A Study on the BIM-Based Application in Low-Carbon Building Evaluation System

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***Abstract*—Carbon emission of a building is the evaluation index of low-carbon construction nowadays. This paper establishes a low-carbon building evaluation system by life-cycle assessment. A key problem of using the evaluation system is how to obtain the calculation data. Since BIM (Building Information Modeling) software contains a large number of corresponding information, they can be well used to solve the problem. In this paper, a BIM-based practical tool named TJLCE is proposed to calculate the building carbon emission by creating data interface with the existing BIM software and getting the related data. The proposition of the low-carbon building evaluation system and the realization of TJLCE are effective ways to improve the calculation of building carbon emission.**

***Index Terms*—BIM, low-carbon building, life-cycle assessment, carbon emission calculation, secondary development of revit**

I. Introduction

Construction industry has consumed a lot of natural resources and caused serious negative impacts on the environment. Statistics indicates that building sector accounted for nearly 40% of the world's energy consumption, 30% of raw material use, 25% of solid waste, 25% of water use, 12% of land use, and 33% of the related Global Greenhouse Gas (GHG) emissions [1]. At the same time, greenhouse gas emissions have been increasing by the energy consumption and the disposal of solid waste during the process of design, construction, use and demolition of buildings. Therefore, it is extremely urgent to construct low-carbon buildings.

The reduction of building carbon emission is the primary goal of low-carbon buildings. Life-Cycle Assessment (LCA) is chosen as a quantitative evaluation method to assess the resource consumption and environmental impact of buildings during the entire process [2]. A low-carbon building evaluation system with detailed calculation method of carbon emission is proposed by this paper, using life-cycle assessment. The theoretical research and engineering practice of BIM over the past decade proved that the effective use of information is one of the main progresses which BIM brought to construction industry [3]. The substantial existing BIM software can basically cover all kinds of simulation and analysis needed in the whole lifecycle. For instance, Autodesk Revit, Autodesk Navisworks and Autodesk Ecotect Analysis can achieve building modeling & quantities statistics, construction process simulation and energy consumption analysis, respectively.

The building information model of the above three software greatly meet the analysis data required in the life-cycle assessment. In addition, these software have good compatibility and share the same model information. Therefore, this paper presents a framework of a BIM-based application, named TJLCE, which can calculate whole life cycle carbon emission of buildings by creating data interface with the existing BIM software mentioned above and getting the related data.

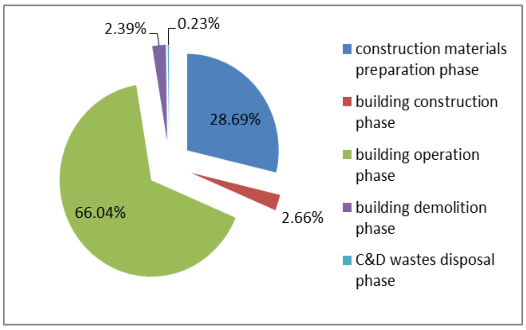

Figure 1. The carbon emissions proportion of each stage of a pavilion.

II. Life-Cycle Assessment

According to ISO 14040 Environmental management – Life cycle assessment – Principles and framework, there are four phases of the LCA study: (1) goal and the scope definition, (2) life cycle inventory analysis, (3) life cycle impact assessment, and (4) life cycle result interpretation [4]. The main goal of the LCA study is to assess and reduce the resource consumption and environmental impact of the assessed building during the entire life cycle. The life cycle inventory data and analysis results calculated in this LCA method are expected to assist designers with a better understanding of building material selection, construction methods selection, usage scheme selection and system improvement from the perspective of whole life cycle. To meet the goals mentioned above, a detailed life cycle inventory analysis is put forward. In the LCA study, the whole life cycle of buildings consists of five phases: construction materials preparation phase, building construction phase, building operation phase, building demolition phase and C&D wastes disposal

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phase [5]. And the component of the life-cycle carbon emission, calculated in [5], is shown in Fig. 1. Considering of the minimal amount and complex calculating process of demolition phase and C&D wastes disposal phase [1], the analysis of these two phases are not included in this paper. The carbon emission in the entire life cycle of building is chosen as an evaluation index, in accordance with Global Warming Potential (GWP). Fig. 2 shows a summary of the life-cycle assessment of buildings.

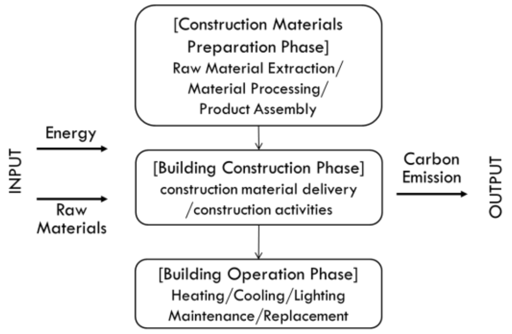

Figure 2. The summary of life-cycle assessment of building

A. Construction Materials Preparation Phase

Construction materials preparation phase is one of the main sources of carbon emissions in the entire life cycle. The processes that typically occur in this phase include raw material extraction, material processing and product assembly. However, due to data unavailability, only raw material extraction and material processing are considered in this study. The construction materials that are consumed and prepared include steel, cement, timber and so on.

B. Building Construction Phase

Building construction phase ranges from the start to the end of the construction project. The processes that typically occur in this period of construction include construction material delivery and construction activities. And construction activities include construction machinery operation, and provisional measures on construction sites (e.g., temporary lighting and power supply).

C. Building Operation Phase

When analyzing the carbon emissions of building, the operation phase is not only the longest, but also the most consumptive one. Theoretically, the energy consumption in this phase can be divided into use phase and maintenance phase.

Use phase: The key source of carbon emission at this phase is the energy (mainly electricity and natural gas in China) consumed by end uses for the purpose of space heating, cooling, lighting and so on.

Maintenance phase: All building elements have their life spans. When maintenance or replacement occurs, additional energy is consumed. The calculation method is similar to that on the construction phase, which finally can be converted into carbon emissions of material delivery and materials.

III. The Calculation Method of CO_2 Emission

In this chapter, a calculation method of the detailed life cycle inventory is proposed. The carbon sources are classified from construction materials preparation phase, building construction phase to building operation phase. To mention that what is calculated by this method is not the actual CO_2 emission of the building's whole life cycle, but the conversion CO_2 emission of the building's total materials usage and energy consumption of the various stages. The amount of life cycle carbon emissions (C_{All}) can be computed by (1).

$$C_{All} = C_{Mat} + C_{Con} + C_{Ope} \tag{1}$$

where C_{Mat}, C_{Con} and C_{Ope} represent the CO_2 emissions during the construction materials preparation phase, building construction phase and building operation phase, respectively.

A. Construction Materials Preparation Phase

The amounts of carbon emissions in this phase are embedded in materials preparation processes, like raw material extraction, material processing and product assembly. The sum of carbon emissions in this phase can be computed by (2).

$$C_{Mat} = \sum_{i=1}^{n} \lambda_{m,i} q_{m,i} \tag{2}$$

where n is the total number of the types of construction materials used in the calculated building, $q_{m,i}$ is the consumption of i^{th} used building materials, $\lambda_{m,i}$ is the conversion coefficient of the i^{th} building materials to CO_2 emission. In China, the table of $\lambda_{m,i}$ can be found in [6]. It is not difficult to find that different studies have different values of $\lambda_{m,i}$ [1]. However this is not the focus of this paper.

One important thing in this phase is to obtain the information about building materials. To estimate the embodied energy content for a building or building design, a vast number of studies have adopted methods like: relying on bill of materials, turning to estimated quantities from building drawings or using field measured data [2].

B. Building Construction Phase

Carbon emissions in building construction phase consist primarily of two components: construction material delivery (C_{Ctran}) and construction activities (C_{Cact}). The sum of carbon emissions in this phase can be computed by following equations.

$$C_{Con} = C_{Ctran} + C_{Cact} \tag{3}$$

$$C_{Ctran} = \sum_{i=1}^{m} \mu_{c,i} q_{c,i} d_{c,i} \tag{4}$$

$$C_{Cact} = \sum_{i=1}^{l} \rho_{c,i} e_{c,i} t_{c,i} \tag{5}$$

where m is the total times of the construction material delivery, $q_{c,i}$ is the amount of building materials transported by i^{th} delivery, $d_{c,i}$ is the transport distance of i^{th} delivery, $\mu_{c,i}$ denotes the conversion coefficient of delivery quantity to carbon emissions; l is the total types of equipment used in construction, $e_{c,i}$ is the energy consumed by the i^{th} equipment for unit working time, $\rho_{c,i}$ is the conversion coefficient of i^{th} energy to CO_2 emission. Similarly, the values of $\mu_{c,i}$ and $\rho_{c,i}$ varies from different studies.

The value of C_{Con} is based on energy procurement records, in some studies [6].

C. Building Operation Phase

Carbon emissions in building operation phase are from operational energy consumed by day-to-day operation processes of buildings such as heating, cooling, lighting, ventilation systems as well as appliances. The sum of carbon emissions in this phase can be computed by (6).

$$C_{Ope} = \sum_{i=1}^{p} \rho_{o,i} e_{o,i} \tag{6}$$

where p is the types number in this phase, $e_{o,i}$ is the i^{th} kind of energy consumed in this phase, $\rho_{o,i}$ is the conversion coefficient of the i^{th} energy to CO_2 emission. Non-renewable energy resources (such as coal, oil, and natural gas) are used widely in buildings. However, investigation of clean and renewable energy resources such as solar energy, wind energy, nuclear power, and biomass energy has recently become widespread owing to the fossil energy crisis and advances in energy saving technology [6].

Three major approaches have been used to estimate the operational energy use of buildings: relying on the actual energy consumption records obtained from utility bills, or energy audit exercises, referring to some energy use databases and using energy simulation methods. The pros and cons of the approaches mentioned above can be found in [1].

To sum up, compared with other studies [1], the evaluation system proposed by this paper may not be the most scientific, for it ignores some minimal influences. However, the main focus of this study is to point out all the necessary data and find the ways to get access to the data needed.

IV. The Use of BIM Data

The substantial existed BIM software can basically cover all the simulation and analysis of building constructions from construction materials preparation phase to building operation phase. For instance, Autodesk Revit, Autodesk Navisworks and Autodesk Ecotect Analysis can be uesd to achieve building modeling, quantities statistics, construction process simulation and energy consumption analysis respectively. The building information model of the above three software greatly meet the analysis data required in the life-cycle assessment. In addition, these three software have good compatibility and share the same model information [7].

A. Revit and Quantities Statistics

Revit software has powerful and sophisticated three-dimensional modeling techniques. Furthermore, statistical quantities can be automatically and accurately calculated, based on accurate modeling, with an accuracy of a screw.

B. Navisworks and Construction Process Simulation

4D model of construction process can be built by Navisworks software, with the use information of construction equipment and transport vehicles to accurately reproduce the design intent.

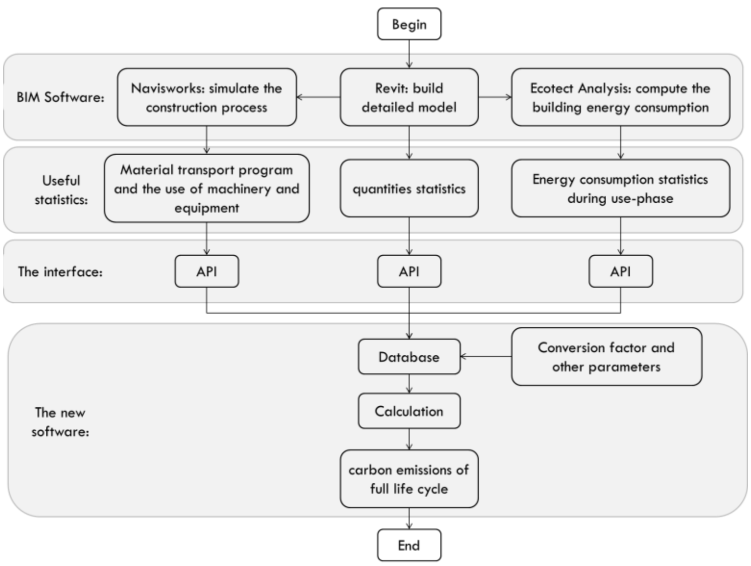

Figure 3. The function of TJLCE

C. Ecotect Analysis and Energy Consumption Analysis

Ecotect Analysis software is a comprehensive sustainable design and analysis tools. This software can complete the energy consumption of building in use and maintenance phase.

The building information model of the above three software greatly meet the analysis data required in the calculation model of CO_2 emission. The function of TJLCE is shown in Fig. 3. The data of existing BIM software which is useful for the calculation of carbon emissions can be imported to the database of TJLCE, by the API interfaces. Some related parameters are also restored in the database. Due to data unavailability, certain processes such as maintenance phase, building demolition phase, C&D wastes disposal phase and some other detailed processes are not inventoried. TJLCE, temporarily, only provide manual method to enter the data of these processes. It has little effect on the overall accuracy of TJLCE, because the carbon emissions of these processes are small.

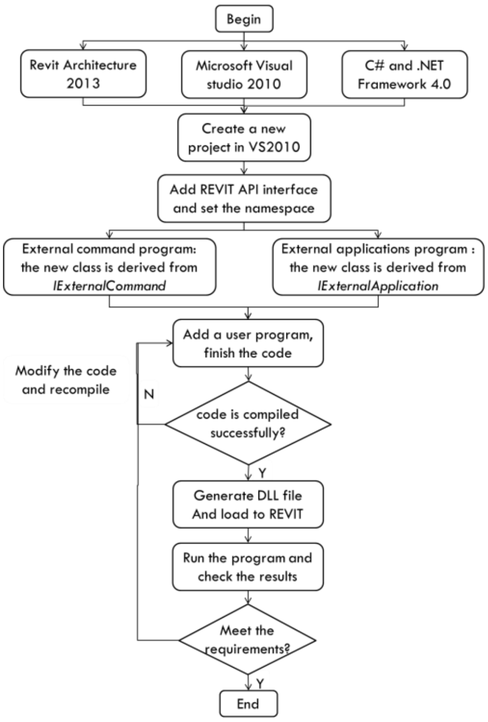

Figure 4. The specific development approach

V. The Secondary Development of Revit

Software mentioned all above belongs to the Autodesk Company and have similar secondary development methods. In this paper, the secondary development of Revit, is illustrated to verify the feasibility of TJLCE.

A. Revit API

Revit API provides access to each function of Revit. During the 7-year-development, Revit API not only increased in number, but also achieved the diversity of function. And now, Revit API has far been able to meet the needs of the work.

B. The Secondary Development

TJLCE use the C# language to complete the secondary development of Revit, based on Visual Studio platform. The specific development approach of TJLCE is shown in Fig. 4.

VI. Conclusion

Decisions made during a building's early design stages critically determine its environmental impact. However, designers are faced with many decisions during these stages and typically lack intuition on which decisions are most significant to a building's impact. This study proposed TJLCE, a BIM-based low-carbon building evaluation system, based on the life-cycle assessment, in order to provide a way to calculate building carbon emissions. By studying the life-cycle assessment, a calculation method for building carbon emission is established. The TJLCE intends to take full advantage of the informational convenience which BIM have brought to the construction industry. The highlighting of TJLCE is that it can automatically read data related to carbon emissions of the whole building life cycle from BIM software such as Autodesk Revit, Autodesk Navisworks and Autodesk Ecotect. With the advantage of convenience and quick calculation, TJLCE can promote the development of low carbon buildings.

This paper focuses on the applying of life-cycle assessment for low-carbon building and providing access ways of BIM data. In order to make TJLCE a mature and practical tool, the following details should be considered:

- As described above, the data of the existing BIM software cannot obtain the corresponding data of carbon emissions during phases, maintenance phase, building demolition phase, C&D wastes disposal phase and so on. In addition, some complex equipment such as photovoltaic power generation, cannot be imported into the database smoothly, for the lack of modeling function or the API limitation. Manually input function can be added to TJLCE to overcome the shortcome and make the calculation results comprehensive and reliable as far as possible.
- When it comes to the conversion coefficient and other parameters described above, each country has the relevant norms and standards. And these data can be built in the database of TJLCE, so that users can make their choices to use the data in the database, or fill out new parameters based on the actual needs.

Above all, the TJLCE greatly meet the developing trendency of BIM. And with the continuously improvement of BIM software, TJLCE has the potential to be increasingly practical.

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