BIM-based Carbon Dioxide Emission Quantity Assessment Method in Korea

Hanjong Jun¹, Namgi Lim² and Mikyoung Kim*³

¹ Professor, Department of Architecture, Architectural Design Computing Centre, Hanyang University, Korea
² Professor, Department of Architectural Engineering, Tongmyong University, Korea
³ Research Professor, Department of Architecture, Architectural Design Computing Centre, Hanyang University, Korea

Abstract

In the existing research on the carbon dioxide emission of buildings, the amount of construction materials in the construction phase is calculated based on the quantity computation sheet. This amount must be recalculated according to the construction material of the quantity computation sheet when changing the construction design; thus, the reliability and compatibility of the quantity calculation is difficult to achieve. If BIM-based standardized data are used, users can immediately apply the edited factors in the design stage. Moreover, since efficiency and compatibility increase, the accuracy of the analysis and computation of CO₂ emission from various building materials can be expected.

The purpose of this paper is to present a BIM-based building carbon dioxide emission quantity assessment method to analyse the reduction of energy consumption and the CO₂ emission quantity objectively and quantitatively. The accuracy of BIM-based quantity estimation according to major construction materials is examined based on the BIM library and the modelling construction method, and guidelines are provided to the users.

Keywords: carbon dioxide emission; template; building information modelling (BIM) model; LCI DB; library

1. Introduction

In November 1988, the UN-affiliated World Meteorological Organization (WMO) and UN Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) to address global environmental issues. In 1992, the Rio de Janeiro environment conference adopted the 'United Nations Framework Convention on Climate Change (UNFCCC)' as the regulation agreement for artificial release of greenhouse gas to prevent global warming. In December 1997 at the Kyoto Protocol, the global activity to prevent global warming was defined as regulations, not recommendations. The 'Emissions Trading Scheme (ETS)' for fulfilling greenhouse gas reduction was also proposed.

Korea agreed to the 4% reduction policy of carbon dioxide emission until 2020, compared to 2005 at the Copenhagen Treaty in December 2009.

Buildings are responsible for more than 40% of all energy consumption, and one-third of all greenhouse gas emissions are from buildings, of which CO₂ accounts for 38.9%. To reduce CO₂ emissions from buildings, it is necessary to utilise a building construction method that minimises CO₂ emissions by introducing a fast and accurate computation plan at the design stage. Toward that end, building information modelling (BIM) is an effective approach.

However, the implementation of the BIM model for BIM-based CO₂ emission quantity assessment yields different results depending on the unstandardized work environment of the designers or users.

As such, the purpose of this research is to present a BIM-based assessment method that verifies and analyses CO₂ emission quantity objectively and promptly in order to support energy-saving building design.

In this research, Autodesk Revit is used on apartment houses. CO₂ emission quantity is analysed using the national Life Cycle Inventory database (LCI DB), which was developed at the Ministry of Land, Transport, and Maritime Affairs, Ministry of Environment, and the Ministry of Knowledge Economy and managed by the Environmental Industry & Technology Institute, and the assessment method was established. The research proceeds as follows.

First, the background, objective, range, and method of the research are described in the introduction.

Second, the CO₂ emission quantity assessment method for buildings and the BIM template concept are...
examined. Based on this examination, the BIM-based CO₂ emission quantity assessment concept and process are established.

Third, the BIM data implementation method is established based on the construction element combination and the CO₂ emission quantity assessment method of buildings is examined.

Lastly, the BIM-based CO₂ emission quantity is assessed by applying the established CO₂ emission quantity assessment method to the building. By improving the requirements, future development plans are established.

2. BIM and CO₂ Emission Quantity Assessment

2.1 Concept of the BIM Template

The BIM-based design method takes into account more information than the traditional design method. BIM-based design requires information on not only the form of the building, but also its elements. The information on building elements is a standard classification system such as the standardised material name. In Korea, each designer defines the building information differently; thus, the assessment results vary depending on BIM-based designs, subsequently leading to confusion.

The dictionary definition of a template can be summarised as a consistent input format in which a certain frequently used structure is established in advance to obtain an output that is appropriate for a certain purpose. A BIM template maintains inconsistent building information in order to obtain an output that is suitable for a certain purpose. A user can obtain a desired output by inputting pre-provided data quickly and without omission through the template.

The BIM template is composed of a building information input support function and a building information output support function. The input support function consists of the pre-set building information in accordance with the role of BIM, and the output support function comprises the product form in accordance with the use of building information (Fig.1.).

Thus, the template has the following functional characteristics:

- Distinguishing functions according to the purposes of the template
- Reusing repetitive work types
- A set of pre-defined input data
- Processing data through a designated input/output format
- Minimising data input omission and user error
- Producing consistent and valid results

To apply the template technique to the BIM-based CO₂ emission assessment, the functions of the template must be classified according to the utilisation purpose of BIM, and frequently used repetitive work types must be identified and configured to be easily reusable. Standardisation of building information and the absence of a consistent BIM modelling method, which are currently pointed out as difficulties in BIM-based designs, can be solved by systematically configuring building elements and parameters by providing necessary information in advance through the template.

Application of this BIM template standardises BIM library and information types, provides a consistent work environment to all workers, and facilitates a more prompt examination of various alternatives using BIM information types compared with 2D-based designs.

2.2 CO₂ Emission Quantity Computation Method

Targeting apartment buildings, CO₂ emissions from construction materials used in construction work can be distinguished via an inter-industry analysis method and a method using the national LCI DB.

First, the inter-industry analysis method calculates and aggregates in detail the resources, energy, and emission used in each process stage of product manufacturing; it calculates energy load directly/indirectly related to a building on the basis of the monetary amount of sectors, encompassing about 500 items, by using the inter-industry relation table. In other words, it is a macro-method in which the data values of a catalogue analysis are estimated by using the inter-industry relation table. Moreover, an estimate of the environmental pollution generated is obtained via an input-output analysis for each industry or product. However, this method is inadequate for analysing respective products and technology because the industry structures and
production activities are simple and equalised in this method.

The national LCI DB contains data that catalogues the amount of resources put into a product system. It encompasses the mining of raw materials required for production of one unit product, processing, transporting, using the product, and discarding it. In addition, it catalogues the amounts of emission and waste generated by the product system. The LCI DB is used as basic data for performing a life cycle assessment.

Major building construction materials are derived on the basis of a cumulative emission ratio with a high environmental effect according to the cutoff criteria provided by KS I ISO 14040. The CO2 emission rate of major construction materials calculated indicated that seven building materials — ready-mixed concrete, steel bars, steel frames, paint, glass, concrete products, and insulators — exceed 95% of the entire CO2 emission quantity.

This material can be calculated as the same material DB by using the basic unit of CO2 emission quantity constructed as the LCI DB by the implemented national LCI database information network, which was developed by the government (the Ministry of Environment and Ministry of Knowledge Economy).

Therefore, this research is an attempt to calculate the CO2 emission quantity using the LCI DB matching operation for the above-mentioned seven materials (ready-mixed concrete, steel bars, steel frames, paint, glass, concrete products, and insulators) as the basis. The major construction materials correspond with the Public Procurement Service (PPS) pure resource code to ensure the accuracy of the materials' property data, and the CO2 emission assessment will be performed using the following quantity computation as the basis.

2.3 BIM-based CO2 Emission Quantity Assessment Process

To assess CO2 emission, it is necessary to ascertain the quantities of the major construction materials. CO2 emission can be assessed by matching these quantities with the national LCI DB. Conventionally, this assessment has been performed by using a statement of quantity estimation. However, this method is problematic due to the large amount of time required for estimating such enormous quantities of materials. BIM can alleviate this problem in that it can perform estimation of material quantities immediately by using the object information.

For BIM-based CO2 emission assessment, one can use the method to extract the desired information from the attribute and object information from the library by utilising the pre-constructed template. The object information is computed as a quantity, and the CO2 emission quantity is assessed as a quantity computation in accordance with the PPS pure resource code by applying a PPS pure resource code to the attribute information.

In the BIM-based CO2 emission assessment process shown in Fig.3., pure resource codes from the Public Procurement Service are input at the data stage as attribute data in the library. This increases the accuracy of LCI DB matching work with respect to CO2 emission assessment in that codes are assigned to non-standardised types of materials. Using this library, modelling is performed with the assistance of the pre-defined BIM template, and the quantity data are extracted in a TXT file. The extracted file contains the quantities of the major construction materials, and by matching these with the LCI DB, CO2 emission can be estimated.

It would be ideal to extract the BIM-based quantity computation through the models for all the materials, but it is impossible practically. Thus, the BIM-based quantity computation must be modelled in accordance with the objective and used selectively.

![Fig.3. BIM-based CO2 Emission Quantity Assessment Process](image)

3. BIM-Model Implementing Method for CO2 Emission Quantity Assessment

3.1 Outline

CO2 emission quantity assessment requires a classification of all major materials and a quantitative amount of each individual material with a PPS pure resource code in accordance with the classification.

Toward that end, the test space for the BIM-modelling is established in a small space of 4 m × 4 m (16 m²). Moreover, the attribute's function and materials within the library were established based on the major material standard, as shown in Table 1.

| Object                     | PPS pure resource code | Unit | Function         | Material                     |
|----------------------------|------------------------|------|------------------|------------------------------|
| Outer walls, inner walls,  | 301115020143287        | m²   | Structure        | Ready-mixed concrete         |
| slabs                      |                        |      | Insulating material | Extruded Foam Poly-styrene |
| Paint                      | 3016150220155521       | m²   | Finishing material | Paint                        |

3.2 BIM-modelling Method Classification for CO2 Emission Quantity Assessment

For a quantity computation based on BIM, the methods of modelling each material as a single material or as one complex material are used.
To analyse the material quantity differences according to the BIM-modelling method, each material type and combination were classified and analysed according to the established functions shown in Table 1., and the result is illustrated in Table 2.

Table 2. Classification by Material Type and Combination

| Division               | A (Complex Material) | B (Complex Material + Single Material) | C (Single Material) |
|------------------------|-----------------------|----------------------------------------|---------------------|
| 1 (Slab-centred modelling) |                       |                                        |                     |
| 2 (Wall-centred modelling) |                       |                                        |                     |
| 3 (Same material combination) |                       |                                        |                     |

Fig.4. Combination Part Comparison of the Complex Material and the Single Material

To confirm the CO$_2$ emission for each design stage, it should be estimated for each construction element. Accordingly, to confirm this, quantities were summarised on the basis of walls, as shown in Table 3.

Table 3. Wall Quantity Depending on the Material Type and Combination

| Division | Ready-mixed concrete | Extruded Foam Poly-styrene | Paint |
|----------|----------------------|----------------------------|-------|
| A1       | 13.47 m$^3$          | 2.66 m$^3$                 | 1.63 m$^3$ |
| A2       | 14.18 m$^3$          | 2.80 m$^3$                 | 1.72 m$^3$ |
| A3       | 13.87 m$^3$          | 2.76 m$^3$                 | 1.67 m$^3$ |
| B1       | 13.69 m$^3$          | 2.51 m$^3$                 | 1.57 m$^3$ |
| B2       | 14.41 m$^3$          | 2.52 m$^3$                 | 1.58 m$^3$ |
| B3       | 14.09 m$^3$          | 2.50 m$^3$                 | 1.57 m$^3$ |
| C1       | 13.69 m$^3$          | 2.51 m$^3$                 | 1.57 m$^3$ |
| C2       | 14.41 m$^3$          | 2.51 m$^3$                 | 1.57 m$^3$ |
| C3       | 14.09 m$^3$          | 2.51 m$^3$                 | 1.57 m$^3$ |

There are differences in the quantity of each material depending on the type of model: one model uses a single material of type C and the other model uses complex materials of types A and B. As shown in Fig.4., the combination of the same materials does not occur in complex materials. Thus, the difference is based on the combination parts between the materials.

Therefore, the single material modelling method is appropriate.

The existing BIM model construction takes into account the worker's convenience, and thus a slab-centred modelling method is implemented. It can be seen that when comparing C1, the slab-centred model, and C2, a wall-centred model used as the construction method in the construction site, C2 has a higher quantity for each material. The difference in the actual case can be presented as a huge difference when considering the special characteristics of an apartment, so it is appropriate to model using the C2 method, which constructs a continuous structural wall to assess CO$_2$ emission accurately.

A comparison of C2 and C3 showed that C3 has less ready-mixed concrete by 0.32 m$^3$ than C2. This was computed small, because the ready-mixed concrete quantity of the intersection part of the slab and wall of A3, B3, and C3, which were operated as the material combination of the modelling, was computed in the slab quantity, not the wall quantity. Wall-centred modelling needs to be used to understand the accurate material quantity for each building part.

Consequently, by considering the modelling method that facilitates the computation of modelling the work quantity and the appropriate quantity, the C2 method, i.e., the wall-centred modelling method that uses the single material, is appropriate.

3.3 BIM Supportability Analysis for CO$_2$ Emission Quantity Assessment

The BIM model implementing method for CO$_2$ emission quantity assessment is modelled by setting the structure and finishing material as a single material. The BIM supportability of the major construction materials is observed through this method, and the result is shown in Table 4.

Table 4. BIM Supportability of Major Construction Materials

| No. | Material               | Unit     | BIM Modelling | BIM Supportability |
|-----|------------------------|----------|---------------|--------------------|
| 1   | Ready-mixed Concrete   | m$^3$    | O             | BIM Template       |
| 2   | Steel bars             | Kg, ton  | X             | Applying the minimum steel rate |
| 3   | Steel frames           | Kg, ton  | O             | BIM Template       |
| 4   | Paint                  | m$^3$    | O             | BIM Template       |
| 5   | Glass                  | m$^3$    | O             | BIM Template       |
| 6   | Concrete products      | m$^3$    | O             | BIM Template       |
| 7   | Paint                  | m$^3$    | O             | BIM Template       |

The quantity of steel bars among the major construction materials does not support BIM.
Since the PPS pure resource code of steel bars is composed complexly of ready-made concrete, vertical reinforcement, and horizontal reinforcement within the wall structure, it is difficult to calculate each of these quantities. Thus, steel bars can support the quantity by applying the minimum steel rate.

4. Apartment BIM Model Application
4.1 Summary of the Assessment Target Building

To develop an appropriate modelling method, the modelling methods of complex materials and a single material were applied to the first floor with two apartment units and analysed using the quantity comparison as the basis.

The library form that the existing BIM model uses is a complex material form. The differences of the CO₂ emission quantity that uses this and the CO₂ emission quantity that uses the single material, the appropriate method that this research presents, were analysed comparatively.

The national LCI DB in Korea was used to compute the basic unit CO₂ emission quantity of the building material.

Table 5. Apartment Outline

| Modelling | Division                        | Contents                           |
|-----------|---------------------------------|------------------------------------|
|           | Developing business district of the city of Magog, Gangseo-gu, Seoul, Korea |
|           | Building area                   | 606.13 m²                          |
|           | Structure                       | Reinforced concrete construction,  |
|           | Life                            | 60 years                           |

4.2 BIM Library Implementation for CO₂ Emission Quantity Assessment

The library should be used for BIM modelling. As a prerequisite for assessing BIM-based CO₂ emission, the library construction types provided by the conventional BIM authoring tool were analysed.

An examination of about 100 libraries being basically implemented showed that the library is composed of the wall, door, window, compartment, pillar, roof, ceiling, curtain wheel system, curtain grid, and mullion, which are in the object form within the work frame. The structural part of the attribute information is composed of the function and the material.

The library applied for the existing BIM modelling uses complex materials, expressed as the same structural, insulation, and finishing material.

However, an additional library implementation is required in order to use the method that employs a single material, presented as the appropriate method in this research.

Thus, a summary of the library used for complex material modelling (Table 6.) and the library used for single material (Table 7.) is shown below.

Table 6. Library Used for the Complex Material

| Division | Library Used for the Complex Material | Number |
|----------|--------------------------------------|--------|
| Ceiling  | Complex Ceiling: Ceiling _ Plasterboard _ 9.5T | 34     |
| Beam     | E232-01 Beam RC rectangular form: 250 x 450 | 16     |
| Beam     | E232-01 Beam RC rectangular form: 400 x 450 | 2      |
| Beam     | E232-01 Beam RC rectangular form: 500 x 450 | 37     |
| Slab     | Slab: E251-01 Slab 150               | 35     |
| Column   | E229-02 Column SRC rectangular form: RC500 x 500 + S300 x 200 5 | 8      |
| Column   | E229-02 Column SRC rectangular form: RC500 x 600 + S300 x 200 3 | 4      |
| Column   | E229-02 Column SRC rectangular form: RC500 x 650 + S300 x 200 3 | 20     |
| Column   | E229-02 Column SRC rectangular form: RC500 x 700 + S300 x 200 2 | 8      |
| Column   | E229-02 Column SRC rectangular form: RC500 x 800 + S300 x 200 4 | 12     |
| Column   | E229-02 Column SRC rectangular form: RC540 x 650 + S300 x 200 6 | 4      |
| Wall     | Basic wall: E000- Plasterboard 12.5  | 4      |
| Wall     | Basic wall: E241-01 Outer wall RC 150 | 28     |
| Wall     | Basic wall: E241-01 Outer wall RC 250 | 16     |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 50 | 4      |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 80 | 2      |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 100 | 90     |
| Wall     | Basic wall: E241-01 Outer wall RC 150 + insulating material 12.5 | 8      |
| Wall     | Basic wall: E241-01 Outer wall RC 150 + insulating material 55 | 20     |
| Wall     | Basic wall: E241-01 Outer wall RC 150 + insulating material 120 + Lightweight wall 50 | 6      |
| Wall     | Basic wall: E241-01 Outer wall RC 150 + insulating material 150 + Lightweight wall 50 | 6      |
| Wall     | Basic wall: E241-01 Outer wall RC 150 + insulating material 152.5 + Plasterboard 12.5 | 12     |
| Wall     | Basic wall: E241-01 Outer wall RC 250 + insulating material 55 | 8      |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 50 + Airspace 50 + insulating material 50 + Lightweight wall 50 + insulating material 57.5 + Plasterboard 12.5 | 10     |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 50 + insulating material 50 + Airspace 50 + Lightweight wall 50 | 24     |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 50 + insulating material 55 + Airspace 45 + Lightweight wall 50 | 6      |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 100 + insulating material 55 | 12     |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 100 + insulating material 67.5 + Plasterboard 12.5 | 42     |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 100 + insulating material 67.5 + Plasterboard 12.5 (Two-sided) | 6      |
| Wall     | Basic wall: E332- Secondary wall Lightweight wall 100 + insulating material 122.5 + Plasterboard 12.5 | 6      |
| Total    |                                    | 31     |

498
Table 7. Library Used for the Single Material

| Division | Library | Number |
|----------|---------|--------|
| Ceiling  | Complex Ceiling  | 9.5T   |
| Beam     | E232-01 Beam RC rectangular form: 250 x 450 | 16 |
| Beam     | E332-01 Beam RC rectangular form: 250 x 450 | 9 |
| Slab     | Slab: E251-01 Slab | 150 | 35 |
| Column   | E229-02 Column SRC rectangular form: RC500 x 500 + S300 x 200.5 | 8 |
| Column   | E229-02 Column SRC rectangular form: RC500 x 600 + S300 x 200.3 | 4 |
| Column   | E229-02 Column SRC rectangular form: RC500 x 650 + S300 x 200.3 | 20 |
| Column   | E229-02 Column SRC rectangular form: RC500 x 700 + S300 x 200.2 | 8 |
| Column   | E229-02 Column SRC rectangular form: RC500 x 800 + S300 x 200.4 | 12 |
| Column   | E229-02 Column SRC rectangular form: RC540 x 650 + S300 x 200.6 | 4 |
| Wall     | Basic wall: E000- Plasterboard 12.5 | 32 |
| Wall     | Basic wall: E000- Secondary wall insulating material 50 | 14 |
| Wall     | Basic wall: E000- Secondary wall insulating material 55 | 22 |
| Wall     | Basic wall: E000- Secondary wall insulating material 57.5 | 2 |
| Wall     | Basic wall: E000- Secondary wall insulating material 67.5 | 14 |
| Wall     | Basic wall: E000- Secondary wall insulating material 120 | 2 |
| Wall     | Basic wall: E000- Secondary wall insulating material 122.5 | 2 |
| Wall     | Basic wall: E000- Secondary wall insulating material 150 | 2 |
| Wall     | Basic wall: E000- Secondary wall insulating material 152.5 | 6 |
| Wall     | Basic wall: E241-01 Outer wall RC 150 | 44 |
| Wall     | Basic wall: E241-01 Outer wall RC 250 | 22 |
| Wall     | Basic wall: E332-- Secondary wall Lightweight wall 50 | 42 |
| Wall     | Basic wall: E332-- Secondary wall Lightweight wall 80 | 2 |
| Wall     | Basic wall: E332-- Secondary wall Lightweight wall 100 | 114 |
| Total    | 25 | 500 |

The result of comparing the library that uses complex materials and the library that uses the single material indicates that the number of library types implemented with the single material is lower. That is because the single material is combined through modelling in accordance with the construction of each building material. On the other hand, the number of libraries using the complex material increases according to material types since libraries with the complex material can be used only when they are all constructed with a combination according to the materials.

4.3 BIM-modelling Method Application for CO₂ Emission Quantity Assessment

The CO₂ emission quantity assessment is computed as the national LCI DB matching operation following the BIM quantity.

Table 8. LCI DB

| Division | Material | CO₂ Emission Quantity | Unit |
|----------|----------|------------------------|------|
| 1        | Concrete Brick | 1.2300E+01 | Kg CO₂-eq/kg |
| 2        | Extruded Foam Poly-styrene | 2.0100E+00 | Kg CO₂-eq/kg |
| 3        | Double glazing | 2.2420E+01 | Kg CO₂-eq/m² |
| 4        | Tempered glass | 1.1330E+01 | Kg CO₂-eq/m² |
| 5        | Ready-mixed Concrete 25-210-12 | 4.0900E+02 | Kg CO₂-eq/m² |
| 6        | Ready-mixed Concrete 25-210-15 | 4.1900E+02 | Kg CO₂-eq/m² |
| 7        | Ready-mixed Concrete 25-240-12 | 4.1400E+02 | Kg CO₂-eq/m² |
| 8        | Ready-mixed Concrete 25-240-15 | 4.2900E+02 | Kg CO₂-eq/m² |
| 9        | Plaster Board | 1.3800E+01 | Kg CO₂-eq/kg |

If the BIM quantity is computed for the national LCI DB matching operation, it is the same as that shown in Table 9. and Table 10.

Table 9. BIM Model Quantity (Complex Material)

| Division | 2D quantity computation sheet (m²) | BIM (m²) | Error range (m²) | Error range (%) |
|----------|-----------------------------------|----------|------------------|-----------------|
| Column   | Concrete                          | 26.404   | 27.121            | -0.717          | -2.715          |
|          | Steel frames                      | 0.717    | 1.45             | -0.733          | -102.231        |
|          | Lightweight wall                  | 50T      | 11.146           | -0.226          | -2.027          |
|          | 80T                               | 0.297    | 0.297            | 0               | 0               |
|          | 100T                              | 48.773   | 50.429           | -1.656          | -3.395          |
|          | 50T                               | 3.636    | 3.541            | 0.095           | 2.612           |
|          | 55T                               | 3.503    | 3.568            | -0.065          | -1.855          |
|          | 57.5T                             | 0.563    | 0.492            | 0.071           | 12.611          |
|          | 67.5T                             | 6.004    | 6.037            | -0.033          | -0.549          |
|          | 120T                              | 2.54     | 2.653            | -0.113          | -4.448          |
|          | 122.5T                            | 0.822    | 1.012            | -0.19           | -23.114         |
|          | 150T                              | 0.441    | 0.495            | -0.054          | -12.244         |
|          | 152.5T                            | 1.937    | 1.753            | 0.184           | 9.499           |
|          | Plasterboard                      | 12.5T    | 1.625            | -0.244          | -15.015         |
|          | Concrete                          | 67.093   | 66.440           | 1.247           | 1.842           |
|          | Wall total                        | 148.98   | 149.964          | -0.984          | -0.66           |
|          | Ceiling                           | 3.633    | 36.333           | 32.697          | -900            |
|          | 1st floor slab                    | 86.467   | 86.467           | 0               | 0               |
|          | 2nd floor slab                    | 63.013   | 83.89           | -20.877         | -33.131         |
|          | Beam                              | 47.059   | 43.337           | 3.722           | 7.909           |
|          | Slab Total                        | 196.539  | 213.694         | 17.155          | -8.728          |

When the quantity of the BIM model is computed and the 2D quantity computation sheet is compared with the used quantity, the complex material generates an error range between 0 and 23% excluding the steel frame, which is unlikely to be calculated as the BIM quantity with the wall as the standard. The error range can be determined if it is the quantity computed within the allowable error range by the material premium rate presented in the construction estimating standard of Table 11.
In the case of complex material, the allowed error range of insulation is 10%. However, the BIM quantity generates a maximum error of 23%, thereby leading to a great difference in the CO₂ emission quantity computation value.

In the case of single material excluding a steel frame, the error range is 0–5%. This error range is within the allowed error range presented in the material premium rate, and it is appropriate for CO₂ emission quantity computation.

Thus, an appropriate value can be computed by performing the assessment that uses quantity computation of modelling, which uses a single material, for BIM-based CO₂ emission assessment.

If the CO₂ emission is computed based on the BIM quantity computed in this assessment method, it is as shown in Table 12.

If the target assessment building is compared and analysed with the CO₂ emission quantity assessment result that uses the general 2D quantity computation sheet, the CO₂ emission quantity assessment result of the building material quantity that uses the general 2D quantity computation sheet is assessed as 15.0628 kg-CO₂/m². The CO₂ emission quantity of the target assessment building that uses the BIM template was assessed to be 15.0923 kg-CO₂/m². It has less CO₂ emission by approximately 0.2% than the general 2D quantity computation sheet.

5. Conclusions

The findings of this research indicate that it would be advantageous to develop a BIM model for CO₂ emission quantity assessment by using a single material to calculate the accurate quantity. Based on these findings, the following conclusions are derived.

First, the library information regarding the building targeted for BIM modelling must be implemented as a single material based on the PPS pure resource code, and this requires less library operation than implementing with complex material.

Second, a BIM-based building CO₂ emission quantity computation process was established. Using the BIM-based national LCI DB, the base unit CO₂ emission quantity DB of the building material was matched and the quantity of the building material was computed to establish the process that computes the building’s CO₂ emission quantity.

Third, when the assessment target building’s BIM quantity was computed by classifying it into the complex material and the single material, the single material was within the allowed error range of the material premium rate presented by the estimation standard of construction.

Fourth, a comparison was done of the method using a statement of quantity estimation, which is a conventional CO₂ emission assessment method, and that using BIM-based CO₂ emission. The results of
this comparison indicates that the BIM-based CO$_2$ emission is about 0.2% lower. Because this value is within the allowable error limits, the use of BIM as a method of estimating CO$_2$ emission is determined to be appropriate.

The limitation of this research is related to the national LCI DB. Information on all of the building material (materials or complex structure) that structures the actual building is needed to compute the total CO$_2$ emission quantity of the BIM-based designed building. However, there are 92 items related to the building material of the national LCI DB in the current structure, and the information on all of the building materials could not be converted into the DB; thus, it was insufficient to compute the total CO$_2$ emission quantity of the building.

In the future, it will be necessary to reduce the error range through comparative analysis of a BIM-based quantity and a quantity derived from a computation sheet, and to increase the accuracy of the matching operation by developing the national LCI DB.

Acknowledgement

This research was supported by a grant (15AUDP-C067817-03) from the Architecture & Urban Development Research Program funded by the Ministry of Land, Infrastructure and Transport of the Korean government.

References

1) Agrawala, S. "Structural and Process History of the Intergovernmental Panel on Climate Change". Climatic Change 39 (4): 621–642, 1998.08.
2) EU Emissions Trading System (EU ETS). "UK Department of Energy and Climate Change". 2009.01.
3) Grubb, M. et al. "Climate Policy and Industrial Competitiveness: Ten Insights from Europe on the EU Emissions Trading System". Climate Strategies. Retrieved 28 June 2010, 2009.
4) H. Tae, S. W. Shin, J. H. Woo, S. J. Roh, "The development of apartment house life cycle CO$_2$ simple assessment system using standard apartment houses of South Korea". Renewable & Sustainable Energy Reviews, pp.1454-1467, 2011.
5) Hanjong Jun, Iksung Kim, Yongju Lee, Mikyoung Kim, "A Study on the BIM Application of Green Building Certification System", Journal of Asian Architecture and Building Engineering Vol. 14 No. 1, pp.9-16, 2015.
6) Hak-Gun Kim, Jong-Ho Yoon, Won-Goo Lee, Hyun-Joon Min, "Peep at the practical work of environment-friendly architecture", Publishing company Goomi Book, 2014.03.
7) Heindl, Peter: Transaction Costs and Tradable Permits: Empirical Evidence from the EU Emissions Trading Scheme. Discussion Paper No. 12-021. Centre for European Economic Research, 2012.
8) Jang Hyeong Jae, "The evaluation of CO$_2$ Emissions and Economical efficiency of apartment buildings by plan types", The Graduate School Hanyang University, 2013.08.
9) Korea Construction Promotion Association, 2014 estimating standards of construction work, Construction and Transport Journal Corporation, 1990.
10) Lieyun Ding, Ying Zhou, Burcu Akinci, "Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD", Automation in Construction, Volume 46, pp.82-93, 2014.
11) M. Finkbeiner, A. Inaba, R. Tan, K. Christiansen, H. J. Kluppel," The new international standards for life cycle assessment: ISO 14040 and ISO 14044", The international journal of life cycle assessment, pp.80-85, 2006.
12) National LCI Database Information Network, http://www.edp.or.kr/lcidb/main/main.asp
13) Nordhaus, W.D. and J.G. "Boyer. Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol". 2009.08.
14) Seyoung Moon, Hyejung Kang, Sangheon Lee, Hanjong Jun, "A Basic Study on the Development of BIM Template in Korean Architectural Design Firm", Asian Conference on Design and Digital Engineering, 2012.
15) UNFCCC, "Information provided by Annex I Parties relating to Appendix I of the Copenhagen Accord (quantified economy-wide emissions targets for 2020)"; UNFCCC, 2011.02.
16) United Nations Environmental Programme (UNEP), "Building and Climate Change", UNEP, 2009.
17) Zhuguo Li, "A new life cycle impact assessment approach for buildings", Building and Environment, Volume 41, Issue 10, 1414-1422, pp.1414-1422, 2006. 10.