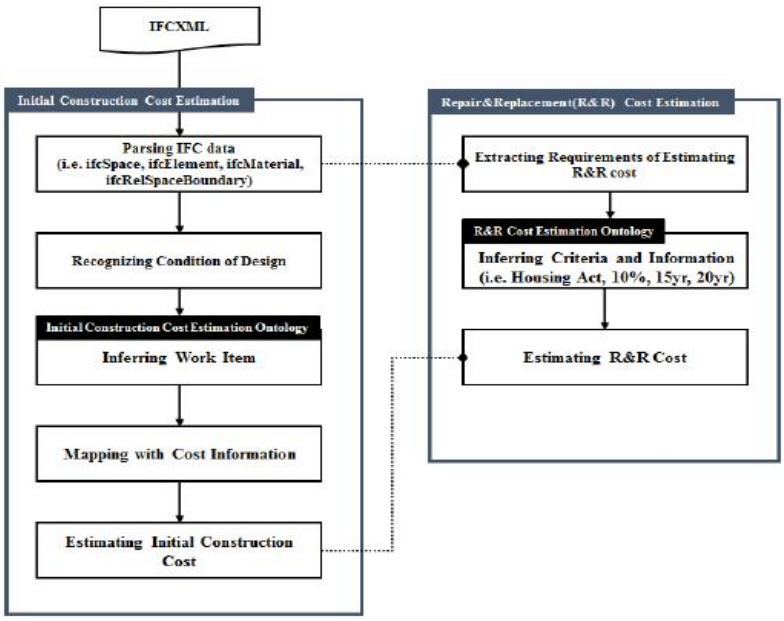


Figure 1 Process of BIM-based R&R Cost Estimation by Ontology

The Repair & Replacement Cost Estimation Ontology (RRCEO) is based on initial construction cost where the determination is automated and inferred from ICCEO and the framework is similar to ICCEO. The requirements for estimating R&R cost is defined in the second chapter by analysing R&R criteria. It includes space information, element type, material type, and building usage. They can be extracted from BIM as IFC data and it goes to input data of RRCEO. There are various types of R&R criteria and each of them provide different classification and repair cycle, repair rate, and replacement cycle. Accordingly, the best and the most appropriate repair cycle, repair rate, and replacement cycle is recommended by an automated inference process in RRCEO by searching for all criteria. The result of RRCEO is specific R&R criteria and R&R information. For example, Housing Act and repair cycle 15 year, repair rate 10%, and replacement

cycle 20 year. R&R cost is then estimated.

A. Initial Construction Cost Estimation Ontology (ICCEO)

The objective of this study is to develop an automated process for estimating the repair and replacement cost of buildings. In general, the repair and replacement cost of buildings are estimated by applying repair cycle, repair rate, and replacement cycle of each object to the initial construction cost. Therefore, it is essential to accurately estimate initial construction costs.

This study aims to estimate consistently and accurately repair and replacement costs by reflecting reality. According to this purpose, this study established both an Initial Construction Cost Estimation Ontology (ICCEO) and Repair & Replacement Cost Estimation Ontology (RRCEO) based on a semantic web. An outline of the Initial Construction Cost Estimation Ontology (ICCEO) is provided in Fig. 2.

The ICCEO is an ontology with BIM data that is extracted from IFCXML. The IFCXML file contains IFC data such as *IfcSpace*, *IfcBuildingElement*, *IfcMaterialLyer*, etc. These are transferred to a RDF file in order to be combined to an ontology (OWL). The ICCEO contains three main classes and others can be added per specific requirements from feature of materials. The three main classes are *RoomUsage* and *BuidlingElement*, and *WorkCondition*. The *WorkCondition* class is able to apply semantic reasoning by rules defined by combining the other classes of ICCEO. Other classes can be added such as *FinishTHK*, *BaseType*, *WaterproofingTHK*, etc. These are determined by material specification. For instance, if the material type is membrane waterproofing, the requirements for estimating initial construction cost are room usage, building element, and thickness of waterproofing. In this case, the class *WaterproofingTHK* should be added to ICCEO. These classes are recognized as a work condition (input data) and work items are inferred from semantic reasoning rules such as size, thickness, work type, joint width, and joint materials (output data). The union of extracted IFC data and inferred data from ICCEO goes into a cost database such as a standard unit cost and mapping with specific item.

B. Repair and Replacement Cost Estimation Ontology (RRCEO)

The Repair & Replacement Cost Estimation Ontology (RRCEO) is based on initial construction cost which is inferred by ICCEO and each repair cycle, repair rate, and replacement cycle for objects. Fig. 3 depicts a framework that describes the RRCEO logic. The RRCEO also has the same framework as the ICCEO and the difference is output data. First, requirements for repair and replacement cost estimation must be defined as space, building element, material type, and building usage. The three requirements of space, building element, and material type can be extracted from the BIM model by IFCXML, but the data related to building usage should be extracted by property set in BIM. Then, these items are defined as classes *Space*, *BuildingElement*, *Material*, *BuildingUseage* and comprise the R&R Estimation Condition. These IFCXML data are converted into a RDF file format in order to insert this into RRCEO, which is an OWL file format. The RRCEO logic is to infer the best R&R criteria type with input data. In fact, there are many R&R criteria types and each of them requires different kinds of information such as from the Housing Act, which requires space, building element, material, while the Education Office only needs material type. Therefore, the RRCEO recommends the best repair cycle, repair rate, and replacement cycle by considering all of the criteria that exist.

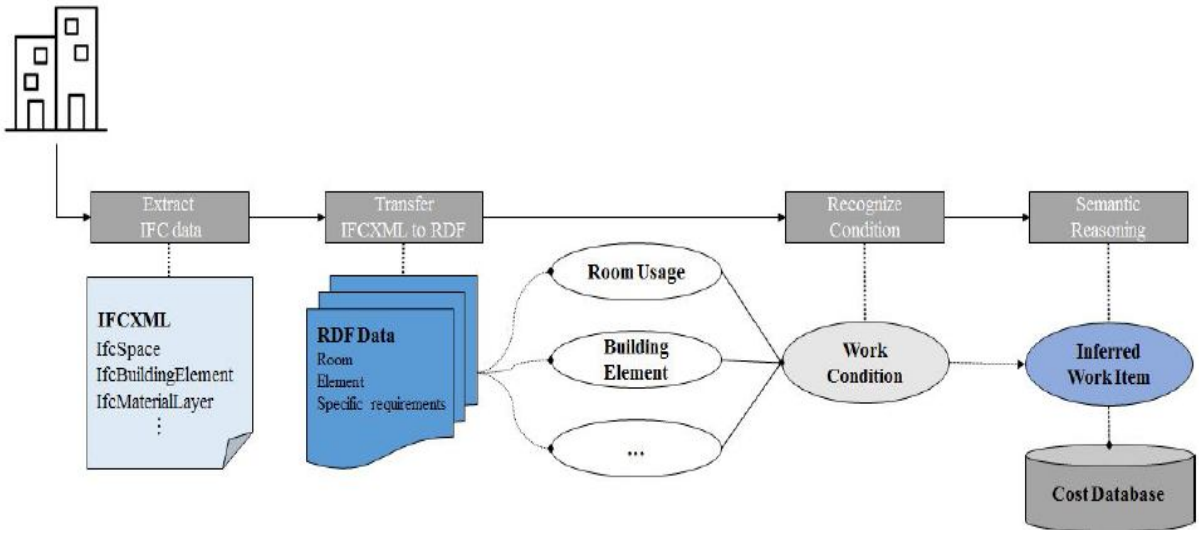


Figure 2 Framework of Initial Construction Cost Estimation Ontology (ICCEO)

CONCLUSION

This study proposed a new process for automated estimation of repair and replacement cost of a building, which is one of the components of LCC. The BIM-based information from IFC data extracted from a BIM model was more accurate and a semantic web based ontology was applied for consistent results. LCC analysis currently involves manually matching an amount calculated based on information about replacement and repair costs. The manual process is prone to errors or missing information. As BIM application is currently mandated, BIM can be utilized to address the above problem. Using IFC is more objective and accurate for obtaining R&R cost. It is more accurate and consistent to infer the appropriate R&R criteria and information based on ontology technology. This study makes a contribution by applying such IFC data to estimate repair and replacement costs. Reliability and accuracy will increase with the automated modeling results for such costs.

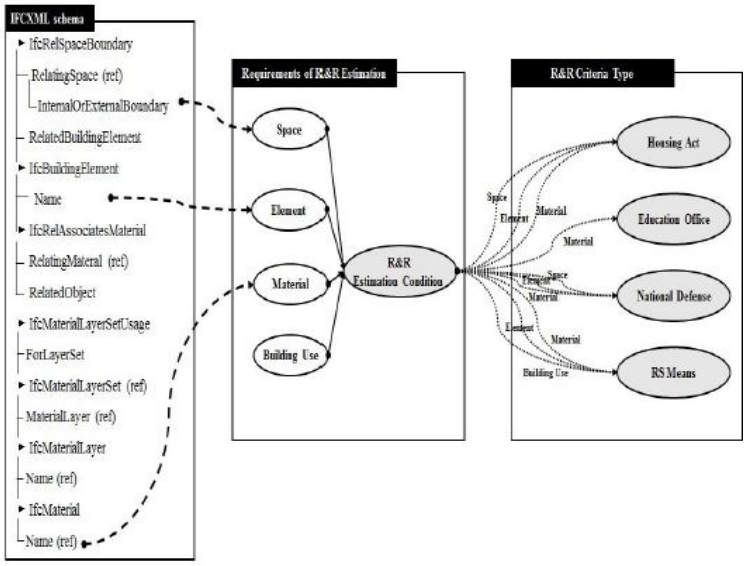


Figure 3 Mapping from IFC schema to RRCEO input

The scope of the present study was limited to repair and replacement costs. The suggested process should be verified for specific building elements. Future research can expand on the scope of this study to include all components of LCC, such as energy costs, and also suggest automated processes for other specific building elements.

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