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INTEGRATING BUILDING INFORMATION MODELING AND VISUAL PROGRAMMING FOR BUILDING LIFE-CYCLE COST ANALYSIS

VEERASAK LIKHITRUANGSILP[1], HANG T. T. LE[1], NOBUYOSHI YABUKI[2], and PHOTIOS G. IOANNOU[3]

[1]*Dept of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Pathumwan, Thailand*
[2]*Division of Sustainable Energy and Environmental Engineering, Osaka University, Osaka, Japan*
[3]*Dept of Civil and Environmental Engineering, University of Michigan, Ann Arbor, USA*

In recent years, the fierce competition in worldwide real-estate market has pushed the stakeholders towards the sustainability for buildings. Life-cycle cost (LCC) is an effective economic evaluation tool that provides a detailed account for all costs related to constructing, operating, maintaining, and disposing a construction project over a defined period of time. Awareness of better value of money throughout the LCC is beyond the initial price. Governments and Contracting authorities add the LCC as a key provision in the context of National Codes and Council Directives to promote the growth of sustainability concept. Current LCC analytical methods are costly, laborious, and time-consuming due to the difficulties of obtaining information and implementing many single LCC analyses for all building elements, which may be attributed to the inaccuracy of results. Building information modeling (BIM) is a modern technology that can potentially overcome the asperities that obstruct practical LCC implementation. This paper develops a new automated system for performing LCC analyses for new building projects by integrating BIM authoring programming with visual programming. The proposed system consists of two main modules. The BIM module is designed to retrieve 3D geometric and physical parameters of building element types. The life-cycle cost calculation module can perform automatic estimating and report results. This system provides an economic evaluation tool for the owner to manage the total life-cycle budget of their projects.

Keywords: Sustainability, Economic evaluation, BIM authoring programming, Contractor selection.

1. INTRODUCTION

Buildings serve many vital functions in human life. They provide space for work, education, living, and other public and private uses. In many developing countries, building construction is one of the most important sectors of the construction industry. It is also a sector that consumes natural resources the most and accounts for a high percentage of the greenhouse gas emission, which has an adverse impact on the environment and occupants' health. According to the U.S. Green Building Council (2015), buildings in the U.S. are responsible for 41 percent of total U.S. energy consumption. In addition, they account for 38 percent of total U.S. CO_2 emissions, 40 percent of total raw material use globally, and create 250 million tons of total U.S. solid waste output. The global goals for sustainable development have pushed investors toward sustainable buildings, which are driven with the low running costs in the construction industry. The life-cycle cost (LCC) is an economic evaluation tool that provides a detailed account for all costs related to the design, construction, operation, maintenance, and disposal of a construction project over a defined period of time. The LCC implementation is challenging as cost estimators must cope with various problems concerning collecting and storing relevant information, especially operation and maintenance costs. Assaf *et al.* (2002) pointed out that the difference and lack of data requirements were main barriers for the application of LCC analysis in the construction industry. The LCC calculation will be accurate if the collected data are reliable (Emblemsvåg 2003). In practice, capturing data for LCC analysis is challenging due to numerous data documented in paper forms, the limited existence of data sources, and errors in inputting and transferring data manually to implement many calculation processes.

Building information modeling (BIM) is a modern technology that can improve the productivity of the construction industry. Likhitruangsilp *et al.* (2016) presented thirty BIM uses in various aspects of construction management. Recently, the use of BIM has increased significantly. Integrating BIM platforms in various construction management aspects is another trend in academic research. This will transform the traditional construction industry to the digital industry. Likhitruangsilp *et al.* (2018a) also proposed a BIM-enabled system for calculating the time and cost impacts for construction change orders. This system provides the 3D visual outputs and can save a significant amount of time as compared with traditional paperwork methods. BIM adoption in the construction industry was only at 28 percent in 2007, but the level of adoption became 71 percent in 2012 and kept increasing. In addition, 93 percent of BIM users believed that there was potential that we will gain more value from BIM in the future. Two-thirds of BIM users said that they observed positive ROI on their investment in BIM, and 87 percent of experts were experiencing positive ROI with BIM (Koppinen and Morrin 2012).

Even though there have been several publications related to the LCC analysis, most of them did not consider all cost categories for their computations, especially the energy cost. This contributes to the limited use of LCC as a sustainability-based tool in the construction industry (Langdon 2007). Flanagan *et al.* (1989) proposed a framework for collecting data that are necessary for determining project life-cycle costs. Ashworth (1996) proposed a method for estimating the life expectancies of different building components by using a combination of objective analysis and subjective judgment. Alqahtani and Whyte (2016) used the multiple regression models and artificial neural networks to predict more accurate running costs of building projects. Kehily and Underwood (2016) presented a methodology to embed LCC within an existing 5D BIM technology (CostX) to produce a 5D BIM based LCC artifact. Although this research work provided a solution to develop a LCC tool, it is dependent on a commercial 5D BIM estimating software, which is a major cost for building designers. To alleviate the aforementioned difficulties, this paper proposes an automatic system for building LCC analysis using open-source visual programming, which functions with BIM via Dynamo script for Autodesk Revit. It allows users to extend BIM capacity by using the graphical algorithm editor and Python programming language. Some research works integrated BIM platforms to develop the automatic systems in various construction management areas. For example, Likhitruangsilp *et al.* (2018b) integrated Autodesk Revit Architecture, Excel spreadsheet, Visual Basic for Application, and Revit Dynamo to develop a BIM-enabled change detection system for assessing impacts of construction change orders. Dynamo programming language is easy to understand for cost managers who are usually nonprogrammers. The proposed system is a comprehensive, but user-friendly, tool that can replace the conventional LCC analysis. In addition, we also investigate the extension of current BIM capacities to the LCC calculation for building structure types concerning the element properties of BIM element models.

2 LIFE-CYCLE COST ANALYSIS FOR SUSTAINABLE BUILDINGS

A construction project can be divided into a number of phases: planning design, construction, operation, maintenance, and disposal. Most of them last from one to three years, except for the operation and maintenance phase that may last 30 to 50 years. This is why 30 to 40 percent of the total LCC for a facility incurs in these first three phases, and 60 to 70 percent incurs in the later phases (GCR 2004). For the traditional competitive tendering approach, contractors are often chosen based on their lowest construction costs, which are a small part compared to the running costs of the building life-cycle cost. This is an irrational method because the higher cost may have been created by building owners due to inadequate operation later on. In this paper, we focus on four main cost categories for the LCC analysis. The total life-cycle cost can be calculated as shown in Eq. (1):

$$C_{Life\_cycle} = C_{Construction} + \frac{(1+i)^n - 1}{i(1+i)^n} C_{Maintenance} + \frac{(1+i)^n - 1}{i(1+i)^n} C_{Operation} - \frac{1}{(1+i)^n} C_{Salvage} \qquad (1)$$

where C_{Life_cycle}, $C_{Construction}$, $C_{Maintenance}$, $C_{Operation}$, and $C_{Salvage}$ are the total life-cycle cost, construction cost, maintenance cost, operation cost, and salvage cost of a building structure type, respectively. i is the discount rate of money, and n is the period of analysis.

The construction costs related to material, labor, and equipment to construct a building element are obvious compared with other cost categories in the LCC analysis. The maintenance costs are related to the costs of regular care, repair, and replacement of a building element or system. The data sources usually contain the average annual maintenance per structure unit. The expense for maintenance depends on the type of the building structure. This cost may be part or total of initial construction costs to replace such element. The operation costs encompass service, security, and insurance for operating all the building structures under the condition considered. The energy cost usually takes up the greatest share of the operation cost. Most of the building operation cost incur in its operation period. The amount of energy consumption for a building depends heavily on the use hours of building system operations, weather conditions, the performance level required by building owners, as well as the building design and insulation provisions. Thus, project managers should not overlook the energy cost of building elements. Each building element type has a unique expected service life. Once it reaches such expected life, the building element will lose its technical capacity, reliability, and quality due to natural ageing and use. The salvage cost is the value of a building structure at the end of the service life. It is calculated as the difference between the resale and the original values of the building structure. While construction costs are clear, operation and maintenance costs are not obvious in the design phase. Thus, the LCC analysis plays an important role in making a funding decision.

3 RESEARCH METHODOLOGY

To develop the BIM-enabled system for building life-cycle cost analysis, we first did comprehensive literature review on the life-cycle cost analysis, applications of BIM to cost management, and other relevant issues. We then defined the system requirements in accordance with the research objectives. The conceptual framework for proposed system was then established. The next step was to choose the potential platforms for the relevant functions of the proposed system. Once the system has entirely been developed, it was applied to an actual building project as a case study for illustrating and verifying the applicability and practicality of the proposed system.

4 RESEARCH SYSTEM ARCHITECTURE

The proposed BIM-enabled LCC analysis system is a computerized system, which is developed based on the synthesis of LCC analysis practice, the capabilities of BIM tools, and Python programming language. The system can address two main problems of the conventional LCC analysis. The first problematic issue is data management. The LCC calculation heavily relies on various information. In the design phase, owners must usually deal with the issue of information retrieval, especially energy costs. The proposed system can provide the coefficients of heat transfer for all materials, which are essential building element properties required for estimating energy consumption. In addition, the database management system is used to organize, store, and query data for BIM models.

The second challenge of the conventional LCC implementation is time consumption resulting from multiple computations such as performing quantity takeoff as well as estimating construction costs, maintenance costs, energy costs, and salvage costs for all the building structure types. All these calculations often require many inputs (e.g., coefficients), and each input requires many relevant parameters. By using visual programming, the proposed system can implement all the LCC computation in a single simulation process. The system architecture consists of two main modules: the BIM module and the LCC calculation module, as shown in Figure 1.

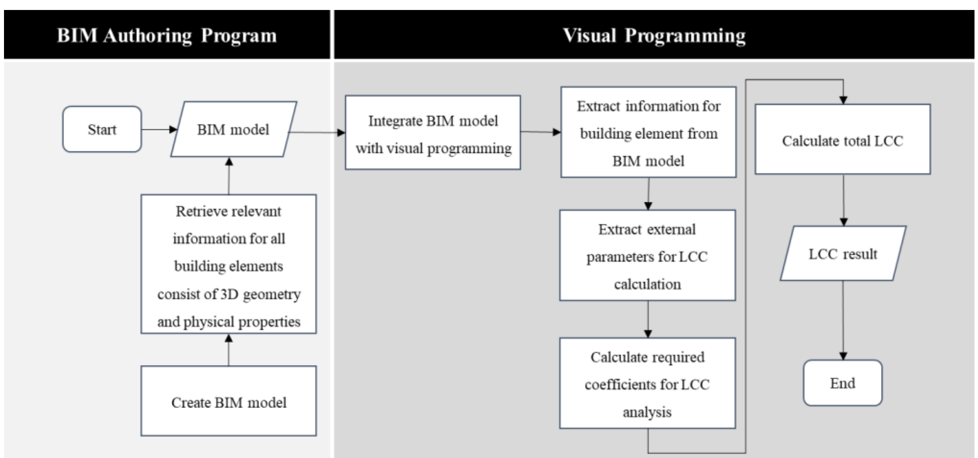

Figure 1. Overview of the architecture of the proposed system.

The BIM module has two significant roles. First, it represents the visual models with geometry parameters for all the building elements. Second, it stores other parameters that are exported from external database into the BIM internal database. The required data of the BIM module are collected from three data sources. The first source is historical data (i.e., project database). The second source is the RSMeans data 2018 book (Phelan 2018). The data consist of material cost, labor cost, and equipment cost for constructing the building element type. The third source is life-cycle costing for design professional books. The retrieved data consist of the expected service life, the annual service unit price, and the percent replaced for each building element type. The LCC analysis module is designed to implement the estimating function and report the results. The information requirements for cost estimating are extracted from the element properties and the spreadsheet LCC template. This module is based on Dynamo script with Python programming language.

5 DATA ACQUISITION AND INTEGRATION

An academic facility is used to illustrate the application of the proposed system. The department of civil engineering building is a five-story building located at Chulalongkorn University, Bangkok, Thailand. After creating and assigning all the element properties of the BIM model, the integrated model was analyzed to automatically extract information required for the LCC coefficient calculations. Figure 2 shows an example for applying the proposed system to a typical external wall type of the case study building.

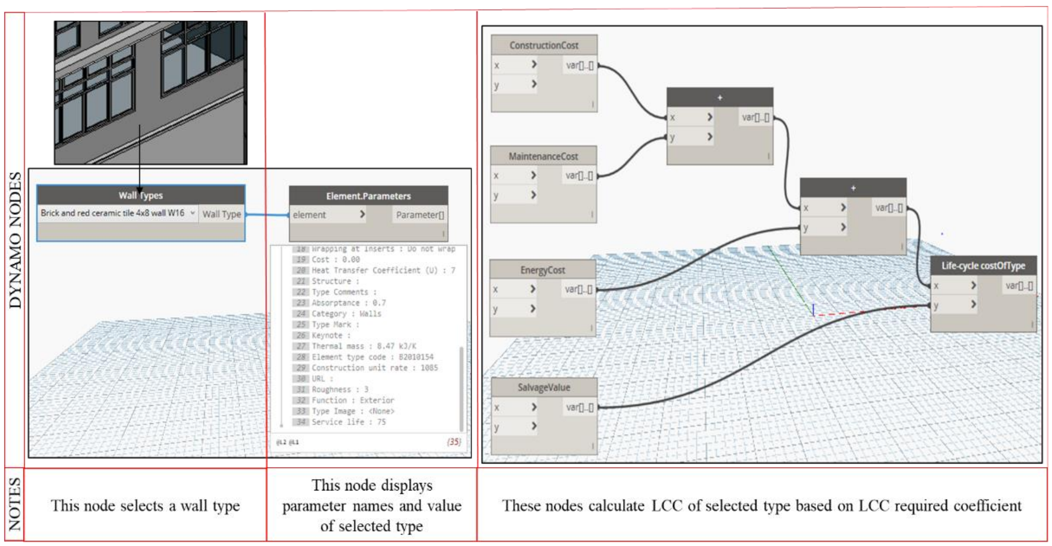

Figure 2. An example for applying the proposed system to a typical external wall type.

6 CONCLUSIONS

This paper presents a new BIM-based system for building life-cycle cost analysis. We propose a methodology for extending the capabilities of current BIM tools for addressing the limitations of conventional LCC implementation, including data management and lengthy estimating processes. The system is then applied to an academic building to verify its capacity and practicality in the construction industry. For future research, green procurement is a key to green growth in order to provide a sustainable approach for the building industry, we intend to investigate a method to integrate our proposed system with green procurement.

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