Article

A BIM-Integrated Relational Database Management System for Evaluating Building Life-Cycle Costs

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Abstract. Sustainable procurement is an important policy for mitigating environmental impacts attributing to construction projects. Life-cycle cost analysis (LCCA), which is an essential requirement in sustainable procurement, is a principal tool for evaluating the economic efficiency for the total life-cycle budget of a building project. LCCA is a complex and time-consuming process due to repetitive complicated calculations, which are based on various legal and regulatory requirements. It also requires a large amount of data from different sources throughout the project life cycle. For conventional data management systems, data are usually stored in the form of papers and are input into the systems manually. This results in data loss and inconsistent data, which subsequently contribute to inaccurate life-cycle costs (LCCs). Building information modeling (BIM) is a modern technology, which can potentially overcome the asperities of the conventional building LCCA. However, existing BIM tools cannot carry out building LCCA due to their limited capabilities. The relational database management system (RDBMS) can be integrated with BIM for organizing, storing, and exchanging LCCA data in a logical and systematic manner. In this paper, a BIM-integrated RDBMS is developed for compiling and organizing the required data and information from BIM models to compute building LCCs. The system integrates the BIM authoring program, the database management system, the spreadsheet system, and the visual programming interface. It is part of the BIM-database-integrated system for building LCCA using a multi-parametric model. It represents a new automated methodology for performing building LCCA, which can facilitate the implementation of sustainable procurement in building projects.

Keywords: Sustainable procurement, life-cycle cost analysis, building information modeling (BIM), 6D BIM, relational database management system, visual programming interface.

1. Introduction

Life-cycle cost analysis (LCCA) is an economic method of project assessment, which takes into account all costs of owning, operating, maintaining, and ultimately disposing of a facility to achieve the long-term value of money [1]. Many nations have emphasized the importance of building LCCs in the tender decision of public procurement, which reflects the awareness of sustainable development. For example, the Directive of European Council decreed that building LCCA was applied to identify the most economically-effective tender for public projects in sustainable procurement [2]. The Italian government has embedded LCCA in the public contract to promote sustainable building projects throughout the feasibility study, design, procurement, tendering, and facility management stages [3]. LCCA was used to examine the sustainability of building projects by comparing the costs of energy use and the maintenance costs of different design alternatives [4]. The use of LCCA ensured that the completed buildings met the environment requirements of the projects' end-users [5]. In addition, LCCA assisted in evaluating the economic aspects of a building project at the early project stage, which contributed to environmental sustainability [6].

Although the advantages of building LCCA have been widely recognized, many previous studies have revealed several barriers related to the availability and reliability of required data, which limit the applications of building LCCA in actual construction projects. For example, building LCCA was limitedly adopted in the construction industry due to the lack of appropriate and reliable historical data [7]. Inadequate time and high costs of data collection were critical barriers for implementing building LCCA in practice because most of the data were recorded in paper documents, which were not readily retrieved [8]. Besides, the quality of available data had a decisive role in implementing building LCCA in practice [9]. To eliminate these barriers, it is necessary to engineer a new system for organizing and managing the required data for building LCCA.

In recent years, building information modeling (BIM) has increasingly been mandated in the construction industry. In 2016, the United Kingdom government required BIM level 2 for the public projects with the initial capital value of over 5 million euros [10]. The Netherlands, Denmark, Finland, and Norway governments also mandated the use of BIM for their public procurement to support sustainable growth [11]. The Chinese government strongly encouraged the introduction and adoption of BIM technologies in the architecture, engineering, and construction (AEC) industry [12]. BIM has also been widely adopted in the US because it can help reduce waste, increase productivity, and save project costs. It was reported that the BIM adoption rate in US was only 28 percentages in 2007. Yet, it increased to 71 percent in 2012 and kept growing every year [13]. In addition, construction costs can be estimated more efficiently and accurately by using BIM technologies [14]. It was also reported that there was no variation between the quantity of construction works measured by BIM and the actual quantity [15]. Although BIM uses have been widely recognized, its application in building LCCA is still extremely limited. This is because existing BIM tools cannot fully manage all the required data for computing building LCCs. The cost database and unit of measurement were usually based on traditional standards that were not applicable to BIM objects. Thus, conventional cost estimating cannot be directly adopted unless the cost-per-standard method is replaced by the cost-per-BIM object method [16].

In present, the construction industry must embrace a great amount of data arising from various sources throughout the life cycle of a facility [17]. Data management and exchange were usually carried out manually in construction projects [18]. This leads to time and cost waste caused by data loss and inconsistent data during the data exchange process. To compute the LCC of a building, various data need to be acquired from various project participants such as the analyzed period and discount rate established by the project owner, construction costs provided by the contractor, as well as maintenance, operation, and disposal costs provided by the facility manager. Consequently, data management has become a major challenge of the architecture, engineering, construction, and operation (AECO) industry. The relational database management system (RDBMS) is an advanced technology that can address the challenges concerning data management. It can manage a large volume of organized data and support interoperability with other platforms [19].

In this paper, the BIM-integrated RDBMS is developed for compiling and organizing the required data and information from BIM models to compute building LCCs. The proposed system is part of the BIM-database-integrated system for evaluating building LCCs using a multi-parametric model, called the BIM-BLCC. The system development consists of three stages. The first stage is the development of the relational database management module of the BIM-BLCC by using a database management system (*Microsoft Access*). The second stage is the development of the visualized BIM-integrated module of the BIM-BLCC by using a BIM authoring program (*Autodesk Revit*). The third stage is the integration of the two previous modules to extract the required data for the BIM model by using the visual programming interface (*Dynamo*) and the spreadsheet system (*Microsoft Excel*).

2. Literature Review
2.1. Life-Cycle Cost Analysis (LCCA)

LCC is the total ownership cost of a project over its useful life. It encompasses all costs associated with the project throughout its life, including design costs, construction costs, operation costs, maintenance costs, and the disposal value [20]. LCCA is used for assessing the cost performance of constructed assets to achieve the long-term value of money. It is also used to

determine whether a project meets the users' requirements [21].

LCCA has been applied in various aspects of construction management. It has been used as an engineering tool for supporting decisions in design and procurement of major construction systems, an effective tool in cost accounting and management, and a design and engineering tool for environmental purposes [22]. Despite the benefits of LCCA are well recognized, it is not widely implemented in practice. This is because construction projects often lack reliable data, standard and guide of documentation, and procurement award incentives [23]. In addition, quantity surveyors (QSs) usually faced with difficulties in collecting and obtaining appropriate, accurate, and consistent data for building LCCA [7, 24, 25]. Since most of the data required for building LCCA are stored in paper documents, compiling such data consumes enormous time [26]. Besides, the data of the existing LCCA tools are usually input manually [27]. These contribute to human errors and mistakes in computation, which subsequently lead to incorrect results.

2.2. BIM for Construction Cost Management

BIM is considered a major digital disruption in construction. It a digital representation of building information throughout different phases of the project life-cycle [28]. BIM is also defined as the creation of coordinated and consistent information of a building for design decision making, high quality construction documents, prediction of building performance, cost estimating, and construction planning [29].

BIM offers various innovative benefits for construction management such as enhancing the efficiency of resource uses, reducing the errors due to lack of information, and providing the efficient management of building operation [30]. BIM also assists in visualizing real-world conditions through the 3D models of a building [31] and performing quantity takeoff by measuring directly from 3D models [32]. BIM can extract the thermal properties from building element models to estimate the energy cost throughout the building element surface [33]. Yet, BIM research on building LCCA is extremely limited. The capabilities of current BIM tools cannot manage the required data for carrying out building LCCA [16]. The interoperability was a major barrier to adopt BIM for evaluating building LCCs [34]. Data input is an extremely challenging task due to the lack of interoperability between different tools and uncommon data formats [35]. Another major obstacle concerns architectural BIM data structures, which are not compatible with the elemental or cost code structures required by the classification systems [15]. The segregation of standards, calculation methods, and interoperable technologies essentially limits the application of BIM in building LCCA [36]. Moreover, incomplete interoperability results in missing data in the cost estimating process, which is a major problem for the BIM adoption for LCCA [38].

2.3. Relational Database Management System (RDBMS)

A relational database management system (RDBMS) is complex application software that is used to enhance the availability and the consistency of data with minimum redundancy [39]. An RDBMS can be used for facilitating building LCCA by creating an environment in which the project participants can store the required data and update changes throughout the project life cycle. It can also enhance data security by the framework of security policies, share data with other parties, minimize inconsistent data when exchanging data on various platforms, and save time and cost for data collection.

Interoperability is a complex process that computer programmers need to access and customize the application programming interface (API) [40], which is a challenging task for nonprogrammers. As a result, the visual programming interface has been developed for BIM software such as *Dynamo* for *Autodesk Revit*. It is application software that can stand alone as a plugin in other applications. The visual programming interface can replace conventional coding tools with the visual metaphor of connecting small blocks of independent functionality into a whole system. It allows users to extend BIM capacities by building and running the graphical algorithms within native software by connecting nodes together to form an overall program. In this paper, the visual programming interface is used as a connected platform to exchange data between a BIM authoring program (*Autodesk Revit*) and an RDBMS (*Microsoft Access*) of the BIM-integrated RDBMS for evaluating building LCCs.

2.4. Other Related Research

A project-oriented data warehouse was proposed to store four types of information for medium and large construction contractors: (1) performance, (2) materials, (3) estimates, and (4) contracts [41]. A sewer data warehouse was designed to improve data management for sewer infrastructure projects [42]. This data warehouse was connected with the decision supporting module for determining appropriate inspection and renewal methods of pipelines.

A number of research projects have investigated the integration of BIM and database management systems. A database management system was integrated with BIM for sustainable design [43]. A relational database was created to store green materials available in the construction industry. This green building material database was then linked to the building database in *Autodesk Revit* through its system families. Another research work concerns integrating a BIM tool with a relational database for life-cycle assessment (LCA) [44]. This relational database was designed to store information about sustainable materials and link to BIM models to create sustainable design. Another research work proposed a work breakdown structure (WBS)-based dynamic multi-dimensional BIM database structure to incorporate construction records with BIM objects

[45]. This system can convert the heterogeneous and unstructured data format of construction records to as-built documents.

Even though a number of previous research works have been proposed to manage construction data, none of them developed a database that can directly link BIM tools to perform 6D BIM. Thus, we propose a new methodology for organizing, storing, and extracting the required data from BIM models to perform building LCCA by integrating the BIM authoring program, the RDBMS, the visual programming interface, and the spreadsheet system. As a result, this system can create BIM models that contain all required data to perform the economic evaluation throughout the entire project life cycle.

3. BIM-Integrated Relational Database Management System

The BIM-integrated relational database management system (RDBMS) consists of two interrelated modules, namely, the relational database management module and the visualized BIM-integrated module. It is designed to systematically compile, organize, store, and provide data for building LCCA. Figure 1 illustrates the matrix that describes the system platforms and modules as well as summarizes 12 steps to develop this system.

As can be seen, we begin with designing the structure of the database, and the database tables are then created. The relevant raw data are gathered and analyzed based on the *Uniformat* code that is appropriate for the organization of elements in the project BIM model. The data are then entered into the database tables. Meanwhile, the conceptual BIM model is created for evaluating building LCC. All building element types of the model are identified and their required data are queried. The results are then exported to a spreadsheet file. The BIM model and the project spreadsheet are integrated with the visual programming interface. Finally, we collect the required data for all building elements of the BIM model. The main output is the complete BIM model for building LCCA.

4. Relational Database Management Module

Developing the relational database management module consists of three main steps: (1) define the structure of the database, (2) prepare required data based on the chosen *Uniformat* code, and (3) input the data into the database tables.

4.1. Structure of the Relational Database

The relational database structure is adopted to systematically integrate data of the proposed system. *Microsoft Access* is chosen for developing the relational database module of the BIM-integrated RDBMS. The module development begins with designing the database tables, which contain required data in records and fields. This process consists of six steps, as shown in Fig. 2. In Step 1, click the "CREATE" tab in the design view. Then, click the "Table Design" symbol under the Tables

group. In Step 3, we fill in the table name and click "OK" to save the table. Next, we fill in all field names and select the data type for each field. Then, choose the Table's primary key. Finally, the Table's design is saved.
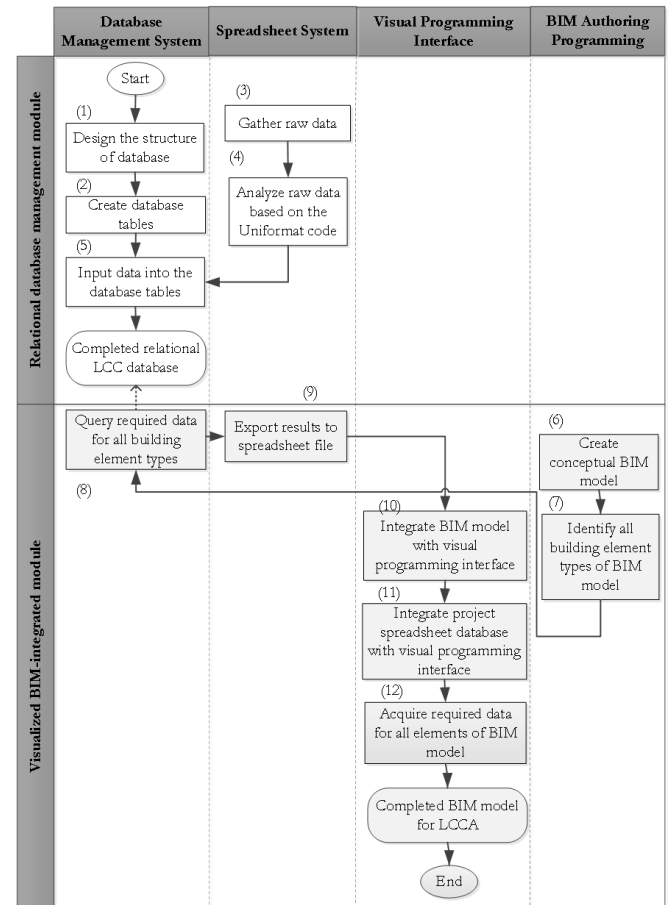

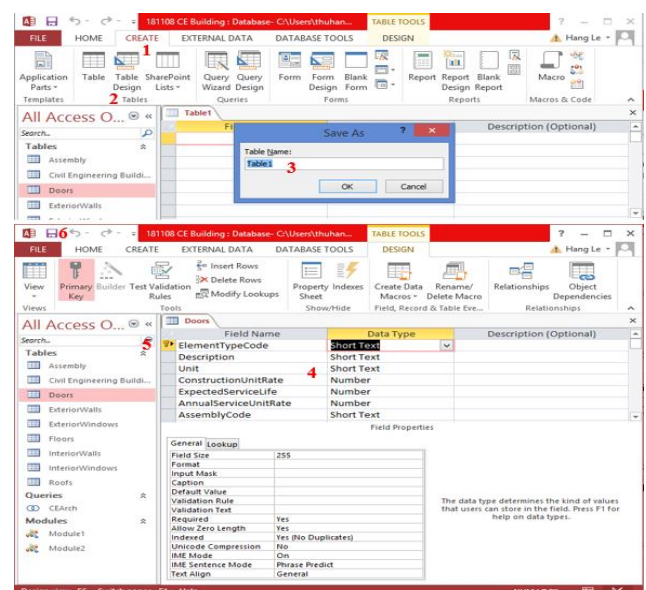Fig. 1. Workflow for developing the proposed system.

Fig. 2. Workflow for developing a table of the relational database.

After the database tables have been created, the next step is to define their relationships by connecting the tables. This process consists of seven steps, as shown in Fig. 3. First, click the "DATABASE TOOLS" tab, and then click the "Relationships" icon under the relationships group. In Step 3, click "Show Table." This prompts the show table dialogue box. In Step 4, we select two table names, click on the "Add" button, and then click the "Close" button. In Step 5, drag the join field with the primary key in the first table to join the field without the primary key of the second table. Next, click "Join Type" in the edit relationship dialogue box. Finally, select the second option, which includes all records from table 1 and only those records from table 2 where the joined fields are equal. Then, click OK.

Figure 4 shows the relational database of the proposed system. As can be seen, the database contains eight tables: *Assembly*, *ExteriorWalls*, *ExteriorWindows*, *Floors*, *InteriorWalls*, *InteriorWindows*, *Doors*, and *Roofs*. The *Assembly* table contains two fields: *Assembly code* and *Description*. Meanwhile, each of the remaining tables contains seven fields, namely, *Element Type Code*, *Description*, *Unit*, *Construction Unit Rate*, *Expected Service Life*, *Annual Service Unit Rate*, and *Assembly Code*. The one-to-many relation is used to connect any two tables in this database. These relations allow users to draw up a query for extracting the data consistently for the BIM models.

4.2. Data Organization

BIM models display the information of a building project in the form of 3D graphical representations of elements. To develop a consistent relational database, *Uniformat* is used as the standard format of the proposed system. Although there is no universally accepted standard for the hierarchical coding structure for BIM models, *Uniformat* is widely used for this purpose [46]. This is to ensure the consistency in the economic evaluation of building projects throughout all stages of their life cycle, which are design, construction, operation, maintenance, and disposal. The code of each building element type entails four levels: (1) major group element, (2) group element, (3) individual element, and (4) detailed element. *Uniformat* organizes construction information based on the physical parts of a facility, which are called systems and assemblies.

For example, the element type code "B2010151" of the red ceramic tile 4x8 wall W66 represents a typical exterior wall type, as shown in Fig. 5. "B" indicates that the major group element (Level 1) of this element type is shell. "B20" indicates that the group element (Level 2) of this element type is exterior enclosure. "B2010" indicates that the individual element (Level 3) of this element type is exterior walls. "B2010151" indicates that the detailed elements (Level 4) of this element types are red ceramic tile 4x8 wall W66. In this paper, *Uniformat* provides a standardized format for analyzing raw data in computing the LCC of new building projects. In addition, it also facilitates data communication and collection among the

members of a project regarding the scope of their work and establishes a consistent database for building LCCA.
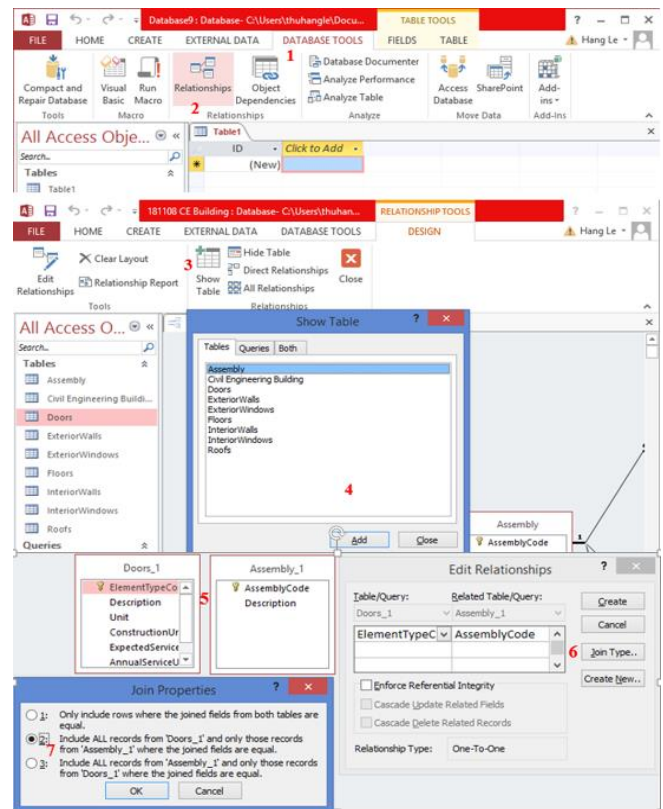

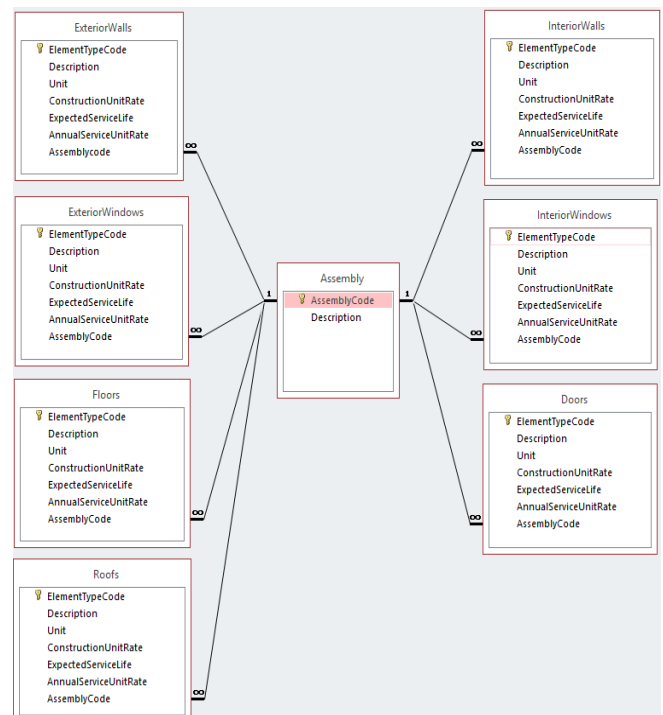Fig. 3. Workflow for creating the relationships of the database tables.

Fig. 4. Structure of the relational database of the BIM-integrated RDBMS.
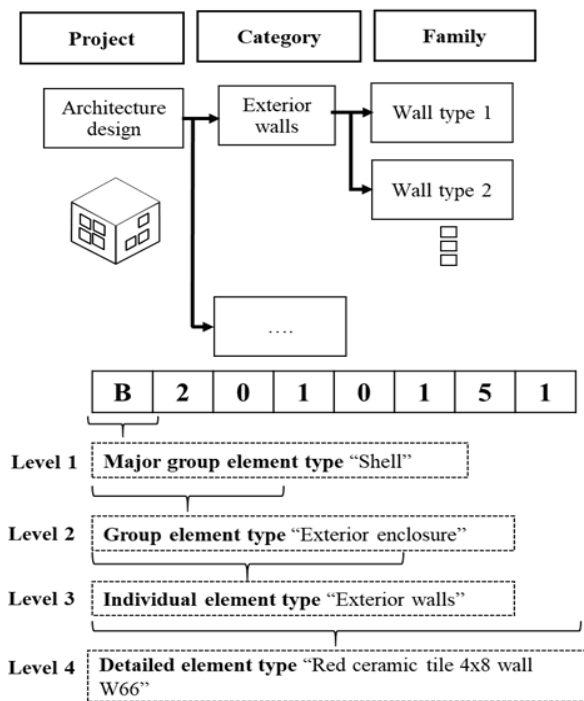
Fig. 5. Example of the hierarchical coding structure of a BIM model.

The raw data in our relational database are compiled from three main sources. The first source is the historical data of similar previous projects. The second source is "*Assemblies Costs with RSMeans Data 2018, 43rd edition*" [47]. Both provide the raw data for calculating the construction unit rate of the aforementioned seven building element types (i.e., exterior wall, interior wall, door, exterior window, interior window, floor, and roof). The raw data include the material unit cost, labor unit cost, and equipment unit cost of each building element type. The third source is "*Life Cycle Costing for Design Professionals*" [48], which primarily provides the expected service life and the annual service unit rate of each building element type. All these data are prepared in *Microsoft Excel* before inputting to the relational database.

After organizing the required data, they are input into the tables of the relational database. Figure 6 displays a partial list of the exterior window types in the *ExteriorWindows* table, which is prepared in *Microsoft Access*. As can be seen, seven fields are created to store the required data of each table. The *ElementTypeCode* field stores the unique code of each exterior window type, which is easier to identify an exterior window type than using its name. The data that can be recorded in this field are a short text that contains up to 255 characters of texts, numbers, and symbols. The *Description* field stores the name attribute of each exterior window type. The data that can be recorded in this field are also a short text. The *Unit* field stores the calculating unit of each exterior window type. The unit of square meter is selected as the calculating unit for all the exterior window types. The type of data recorded in this field is also a short text. The *Construction Unit Rate* field contains the

construction unit cost of each exterior window type. The data that can be recorded in this field are the numbers that store the results of the processed data from the calculations in the data organization section. The *Expected Service Life* field stores a number of useful years of each exterior window type. The recorded data in this field are numbers. The *Annual Service Unit Rate* field stores the annual service unit rate for each exterior window type. The data to be recorded in this field are numbers. The *Assembly Code* field stores the code of the building structure where the exterior window type belongs. This code is developed based on Level 3 of the *Uniformat* classification system of building elements. The primary key of this table is the element type code. This code is uniquely assigned to each exterior window type. It helps identify an exterior window type easier than using its name and avoids any duplication of data in a field. A link is created between the *ExteriorWindows* table and the *Assembly* table to share the data between both tables. The *Assembly Code* field is selected as a joint field between any two tables. The one-to-many relation is used for joining tables through the *Assembly Code* field.

5. Visualized BIM-Integrated Module

The visualized BIM-integrated module performs three main functions: (1) offering better visualization of building LCCA through 3D models, (2) storing the thermal coefficients of the building element models for calculating energy costs, and (3) integrating the relational database management with the BIM model for transferring the required data for building LCCA.

Since there is no specification of level of development (LOD) for the purpose of building LCCA, we adopt LOD 300 for the building element models to be in accordance with the requirements for building LCCA in the procurement phase, which is based on the LOD specification guide of BIM Forum [49]. Before creating the 3D objects in the BIM model, designers need to identify the geometric and non-geometric information of each object. Table 1 defines the LOD of the BIM element models for building LCCA.

For example, each element model of the exterior windows contains both geometric and non-geometric data. The geometric data consist of the thickness, length, height, and glass type of the element. The non-geometric data consist of the element type code, construction unit rate, annual service unit rate, expected service life, heat transfer coefficient, and solar heat gain coefficient. Clearly, different building element types entail unique geometric and non-geometric data for building LCCA.

Since the conceptual BIM model cannot solely manage the required data for building LCCA, additional parameters of the BIM objects need to be extracted to characterize their properties for the complete analysis. These parameters are retrieved from the relational database management module of the system.

Fig. 6. A sample list of the exterior window types in the *ExteriorWindows* table.

Table 1. LOD of the building elements in the BIM models for building LCCA.

Category	Model content requirements for the building LCCA	LOD	Graphical illustration
Floor	_ Geometry (length, height, thick of material layers) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life)	300	
Exterior wall	_ Geometry (length, height, thick of material layers) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life, heat transfer coefficient, equivalent temperature difference)	300	
Roof	_ Geometry (length, height, thick of material layers) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life, heat transfer coefficient, equivalent temperature difference)	300	
Exterior window	_ Geometry (length, height, thick of material) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life, heat transfer coefficient, solar heat gain coefficient)	300	
Door	_ Geometry (length, height, thick of material layers) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life)	300	
Interior wall	_ Geometry (length, height, thick of material layers) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life)	300	
Interior window	_ Geometry (length, height, thick of material layers) _ Non-Geometry (element type code, construction unit rate, annual service unit rate, expected service life)	300	

Each table of the relational database contains various building element types. However, the BIM model needs to retrieve only the necessary building data. The Structured Query Language (SQL) is used to query the necessary data for a target BIM model more efficiently. The queried data are then exported to a spreadsheet file for the subsequent data integration.

A challenging task is how to integrate the BIM model and the spreadsheet file to extract the required data for the BIM model. To address this problem, we develop an automated data acquisition method for the BIM model by using the visual programming interface. This consists of two main steps. First, the spreadsheet file is linked with the visual environment by using *Dynamo* scripts. The required data are then extracted for the BIM model by using *Dynamo* scripts.

Figure 7 illustrates the workflow for integrating the spreadsheet file with the visual environment, which consists of three steps. First, we identify the spreadsheet file that contains the appropriate data for the BIM model in *Microsoft Excel*. Two *Dynamo* nodes are used to perform this task: the *File Path* node and the *File.FromPath* node.

We then identify the sheet name in the spreadsheet file that contains the required data by using the *Code Block* node. This node is written by *Python* scripts to access the target sheet. Finally, all data lists of the selected sheet are identified and entered based on the row format of *Microsoft Excel* using the *Excel.ReadFromFile* node. These data are read as strings in the visual programming interface.

The workflow for extracting the required data for the BIM model by using *Dynamo* scripts consists of four steps. First, select the building element types of the BIM model. Then, identify the required data that need to be extracted from the type properties. The names of the required data are added to the type properties of the BIM model in *Autodesk Revit*. In Step 3, we select the required data from the relevant data lists. Finally, we extract the required data of the selected building element type in the BIM model.

Figure 8 shows four steps for extracting the required data of the exterior window type using *Dynamo* scripts. As can be seen, a target exterior window type is first selected by using the *Family Types* node. We then identify the names of parameters that need to be extracted by using the two *Code Block* nodes. These names are the new parameters that are added to the type properties of the BIM model. In Step 3, we extract the parameters of the selected exterior window type. This step is performed through six sub-steps. The list of the relevant data is first selected by using a *Code Block* node. All values of the list are gathered by using a *List.GetItemAtIndex* node. The locations of the parameters are identified by using a *Code Block* node. Then, we obtain the element type code, construction unit rate, service life, and annual service unit rate parameters by using four *List.GetItemAtIndex* nodes. These parameters are grouped as a list using a *List.Create* node. Finally, the extracted values are transformed from strings to numbers using a *String.ToNumber* node. In the final step (Step 4), the values of the relevant parameters of the selected exterior window type are assigned using two *Element.SetParameterByName* nodes.

6. Case Study

Academic buildings are considered a building type with the highest energy consumption. Yet, it can achieve energy conservation from 6 to 29 percent [50]. In this paper, the proposed system is applied to a university building. The building houses the Department of Civil Engineering at the Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand. It is a six-story building with the total gross area of 3,576 m². It is a conventional building in the hot and humid climate zone. The building consists of architectural, structural, mechanical, electrical, and plumbing systems. However, only the architectural system is investigated in this paper. Figure 9 shows the architectural BIM model of the case study.
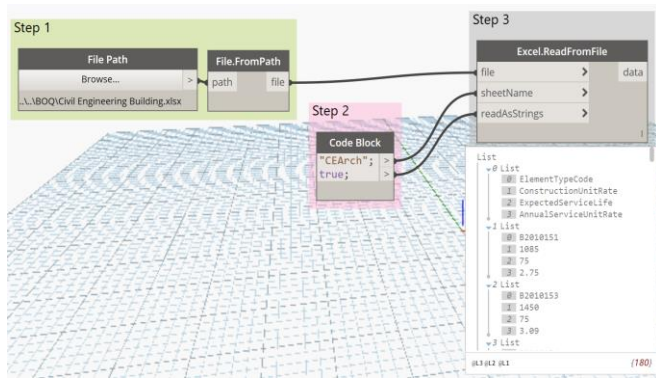
Fig. 7. Workflow for integrating the spreadsheet file into the visual environment using *Dynamo* scripts.
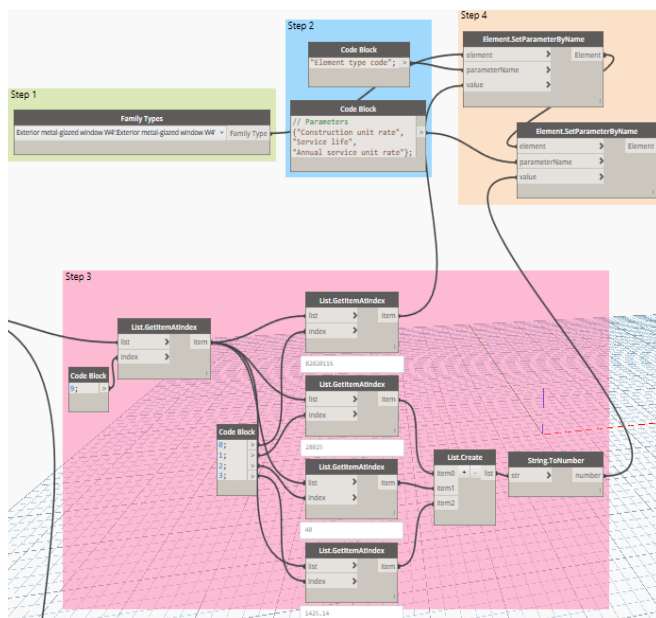

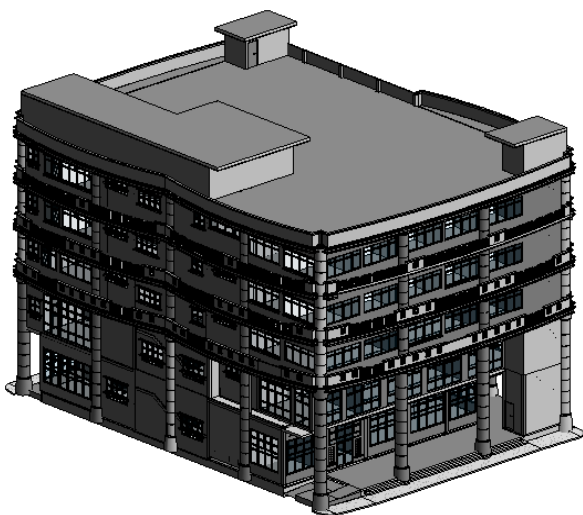Fig. 8. Example of acquiring the required data of an exterior window type.

Fig. 9. Architectural BIM model of the case study.

Applying the BIM-integrated RDBMS in this case study entails five main steps. First, a BIM model of the building is created by using *Autodesk Revit Architecture*. All building element types of the BIM model are identified. The required data of all building elements in the BIM model are extracted using SQL. The query tables are then exported to the spreadsheet file in *Microsoft Excel*. Finally, the required data are extracted for the BIM model by using the visual programming interface.

7. Results and Discussions

The BIM model of this case study entails more than 1,000 elements of 44 building element types. It would have consumed a great amount of time to input the required data manually. Thus, we develop an automated tool for acquiring the required data of all elements of the BIM model by integrating the database management system, the BIM authoring program, the spreadsheet system, and the visual programming interface. Figure 10 illustrates the required data of various element properties in the complete BIM model. As can be seen, the four parameters are extracted for each element: (1) element type code, (2) construction unit rate, (3) annual service unit rate, and (4) expected service life. This can be achieved by using the *Dynamo* scripts.

There are 14 exterior window types in this case study such as the exterior metal-glazed window W1', W1", and W1"'. The element type code of the exterior metal-glazed window W1' is B2020111, and its construction unit rate, expected service life, and annual service unit rate are 17,043 Baht/m², 40 years, and 1033.21 Baht/m², respectively. The system also extracts the four parameters of all element models of the other thirteen exterior window types. Similarly, the system automatically extracts the four parameters of the three interior window types, the eight door types, the four exterior wall types, the four interior wall types, the eight floor types, and the three roof types. Figure 10 displays the parameters of each building element in the BIM model. These parameters can subsequently be used to create a multi-parametric model for evaluating building LCC. Detailed discussions can be found in [51, 52].

8. Conclusions

This paper presents the BIM-integrated RDBMS, which is part of the BIM-database-integrated system for evaluating building LCC. The proposed system consists of two main modules: the relational database management module and the visualized BIM-integrated module. Many research works have been investigating the applications of BIM to construction management. For example, a BIM-enabled system was developed for estimating time and cost impacts for construction change orders [53]. However, the works that focus on building LCCA are extremely limited. This is because existing BIM tools cannot systematically and efficiently manage the required data for evaluating building LCCs. In addition, the unstructured data format is also another

major barrier that limits the application of BIM to LCCA. Our system offers a systematic method to organize and store the necessary data for building LCCA through the relational database integrated with the BIM model. The required data are provided by the integration between the visualized BIM-integrated module and the relational database management module. The relational database is designed to store and update the required data for the BIM model. Compared with conventional building LCCA, the proposed system provides a more convenient and efficient methodology to organize data for building LCCA through the relational database management system. In addition, it presents a robust approach to expand the capacities of current BIM tools for extracting the required data for the BIM model to subsequently perform multi-parametric estimating using visual programming.

Conventional building LCCA is a time-consuming process due to a large amount of data scattered in various documents, and complex calculations. The BIM-integrated RDBMS can manage the required data by integrating the database management system, the BIM authoring program, the spreadsheet system, and the visual programming interface. It can significantly reduce the calculation time. Furthermore, it can also minimize data loss and inconsistent data due to human errors, which lead to more accurate results. With the increasing adoption of BIM in the AECO industry, the proposed system can be a promising alternative to address various problems of construction management.

Fig. 10. Example of extracting the required data in the case study.

Acknowledgement

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