Development of a BIM-based Carbon Dioxide Emission Estimation System -Focus on an Apartment in Korea-

Yong-Ju Lee and Han-Jong Jun
Unified Master’s and Doctor’s Course, School of Architecture, Hanyang University, Korea
Professor, School of Architecture, Hanyang University, Korea

Abstract Recently, a goal was set globally to reduce the Carbon Dioxide (CO$_2$) emission at national levels by 30% in comparison to the Business As Usual (BAU) pursuant to the United Nations Framework Convention on Climate Change. As construction industry accounts for as high as 40% of the CO$_2$ emission by the entire industrial sector in Korea, efforts toward reducing emissions from the construction industry are essential. Buildings are mainly responsible for CO$_2$ emissions, and, to reduce the CO$_2$ emitted from the buildings, a fast and accurate calculation method is required to be introduced in the architectural design phase. If the standardized data based on Building Information Modelling (BIM) is utilized, CO$_2$ emissions can be calculated quickly and accurately during the design phase. However, it is difficult for the designers who lack the knowledge regarding CO$_2$ emissions to reduce and manage such emission during the planning and design phases of buildings by estimating the quantities of various materials and the corresponding CO$_2$ emissions. Accordingly, the objective of this study is to develop a BIM-based CO$_2$ emission estimation system for a rapid and objective analysis and verification of CO$_2$ emissions.

Keywords: Carbon Dioxide Emission; Estimation System; Major Building Material; BIM Template; BIM Add-In

1. INTRODUCTION

After the World Meteorological Organization and the United Nations Environmental Program officially declared (1985) CO$_2$ to be the main culprit behind global warming, it is becoming increasingly necessary for the entire construction industry to conduct national-level Life Cycle CO$_2$ (LCCO$_2$) estimations.

The building sector accounts for 40% of global annual energy consumption, and 30% of global annual greenhouse gas emissions is contributed by buildings. Out of these, CO$_2$ emissions account for 38.9% of the total greenhouse gas emissions from buildings.

The systems for evaluating CO$_2$ emissions from buildings include the estimation programs that are tailored to specific situations and are owned by large construction companies, the carbon emission trading system, and the carbon labelling system; however, these systems are rather inadequate in view of the speed of development of environmentally friendly construction technologies.

Therefore, an estimation system for assessing CO$_2$ emission from the viewpoint of reducing and managing these emissions, such as the green building certification system that is obligatorily applied to the buildings larger than a certain size and owned by public organizations, in the planning and design phases of buildings is required.

Further, while several techniques and technologies for evaluating CO$_2$ emissions have been developed under various programs since the mid-2000s, it is difficult for the designers who lack the knowledge regarding CO$_2$ emissions to reduce and manage such emissions in the planning and design phases of buildings by utilising the estimates based on the quantity of various materials and the related CO$_2$ emissions.

In order to reduce the CO$_2$ emissions generated by buildings, a quick and accurate method for calculating CO$_2$ emission needs to be introduced in the architectural design phase. If a BIM template that can provide BIM-based standardized data is utilized, the CO$_2$ emissions can be immediately calculated reflecting the corrected factors from the design phase and measures for emission reductions can be taken.

This study intends to develop a system for BIM-based estimation of CO$_2$ emissions for apartments utilizing Autodesk Revit®. Our system estimates CO$_2$ emissions using the national Life Cycle Inventory Database (LCI DB) developed by the Ministry of Land, Transport and Maritime Affairs, the Ministry of Environment, and the Ministry of Trade Industry and Energy, and managed by the Korea Environmental Industry Technology Institute.

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Corresponding Author: Han-Jong Jun
School of Architecture, Hanyang University, Seoul, Korea
e-mail: hanjong@hanyang.ac.kr

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Therefore, the objective of this study is to develop a system that enables easy estimation of CO$_2$ emissions utilizing the BIM-based template during the design phase of a building, wherein such emissions can be quickly and objectively analysed and verified to support energy-saving designs.

### 2. THEORETICAL REVIEW

#### 2.1. Main Requisites for CO$_2$ Emission Estimation

For evaluating the CO$_2$ emissions from the construction materials used in the apartments, the national LCI DB can be utilized. The national LCI DB contains data built by cataloguing the amount of resources input in the system for the collection and processing of raw materials required for manufacturing 1 unit of the product, the use of transportation products till they are stopped being used, and the amount of discharges and wastes produced from the product system; and these data are utilized as the basic data for evaluating the entire process of CO$_2$ emission.

A study on the CO$_2$ emission rates of major construction materials carried out in the past by Hanyang University in Korea (Noh et al., 2013) concluded that the emissions from only seven construction materials, i.e., ready-mixed concrete, rebar, steel frame, paint, glass, concrete products, and insulating materials, account for more than 90% of the total CO$_2$ emissions. The emissions from these materials can be calculated by utilizing the basic unit CO$_2$ emission estimates established by the LCI DB developed by the national LCI database information network.

While six construction materials from among the above-listed materials can be supported by the BIM template, rebar is impossible to be supported by BIM as the Public Procurement Service (PPS) pure resource code of each material of the ready-mixed concrete and rebar such as the vertical reinforcement and horizontal reinforcement inside the wall structure are complicatedly organized.

Accordingly, since it is difficult to calculate the individual quantity of rebar for different material codes, the quantity is thought to be able to be supported by applying the minimum reinforcement rate.

In this study, we intend to calculate the CO$_2$ emissions by the 7 main construction materials, ready-mixed concrete, rebar, steel frame, paint, glass, concrete products, and insulating materials, by referencing the LCI DB. We intend to conduct these estimations for the construction materials based on the calculation of their quantities by matching the PPS pure resource code of each material the LCI DB in order to ensure accuracy of data attributed to them.

#### 2.2. CO$_2$ Emission Estimation Programmes

The domestic and overseas programmes developed in relation to CO$_2$ emission estimation are as shown in Table 1.

CO$_2$ emission estimation programmes commonly carry out Life Cycle Assessment (LCA) for buildings based on their 2D drawings, and do not consider any BIM-based technology.

#### 2.3. Setting up the BIM Template

To develop a BIM-based CO$_2$ emission estimation system, the template technique should be applied. The functions of the template should be classified in accordance with the purpose of BIM utilization, and should be organized to allow an easy reuse by identifying the work types that are frequently used. An absence of standardization of building information and a consistent BIM modelling method, which are currently being pointed out to be the difficulties associated with the of BIM-based design, can be solved by salvaging the required information in advance through the template and systematically organizing the building factors and parameters. Application of a BIM template can standardize the BIM library and information types and provide consistent work environment to all workers. In addition, the diverse alternatives can be reviewed, by utilizing the information types in BIM, more

| Division | BeCost | LISA | SUSB-LCA |
|----------|--------|------|----------|
| Country  | Finland| Australia| Korea  |
| Development Agency | VTT | University of Newcastle | Hanyang University |
| Development Year | 2003 | 2003 | 2007 |
| Feature | - The environmental impact of the building is predicted in the beginning of the design phase.<br> - The method utilizes the structural form, materials used, and area.<br> - The results from a step-wise estimation and analysis are provided. | - The programme is organized using a simple design interface.<br> - Since the LCI DB is used, the analysis done for material production part is good.<br> - CO$_2$ can be analysed based on a method utilising simple checklist-type input. | - The LCE, LCCO$_2$, and LCC of buildings can be estimated.<br> - The database can be easily corrected and supplemented.<br> - The basic unit data of carbon dioxide is prepared through an inter-industry analysis. |
| Image | ![BeCost](image1.png) | ![LISA](image2.png) | ![SUSB-LCA](image3.png) |

Table 1. Domestic and Overseas CO$_2$ Emission Estimation Programs
quickly than in the estimation method that utilizes the existing quantity calculation sheet.

As shown in Figure 1, the BIM template is divided into two parts: the basic part of the BIM authoring tool comprising a main frame and a preset, and a part that requires additional development that can be achieved with only the functions of the authoring tool. The main frame of BIM template is the structuralized basic system of the BIM authoring tool, and is set with a working environment where BIM information is input and output. The preset of the BIM template is a predetermined standard element, and building information can be easily input to the main frame using the preset.

The preset contains a library of information and can calculate material quantities by inputting the PPS pure resource code of each material as the attribute information inside the library.

The main frame is organized in accordance with the BIM design process, and the BIM template created by separating the preset part has the advantage of being able to be effectively expanded by adding the presets for other purposes. The additional development enables the calculation of the element that cannot be set in the basic functions of the BIM tool for CO₂ emission estimation.

3. DEVELOPMENT OF A CO₂ EMISSION ESTIMATION SYSTEM

3.1. BIM-based CO₂ Emission Estimation Process

To estimate the CO₂ emissions, the quantities of the main construction materials are required. CO₂ emissions can be estimated by verifying this information from the national LCI DB. Though estimations could be carried out in the past utilizing a quantity calculation sheet, there were difficulties such as the large amount of time required to calculate enormous quantities of materials. A BIM system can overcome such issues. BIM can quickly calculate material quantities utilizing the object information.

For BIM-based CO₂ emission estimations, we can extract the desired information among the object information and attribute information from a library via a template built in advance. The object information is output as quantities and the attribute information is given as the PPS pure resource code of each material, and CO₂ emissions are estimated by calculating the quantity of each PPS pure resource code.

As shown in Figure 2, the PPS pure resource code of each material is input as attribute data in the library during the data entry phase. This enhances the accuracy of the LCI DB matching work for CO₂ emission estimation by assigning a code to each material type that is not standardized. Modelling is performed based on the predetermined BIM template using the library and the data on quantities is extracted in the form of a table. The extracted data consists of quantities of the main construction materials, which can be used to calculate CO₂ emissions through verification with the LCI DB using an add-in template of the BIM application.

3.2. Development Language and Scenario of BIM Add-In

Revit can generate an additional Application Programming Interface (API) by basically providing and using a Software Development Kit (SDK). Revit API can be also developed using C# by Microsoft. C# is an Integrated Development Environment (IDE) with a common user interface and has gained considerable attention as a new programming language that is the basis of the .NET design. C# is a programming language that can be used to prepare applications with diverse purposes such as Web application programs, large capacity server applications, and desktop applications. In addition, it provides access to .NET, COM, automation and general APIs such as C style API. Regarding
the development scenario in Figure 3, a C# source file is generated in a C# project using the SDK of Revit by referring to User Interface (UI) and database (Schedule Database). The database of Revit is the database utilised for calculating the quantity of each material using their PPS pure resource codes, and this data is matched with the LCI DB to provide the users with CO₂ emission estimation results through the Revit UI. It is a plug-in system that enables the users to utilise the BIM-based design and immediately apply the result through this IDE, and can be tailored such that the users can carry out CO₂ emission estimation work in the form of an add-in program under a single BIM application environment.

4. APPLICATION OF A CO₂ EMISSION ESTIMATION SYSTEM

The developed CO₂ emission estimation system was applied to the 16th floor of an apartment building with two flats during the design phase, as shown in Table 2.

To calculate the basic unit CO₂ emissions for the construction materials, the national LCI DB was utilized.

Table 2. Outline of the Apartment Building to which the System was applied

| Image | Division | Contents |
|-------|----------|----------|
| Region | Urban Development District Magok-dong Gangseo-gu Seoul Republic of Kore |
| Building Area | 606.13 m² |
| Structure | reinforced concrete construction |
| Life Expectancy | 60 years |

Table 3 shows the look of the developed Revit Add-In being executed. 1) The quantities calculated for the PPS pure resource code of each material input into the attribute information for the 7 main construction materials, for which the CO₂ emission exceeds...
90% of the total CO₂ emissions, can be found in the table; 2) As modelling is not required to be repeated for all the floors in case an estimation is carried out for an apartment building, only one floor shall be modelled and the estimated floor shall be input as the basic estimation information; 3) When the ‘Estimate’ button is pressed, the quantity calculation data extracted from the table will be entered and provided to the user; 4) These are the CO₂ emissions for the 7 main construction materials; 5) The LCI DB, which is the basis for calculating the CO₂ emissions from the 7 main construction materials, can be checked; 6) This is the final result showing the CO₂ emissions for the 7 main construction materials.

A comparison of the results from our experiment with the result of the CO₂ emissions estimated using the general quantity calculation sheet showed the results from the latter to be 1,582.0176 kg·CO₂/㎡. The CO₂ emissions from the building modelled using the BIM template was estimated to be 1,582.4925 kg·CO₂/㎡; this value was smaller than the one calculated by using the general quantity calculation sheet by about 0.03%.

5. CONCLUSION

In this study, a BIM-based CO₂ emission estimation system has been developed and the following conclusions can be drawn:

First, the main construction materials, for which the CO₂ emissions exceed 90% of the total CO₂ emissions, i.e., ready-mixed concrete, steel frame, paint, glass, concrete product, and insulating material, can be supported by the BIM template; however, it is difficult to calculate the individual quantity of rebar, and the quantity can be supported using the minimum reinforcement rate.

Second, the BIM API (add-in) has been developed using the C# IDE developed by Microsoft, and it is expected to help in designing low-carbon buildings by enabling the users to immediately predict CO₂ emissions using the CO₂ emission estimation system under the same BIM environment when planning and designing a BIM-based building.

Third, the estimation system related to CO₂ emissions is inadequate in comparison to the development speed of environmentally friendly construction technologies, and it is thought that the developed CO₂ emission estimation system can be used as a basis for the system related to estimation when designing buildings based on the carbon labelling system.

In the future, studies are deemed necessary to reduce the error range through a comparative analysis of the quantities based on a quantity calculation sheet and the BIM-based quantities, and to enhance the accuracy of the matching work through development of the national LCI DB.

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