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Development of a building life cycle carbon emissions assessment program (BEGAS 2.0) for Korea's green building index certification system

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ABSTRACT

Carbon emission reduction policies demand tighter building Life Cycle Assessment (LCA) qualification standards. However, it is widely believed that it will be difficult to efficiently reduce the carbon emissions of buildings with only a fragmentary revision of the qualification standards. For this reason, the Korean government has developed the Green Building Index Certification System (GBI certification system), which is a certification framework based primarily upon the carbon emissions of a building. There is currently no assessment program tailored to the GBI certification system. The purpose of this study is to develop the Building Life Cycle Carbon Emissions Assessment Program (BEGAS 2.0) to support Korea's GBI certification system. With a theoretical consideration of the GBI certification system, the building LCA qualification standards of other international green building certification systems were analyzed. These analyses enabled development of BEGAS 2.0 that reflects the characteristics of the GBI certification system and the current state of Korea's construction industry. Consequently, an appropriate building life cycle carbon emissions assessment program was developed, which can support Korea's GBI certification system effectively.

Contents

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1. Introduction

To address the issue of global warming, it is essential to reduce carbon emissions from buildings [1,2], as they are responsible for more than 30% of all carbon emissions [3,4]. The carbon emissions of a building are generated directly and indirectly throughout the building's life cycle stages, including the construction stage, the operation stage, and the disposal stage [5,6]. Thus, the United Kingdom (UK), the United States (US), and Japan reinforce their building Life Cycle Assessment (LCA) qualification standard that evaluates a building life cycle carbon emissions [7–9]. In addition, government-affiliated research institutes and university laboratories are supporting green building by developing building LCA programs [10,11]. The Building Research Establishment (BRE) of the UK has developed Envest2 and IMPACT, which are building LCA programs where the BRE's Environmental Assessment Method (BREEAM) was applied [12]. The Leadership in Energy and Environmental Design (LEED) of the US operates the building LCA qualification standard, which uses Athena Eco Calculator and Building Energy Efficiency Standards (BEES) [13].

The Green Standard for Energy and Environmental Design (G-SEED), which is the Green Building certification system of Korea, has also been used to reduce the carbon emissions of buildings. In G-SEED 2013, part of the qualification standard was revised to extend the existing certification framework, which was focused on the operation stage of a building, from the perspective of the LCA [14]. In G-SEED 2015 (Draft), the Building materials Embodied Greenhouse gases Assessment System 1.0 (BEGAS 1.0) was developed to establish a qualification standard that evaluates the levels of carbon emissions from building materials [15]. It is widely believed that it will be difficult to efficiently reduce the carbon emissions of buildings with only a fragmentary revision of the qualification standard [16–20]. Thus, the Korea Ministry of Land, Infrastructure, and Transport started developing the Green Building Index Certification System (GBI certification system) in 2011 based upon the life cycle carbon emissions data of buildings, and it is currently preparing a demonstration using public buildings. The GBI certification system evaluates the environmental, social, and economic aspects of sustainability and determines a single sustainability score. However, it is necessary to develop a building life cycle carbon emissions assessment program that can implement the GBI certification system and properly reflect the current state of Korea's construction industry.

The purpose of this study is to develop the Building Life Cycle Carbon Emissions Assessment Program (BEGAS 2.0) to support Korea's GBI certification system. Toward that end, the GBI certification system was reviewed from a theoretical standpoint, and the building LCA qualification standards of the international green building certification systems were analyzed. BEGAS 2.0 was then developed, which includes a database (DB) that is in accordance with the LCA guidelines and reflects the characteristics of the GBI certification system and the current state of Korea's construction industry.

2. Literature review

2.1. GBI certification system

The GBI certification system is a new green building certification framework that evaluates sustainability based on the building life cycle carbon emissions. Three aspects of sustainability (environmental, social, and economic) are evaluated, as suggested in Triple Bottom Line (TBL) [21] and ISO 21929-1 [22], regarding the following categories: carbon emission quantity, building habitability, and economic feasibility of carbon emission reduction.

The evaluation of carbon emissions determines the Carbon Emission Index from a quantitative evaluation of the carbon emission levels generated over the course of the building life cycle phases. The evaluation of building habitability determines the Building Habitability Index by assessing habitability through 60 qualification standards in five categories. The evaluation of economic feasibility determines the Carbon Economic Index by analyzing the additional cost for the reduction of carbon emissions. Consequently, it is possible to calculate the GBI (1) that decides the final grade of the GBI certification system. The GBI reflects the concept of Eco Efficiency (= Product or Service Value ÷ Environmental Influence) that the World Business Council for Sustainable Development (WBCSD) suggested [23]. In other words, the Carbon Emission Index is used for Environmental Influence, whereas the Building Habitability Index is used for Product or Service Value. In addition to the Indexes, the Carbon Economic Index is applied in the formula.

$$\mathrm{GBI} = \frac{\text{Building Habitability Index}}{\text{Carbon Emission Index}} \times \text{Carbon Economic Index} \tag{1}$$

Fig. 1 shows evaluation method of the current green building certification systems and the GBI certification system. The current green building certification system is a simple structure that determines the final certification grade by summing up all the grades achieved from the qualification standards [24,25]. It is relatively easy to predict and judge the certification grade, but the main drawback is that the certification score cannot serve as a quantitative representation of sustainability. In fact, some buildings with a higher certification grade were found to consume more energy and emit more carbon dioxide than buildings with a lower certification grade [26–28]. Although the evaluation method of the GBI certification system is more complex than the current green building certification systems, the GBI can consolidate the environmental, social, and economic aspects more quantitatively by using the carbon emission index, the building habitability index, and the carbon economic index.

2.2. Building LCA Qualification Standard of the Green Building Certification System

Table 1 describes the building LCA qualification standards of the green building certification systems. BREEAM 2014 of the UK reflects the LCA of the building in Mat01 program, life cycle impacts qualification standards in the category of materials [29].

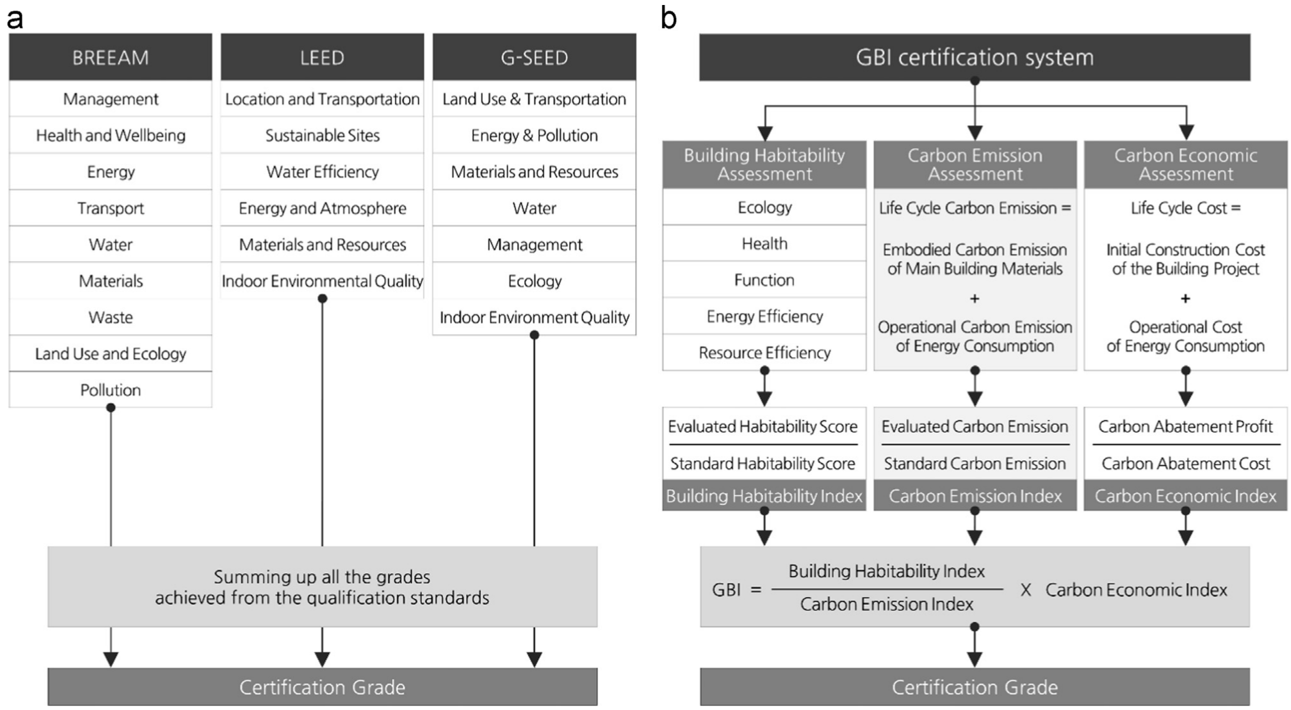


Fig. 1. Evaluation Method of Current Green Building Certification System and the GBI Certification System.

The UK applies the building LCA method in the unit of building materials as the volume of the supply is documented. Here, the building materials are external walls, windows, roof, upper floor slab, internal walls, and floor finishes/coverings. The main building materials to be evaluated are determined according to the purpose of the building, and they can be evaluated using Green Guide, a DB of the environmental performance of building materials, or by using IMPACT, the building LCA system [30]. The evaluation results are computed using 13 environmental effect indexes, including the Global Warming Potential (GWP), which indicates the level of carbon emissions. A maximum of five certification grades can be obtained according to the LCA range and the source LCA data quality [31].

LEED V4 of the United States reflects the building LCA in the unit of the building materials through the M.R. Credit 1. Building Life Cycle Impact Reduction qualification standard of the Materials and Resources category [32]. The building materials are composed of foundation & footings, columns & beams, intermediate floors, exterior walls, windows, interior walls, and roofs. They are evaluated using Athena Eco Calculator for Assemblies, a building LCA system, or BEES [33]. The evaluation range covers three or more environmental effect indexes, including the carbon emission index (GWP). This system may obtain a maximum certification score of 3 when reducing more than 10% of a standard building emission levels [34].

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) of Japan is a certification system with an index concept using Building Environmental Efficiency (BEE) as described in Formula (2) [35]. The qualification standard of the building LCA is described in L2.2.2 Continuing Use of Existing Structural Frame etc. in the Resources and Materials category [36]. Japan applies the building LCA method based on the major building materials as the volume of supply is documented and managed in the unit of the building materials. Here, the major building materials indicate concrete, blast-furnace cement concrete, section steel, rebar, and lumber. Only the carbon emission quantity is treated in the evaluation range, and the evaluation is processed through a spreadsheet of the certification system [37].

$$BEE = \frac{\text{Building Environmental Quality}}{\text{Building Environmental Loadings}} \tag{2}$$

In G-SEED 2015 (Draft), the Korean building LCA qualification standard in Innovation Design will be established. The Korean government applies the building LCA method based on the major building materials (ready-mixed concrete, rebar, and section steel) as the volume of the supply is documented as is done in Japan. The evaluation range is the carbon emission quantity (GWP) considering the six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) of IPCC [38]. In this case, BEGAS 1.0, an evaluation system for carbon emission levels based on the primary building materials, is used, and at most two extra points are granted compared to the standard carbon emissions of the same kind of building [15].

On the other hand, the GBI certification system of Korea performs the building LCA using BEGAS 2.0 to derive the carbon emission index (Formula (3)). The denominator of the carbon emission index indicates the carbon emission quantity over the standard building life cycle, while the numerator indicates the carbon emission quantity over the evaluated building life cycle. The calculated carbon emission index is directly reflected in the GBI calculation formula (refer to Formula (1)), which would determine the GBI and the final certification grade.

Carbon Emission Index

$$= \frac{\text{Carbon Emission Quantity over the Evaluated Building Life Cycle}}{\text{Carbon Emission Quantity over the Standard Building Life Cycle}} \tag{3}$$

Several programs are used internationally to assist the building designer to reduce carbon emissions of buildings. A program is needed which will utilize the best aspects of these international standards for use which considers the current construction industry in Korea.

Table 1
Building LCA Standard for the Green Building Certification System.

Classification	BREEAM 2014	LEED V4	CASBEE	G-SEED 2015 (Draft)	GBI Certification System
Development country	United Kingdom	United States	Japan	Korea	Korea
Development Institute	BRE	USGBC	Ministry of Land, Infrastructure, Transport and Tourism	Ministry of Land, Infrastructure and Transport, and Ministry of Environment	Ministry of Land, Infrastructure and Transport
Professional Field	Materials	Materials and Resources	Resources and Materials	Innovation Design	Evaluation of Carbon Emission Quantity
Qualification Standard	Mat01. Life Cycle Impacts	M.R. Credit 1. Building Life-Cycle Impact Reduction	L2.2.2 Continuing use of Existing Structural Frame etc.	ID01. GHG Emission of Building Input Resources	–
Evaluation method	Building LCA based on the major building Materials Using Green Guide, IMPACT	Building LCA Based on the Major Building Materials Using Eco Calculator, BEES	Evaluation of Building Carbon Emission Quantity Based on the Major Building Materials Using its Spreadsheet	Evaluation of Building Carbon Emission Quantity Based on the Major Building Materials Using BEGAS 1.0	Evaluation of Building Life Cycle Carbon Emission Quantity Based on the Major Building Materials Using BEGAS 2.0
Reflecting Method	Certification Grade of Maximum of 5	Certification Grade of Maximum of 3	BEE Index	Extra Points of Maximum of 2	Carbon Emission Index

3. Research methods

This section describes the development of BEGAS 2.0 that evaluates the environmental aspect (carbon emission quantity) in the GBI certification system. First, the building life cycle carbon emissions assessment method and the scenario were established, with consideration of the characteristics of the GBI certification system and the current state of Korea's construction industry. Then, the building life cycle phases have been divided into the construction stage, the operation stage, and the disposal stage, and the DB of the carbon emission basic unit, required in the evaluation of the carbon emissions for each step, has been constructed in accordance with the LCA guidelines.

3.1. Evaluation method and establishment of scenario

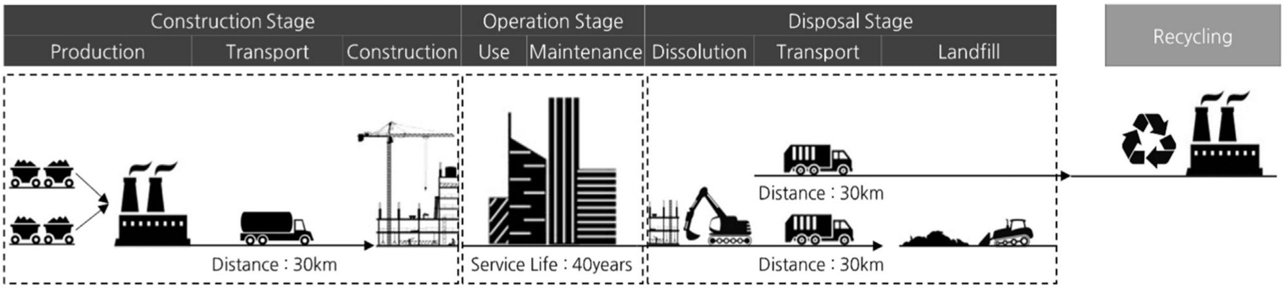
Formula (4) indicates how the building life cycle carbon emissions are calculated. The emissions can be calculated by multiplying all the building materials, used over the life cycle of the building, and the amount of energy by their Carbon Emission Unit [39]. In this study, the life cycle of a building has been classified into the construction stage, the operation stage, and the disposal stage, and the evaluation method and the scenario (refer to Fig. 2) have been established. The evaluation method for the building life cycle carbon emissions and the scenario of this study have been constructed in a streamlined LCA structure to enable many users to easily evaluate them, considering that they are directly related as an international system.

$$\text{Building Life Cycle Carbon Emissions} = \sum(\text{Material or Energy} \times \text{Carbon Emission Unit}) \tag{4}$$

In the construction stage, a concept of major building materials with high carbon emission rates was applied. In addition, processes that are directly connected with the supply of building materials, such as transportation, maintenance, and landfill, have been included because the level of carbon emission can be evaluated automatically based on the supply of the major building materials quantities during the production process. For example, the quantity of ready-mixed concrete input in the production process is transported 30 km, the distance from the manufacturer to the construction site, by a transit-mixer truck according to the scenario in Fig. 2. After the service life of a building of 40 years, the material turns into waste concrete and is transported by a 15 t truck to a landfill or a recycling company, which are 30 km from the building. About 30% of the ready-mixed concrete is expected to be buried in the landfill and 70% to be recycled. On the other hand, the operation stage has suggested that there is a difference between the method that inputs the carbon emission level based on the building energy efficiency rating grade, and the method that inputs the energy consumption, in accordance with the available information at the time of evaluation. The range of evaluation for the carbon emissions has been set to six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) according to the IPCC definition. Also, the evaluation result has been described as Carbon Dioxide Equivalent (CO_{2eq}) through the GWP [38].

3.1.1. Construction stage

The construction stage can be further classified into the production processes of the building materials, the transportation processes of the building materials, and the construction processes of the building. In production processes, the embodied carbon emission level is evaluated [40] to produce the building materials that generally makes up 30% of the building life cycle carbon emissions [41]. The evaluation method for production processes



Main Building Materials	Freight Vehicle	Repair Cycle / Rate	Waste Vehicle	Landfill Rate	Recycle Rate
Ready-mixed Concrete	Transit-mixer Truck	-	15 ton Truck	30% Buried	70% Recycled
Rebar	20 ton Truck			-	100% Recycled
Section Steel					
Glass	8 ton Truck			20% Buried	80% Recycled
Concrete Brick				100% Buried	-
Insulation					
Plaster Board		20 year / 100%		90% Buried	10% Recycled

Fig. 2. Scenario for the Evaluation of the Building Life Cycle Carbon Emissions.

can be distinguished as the evaluation method in the unit of the building members of the framework, and in the unit of the building material. In this study, the evaluation method in the unit of the building material was selected, considering the current state of the Korean construction industry, where the volume of the supply is documented. In this case, the evaluation process is complicated, as more than 3,000 building materials are generally used in buildings. The efficiency of the evaluation method may be increased by applying the concept of major building materials with high carbon emission rates [42]. This study applied the major carbon-emitting building materials for development of the evaluation program (BEGAS 1.0) of the embodied carbon emission quantity of Korean building materials in the preceding research [15]. These are seven major building materials that comprise more than 95% of the building materials applied in the construction work according to the LCA cut-off criteria of ISO 14040 [43]: Ready-mixed concrete, rebar, section steel, glass, concrete brick, insulation, and plaster board. Also, detailed building materials have been classified according to the Pure Resource Code of Korea Public Procurement Service (PPS) in order to consider them for the major building materials [44]. As a result, ready-mixed concrete has been classified into eight detailed building materials according to strength, and the glass and insulation have each been classified into three detailed building materials (refer to Table 3). A total of 18 detailed building materials for all seven of the major categories were set as the target of evaluation for BEGAS 2.0.

In transportation, an evaluation is performed on the carbon emissions during transportation until the building materials are delivered to the construction site based on the specific scenario. Based on the Korean Standard Estimating System of the Construction Work [45], the types of transportation vehicles that are commonly used for each building material have been investigated, and a scenario has been written. As a result, a transit-mixer truck was designated to be used to transport the ready-mixed concrete, and a 20-ton truck was designated to be used to transport rebar and section steel. In addition, an 8-ton truck was designated to be used for the other building materials. All the materials were assumed to be supplied from construction supply businesses within 30 km of the construction site.

In the construction process, the carbon emissions due to the use of equipment during the process of constructing the building are also evaluated. The evaluation can be done through the Life Cycle Inventory Database (LCI DB), which was established according to the fundamental operations needed to install the major categories of building materials.

3.1.2. Operation stage

The operation stage can be divided into building use and maintenance. The use process considers the carbon emissions due to energy consumed during the period of use of the building. This is a major step that makes up about 70% of the building life cycle carbon emissions [46]. The evaluation method of the use process has been divided into a carbon emission quantity input and an energy consumption input according to the type of input information at the time of evaluation. The carbon emission quantity input method used the building energy efficiency rating system that is used for the construction of an apartment building or commercial building in Korea. The carbon emission level per unit area annually due to air-conditioning, heating, hot water, lighting, and the ventilation system was input into the model based upon the building energy efficiency rating certification. In addition, the energy consumption input method was used to enter the energy consumption per unit area for a year for each energy source, such as electricity and gas, which has been calculated by a building energy simulation program. The default value for the life span of the building has been set to 40 years according to the building durable period of the Korea Corporate Tax Act [47].

In the maintenance process, an evaluation is performed on the embodied carbon emission quantity of the building materials that are used for the renovation of the building. The embodied carbon emission evaluation method has been applied based on the repair period and the maintenance rate for each building material suggested by the Korea Housing Act [48].

3.1.3. Disposal stage

The disposal stage can be divided into the dissolution process of the building, the transportation process of the waste building materials, and the landfill process of the waste building materials. In the dissolution process, an evaluation is performed on the carbon emission level from the equipment used to demolish the building. In the dissolution process, the amount of waste building materials is calculated and set equal to the amount of building materials in the production stage.

In transporting the waste, an evaluation is performed on the carbon emissions from the site to the disposal plant. A 15-ton truck was designated to be used as the transportation vehicle according to the Korea Standard Estimating System of Construction Work [45], and the transportation distance was set to 30 km.

In the landfill, an evaluation is performed on the carbon emissions generated while landfilling the waste building materials. This study applied a cut-off method, in which the recycling business covers the carbon emissions of the recycling process of the waste materials, and it has considered only the carbon emissions of the landfill process for the waste building materials that have not been recycled. Toward that end, the current state of waste disposal for each building material has been investigated according to Korea's Statistical Research of Waste [49]. As a result, investigation showed that 70% of the ready-mixed concrete is recycled while the other 30% becomes landfill. A total of 80% of the glass is recycled, while the other 20% becomes landfill. Also, 10% of the plaster board is recycled, while the other 90% becomes landfill. Rebar and section steel are all recycled, while all concrete brick and insulation become landfill.

3.2. Establishment of the Carbon Emission Unit DB

According to the DB selection standard of LCA, a carbon emission unit must be selected based on the following order: territorial correlation, temporal correlation, and technological correlation [50]. It has been applied in the order of the carbon emission coefficient of the Korea Ministry of Environment [51]; the national LCI DB of the Korean Ministry of Trade, Industry and Energy; the Ministry of Environment [52]; the national DB of building material environmental information of the Korean Institute of Construction Technology [53]; the DB of the carbon emission unit of the concrete, previously researched in Korea [54,55]; and Ecoinvent of Switzerland [56], which has been described in Table 2.

In addition, Table 3 describes the analysis of the carbon emission units of building materials that have received the carbon footprint labeling certification in order to evaluate carbon emissions during the authentication process, in which all the information of the building materials used in the building is verified [57,58]. The IPCC 2006 Guidelines for National Greenhouse Gas Inventory [38] were analyzed to determine the carbon emissions during operation processes, and the corresponding DB of the carbon emission unit per energy source has been created as shown in Table 4. The measured carbon emission unit that Korea Power Exchange and Korea District Heating Corporation publicly announced following the application of the country-specific carbon emission coefficient [59,60] for electricity and district heating was applied. Gasoline and kerosene were assigned the basic carbon emission unit of the IPCC 2006 Guidelines for the National Greenhouse Gas Inventory [38].

4. Results

Based on the evaluation method established in the Research Methods section, BEGAS 2.0 was developed to evaluate emissions according to the authentication process of the GBI certification system. BEGAS 2.0 is composed of basic information, carbon emission assessment for the construction stage and the operating stage, and assessment result.

4.1. Basic Information

Fig. 3 shows basic information screen of BEGAS 2.0. The basic information includes selecting the preliminary certification, the certification, the certification division of the GBI certification system, and inputting the architecture scheme so that the building can be assessed. The information that is input is the title of the business, the address, the purpose, the structure, the area

Table 2
Production Process for Each Building Material and Carbon Emission Unit DB.

Major Building Materials	Detailed Building Materials	Production Process Name of DB	Basic Unit	Unit	Source	Landfill Process Name of DB	Basic Unit	Unit	Source
Ready-mixed Concrete	Less than 18 MPa	Ready-mixed Concrete 18 MPa	284.500	kg-CO_2/m³	Ⓓ	Landfill of Waste Concrete	0.007	kg-CO_2/kg	Ⓐ
	21 MPa	Ready-mixed concrete	346.000	kg-CO_2/m³	Ⓐ				
	24 MPa	Ready-mixed concrete	346.000	kg-CO_2/m³	Ⓐ				
	27 MPa	Ready-mixed concrete 27 MPa	364.600	kg-CO_2/m³	Ⓓ				
	30 MPa	Ready-mixed concrete 30 MPa	389.100	kg-CO_2/m³	Ⓓ				
	35 MPa	Ready-mixed concrete 35 MPa	425.400	kg-CO_2/m³	Ⓓ				
	40 MPa	Ready-mixed concrete 40 MPa	465.900	kg-CO_2/m³	Ⓓ				
	45 MPa	Ready-mixed concrete 45 MPa	465.900	kg-CO_2/m³	Ⓓ				
Rebar	All rebar	Electric arc furnace rebar	0.760	kg-CO_2/kg	Ⓑ	–	–	–	–
Section Steel	All section steels	H section steel	0.405	kg-CO_2/kg	Ⓒ	–	–	–	–
Glass	Regular glass	Plate glass	0.789	kg-CO_2/kg	Ⓐ	Landfill of waste glass	0.007	kg-CO_2/kg	Ⓐ
	Tempered glass, Tempered Low-E glass	Tempered glass	13.351	kg-CO_2/m²	Ⓒ				
	Multi-layer glass, Multi-layer Low-E glass	Multi-layer glass	22.425	kg-CO_2/m²	Ⓒ				
Concrete brick	Concrete brick	Concrete brick	0.123	kg-CO_2/kg	Ⓒ	Landfill of waste concrete brick	0.007	kg-CO_2/kg	Ⓐ
Insulation	Bubble insulation	Urethane plate	2.389	kg-CO_2/kg	Ⓒ	Landfill of mixed waste plastics	0.008	kg-CO_2/kg	Ⓐ
	Fibrous insulation	Glass wood	0.190	kg-CO_2/kg	Ⓐ				
	Foam insulation	Polystyrene foam	1.960	kg-CO_2/kg	Ⓐ				
Plaster Board	Waterproof board, Fireproof board	Plaster board	0.215	kg-CO_2/kg	Ⓐ	Waste gypsum /[CH] Treatment of waste gypsum	0.013	kg-CO_2/kg	Ⓔ

Ⓐ: Carbon Emission Coefficient, Ⓑ: National LCI DB, Ⓒ: National DB of building material environmental information, Ⓓ:Own DB, Ⓔ: Ecoinvent.

information, the life span of the building, and information from an assessor. These determine the carbon emission levels of a standard building, which will be compared in the evaluation result, based on input information such as the purpose, the structure, and the area of the building.

Table 3
Carbon Emission Unit DB of the Production Process of the Building Product with Carbon Footprint Labeling Certification.

Classification	Verification code	Product name
Ready-mixed Concrete	C-2012-038	Ready-mixed concrete [Standard: 25-24-150]
	C-2012-039	Ready-mixed concrete [Standard: 25-21-150]
	C-2012-040	Precast concrete (MPS Composite Beam)
Plaster Board	C-2012-060	Gypsum cement plate Astex [6 mm]
	C-2012-020	Ceiling finishes materials Gyptex (Eco)
	C-2012-019	Ceiling finishes materials Gyptex (Classic)
	C-2014-I-003	Regular plaster board [9.5T]
	C-2010-018	Regular plaster board [9.5T]
	C-2014-I-018	Regular plaster board [9.5T]
	C-2013-II-001	Regular plaster board [9.5T]
	C-2012-007	Carbon diet board

Table 4
Carbon Emission Unit DB per Energy Source.

Classification	Basic Unit	Unit	Source
Electricity	0.460	kg-CO_2/kWh	Korea Power Exchange
Gas	2.200	kg-CO_2/Nm^3	IPCC 2006 Guidelines for National Greenhouse Gas Inventory
District Heating	0.051	kg-CO_2/MJ	Korea District Heating Corporation
Kerosene	2.441	kg-CO_2/ℓ	IPCC 2006 Guidelines for National Greenhouse Gas Inventory

4.2. Construction Stage

Fig. 4 shows carbon emission assessment screen of BEGAS 2.0. In the construction stage, the volume information of the building materials that are to be used in the building is input according to the input form consisting of the detailed building materials. The input volume information of the major building materials is connected with the carbon emission unit DB within BEGAS 2.0, and the embodied carbon emission quantities are all evaluated from the production processes of the building materials as well as from the transportation processes, the construction processes, the maintenance processes, and the landfill processes of the building materials. Additionally, it is possible to input the volume information of the building materials with the carbon footprint labeling certification during the authentication step performed at the time of completion of the building.

4.3. Operating stage

In the operating stage, the carbon emission quantity input method and the energy consumption input method are classified and evaluated based on the type of information available regarding operating processes. The carbon emission quantity input method (refer to Fig. 4) inputs the carbon emission quantity per unit area for a year due to the air-conditioning, heating, hot water, lighting, and ventilation system based on the building energy efficiency rating certification. The energy consumption input method inputs the usage amount per unit area for a year of each energy source, such as electricity and gas. This input information describing operating processes selects the total carbon emission quantity generated during the total period of usage of the building as it is connected with the building life span information input from the basic information.

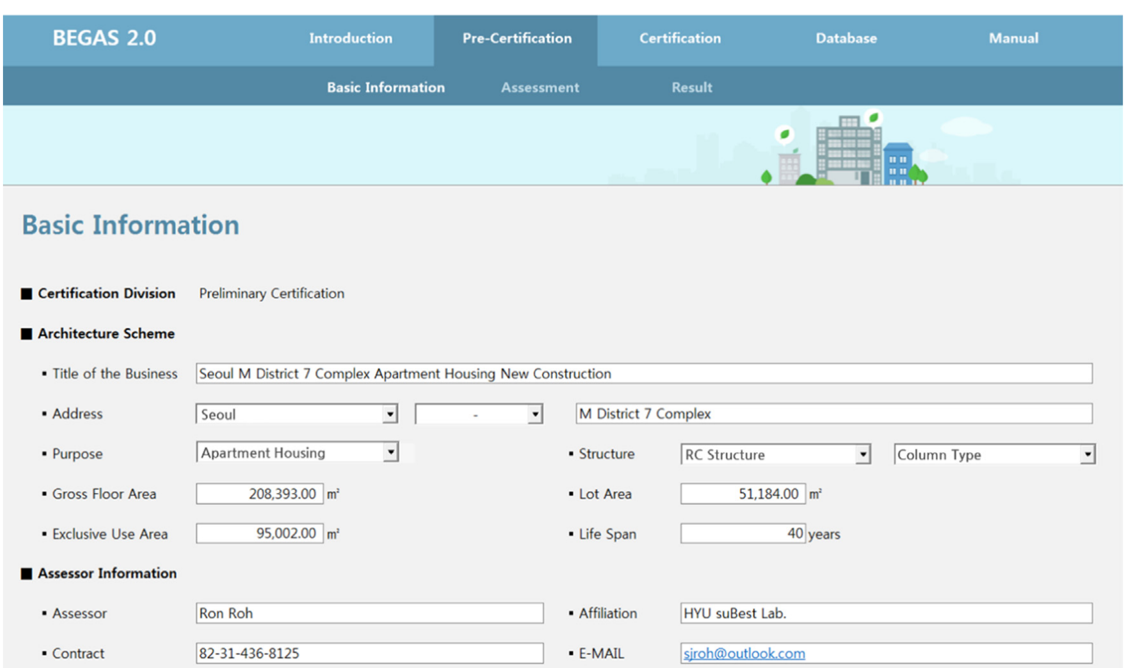
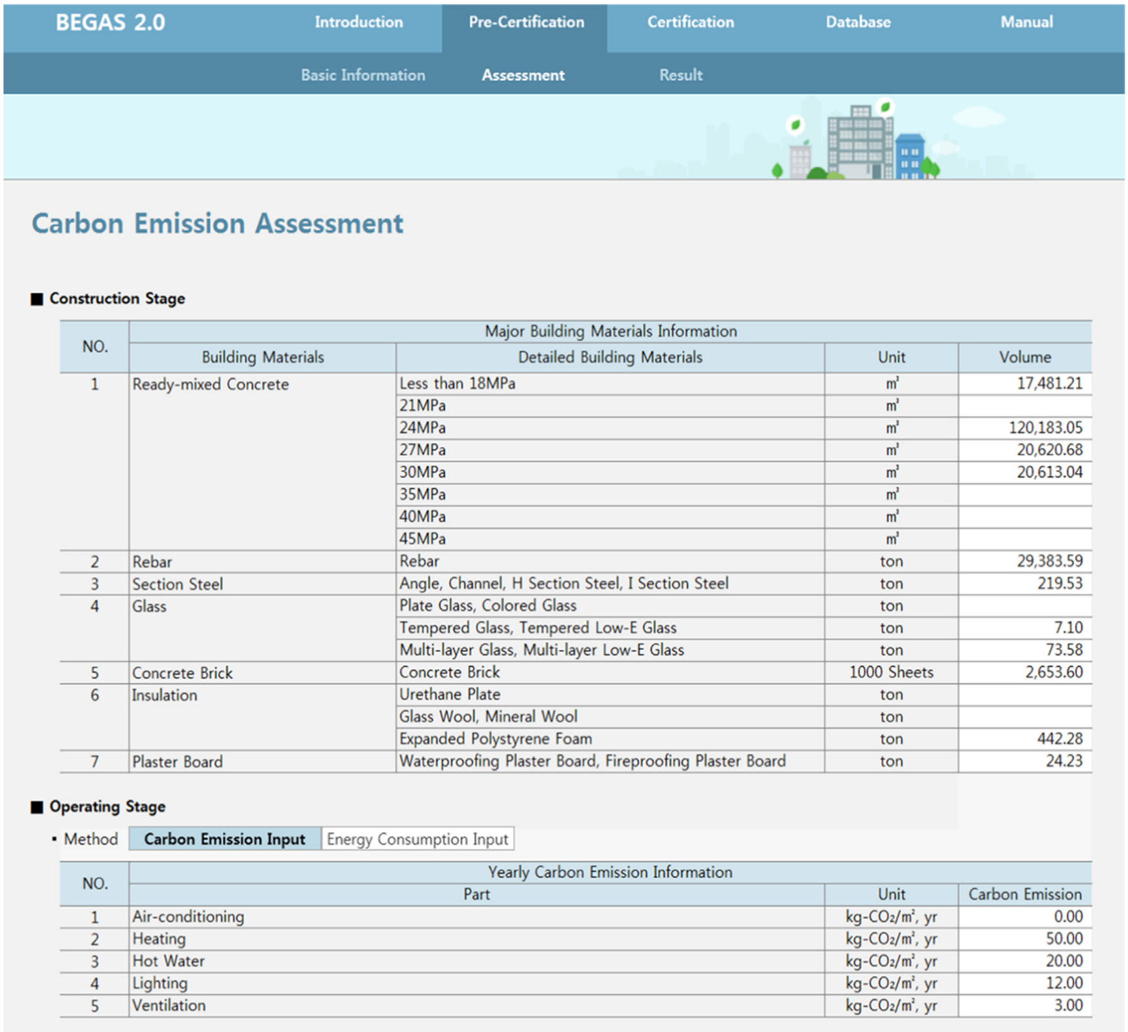


Fig. 3. Basic Information Screen.



NO.	Major Building Materials Information			
	Building Materials	Detailed Building Materials	Unit	Volume
1	Ready-mixed Concrete	Less than 18MPa	m³	17,481.21
		21MPa	m³	
		24MPa	m³	120,183.05
		27MPa	m³	20,620.68
		30MPa	m³	20,613.04
		35MPa	m³	
		40MPa	m³	
		45MPa	m³	
2	Rebar	Rebar	ton	29,383.59
3	Section Steel	Angle, Channel, H Section Steel, I Section Steel	ton	219.53
4	Glass	Plate Glass, Colored Glass	ton	
		Tempered Glass, Tempered Low-E Glass	ton	7.10
		Multi-layer Glass, Multi-layer Low-E Glass	ton	73.58
5	Concrete Brick	Concrete Brick	1000 Sheets	2,653.60
6	Insulation	Urethane Plate	ton	
		Glass Wool, Mineral Wool	ton	
		Expanded Polystyrene Foam	ton	442.28
7	Plaster Board	Waterproofing Plaster Board, Fireproofing Plaster Board	ton	24.23

NO.	Yearly Carbon Emission Information		
	Part	Unit	Carbon Emission
1	Air-conditioning	kg-CO_2/m², yr	0.00
2	Heating	kg-CO_2/m², yr	50.00
3	Hot Water	kg-CO_2/m², yr	20.00
4	Lighting	kg-CO_2/m², yr	12.00
5	Ventilation	kg-CO_2/m², yr	3.00

Fig. 4. Carbon Emission Assessment Screen.

4.4. Assessment result

Fig. 5 shows assessment result screen of BEGAS 2.0. The assessment result describes the carbon emission quantity, which the standard building and the target building generate during their life cycle period, and the carbon emission saving rate of the target building compared to the standard building. This is suggested by the construction processes, the operating processes, and the disposal stage, and the carbon emission index is computed according to Formula 3, explained previously. In addition, it provides a list of detailed building materials input in construction and operating processes, the total amount of carbon emissions generated from the classification of the energy sources, and detailed information on the carbon emission amount per unit area.

5. Case study

A case study was performed to evaluate the applicability of BEGAS 2.0, a program developed to efficiently evaluate a building's life cycle carbon emissions according to the GBI certification system. In this analysis, the method of evaluating life cycle carbon emissions using BEGAS 2.0, as developed in this study, was compared with the existing method in evaluating an apartment complex for both efficiency and the accuracy of evaluation results.

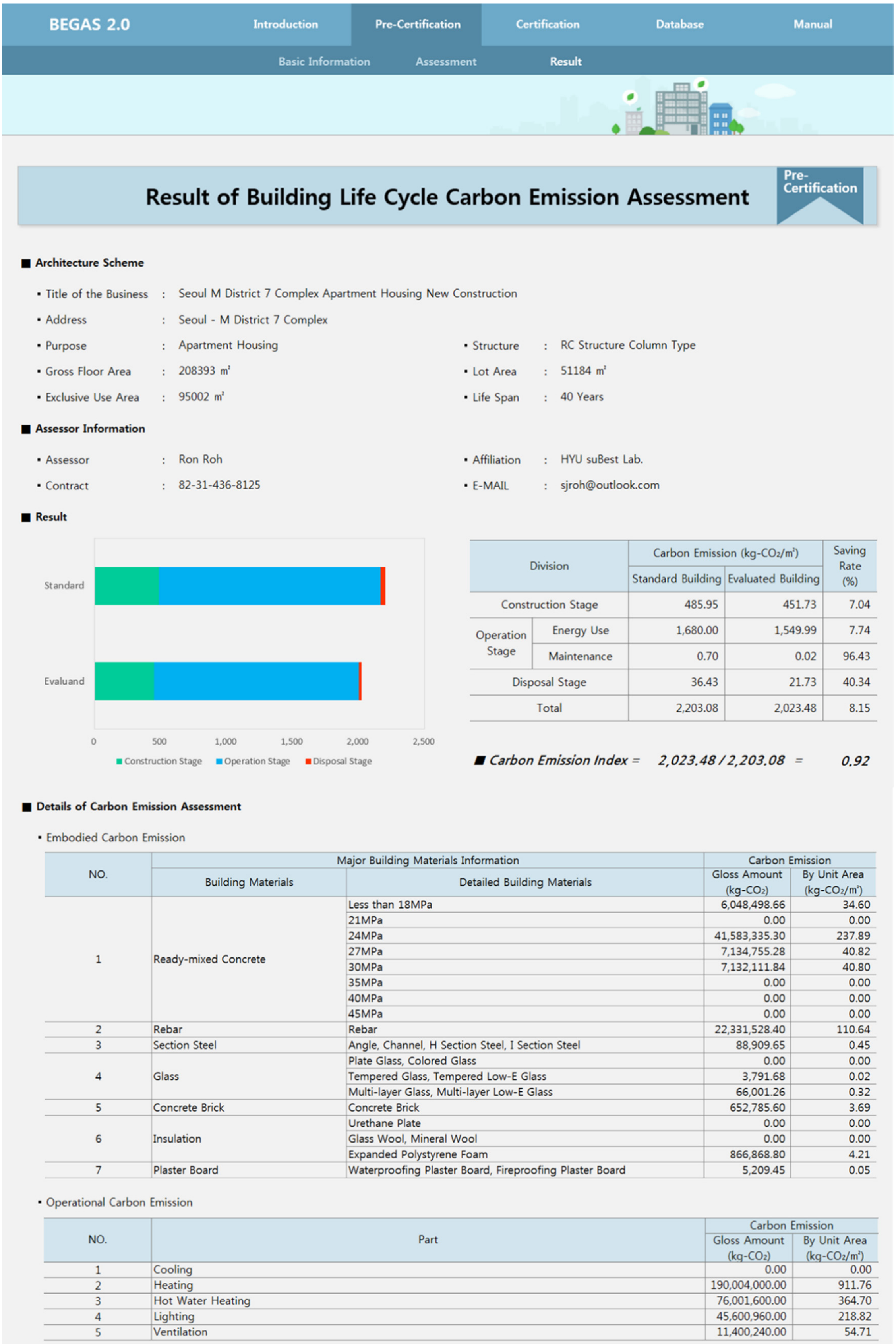
5.1. Evaluation target

The evaluation target was a 15- to 16-story above ground apartment complex in Seoul, Korea. This complex consisted of 13 apartment buildings constructed of reinforced concrete. An architecture scheme of the evaluation target is described in Table 5.

5.2. Evaluation method

The existing evaluation method looked at the production process by examining carbon emissions from 426 specific building materials based on a bill of quantities, and at emissions from operations using the annual carbon emissions evaluation indicated in the building energy efficiency rating certification. Emissions from transportation, maintenance, and landfill processes were evaluated using the scenario established above (refer to Fig. 2).

BEGAS 2.0 evaluated carbon emissions from 18 specific building materials based on seven major materials used in the production process, applying the same criteria for operations as used in the existing evaluation method. In addition, the carbon emissions from transportation, maintenance, and landfill processes were evaluated in accordance with the scenario laid out in Fig. 2. The methods of evaluating life cycle carbon emissions under the existing method and BEGAS 2.0 are illustrated in Table 6.



BEGAS 2.0 | Introduction | Pre-Certification | Certification | Database | Manual

Basic Information | Assessment | Result

Result of Building Life Cycle Carbon Emission Assessment

Pre-Certification

■ Architecture Scheme

- Title of the Business : Seoul M District 7 Complex Apartment Housing New Construction
- Address : Seoul - M District 7 Complex
- Purpose : Apartment Housing
- Structure : RC Structure Column Type
- Gross Floor Area : 208393 m²
- Lot Area : 51184 m²
- Exclusive Use Area : 95002 m²
- Life Span : 40 Years

■ Assessor Information

- Assessor : Ron Roh
- Affiliation : HYU suBest Lab.
- Contract : 82-31-436-8125
- E-MAIL : sjroh@outlook.com

■ Result

Division		Carbon Emission (kg-CO_2/m²)		Saving Rate (%)
		Standard Building	Evaluated Building	
Construction Stage		485.95	451.73	7.04
Operation Stage	Energy Use	1,680.00	1,549.99	7.74
	Maintenance	0.70	0.02	96.43
Disposal Stage		36.43	21.73	40.34
Total		2,203.08	2,023.48	8.15

■ *Carbon Emission Index = 2,023.48 / 2,203.08 = 0.92*

■ Details of Carbon Emission Assessment

- Embodied Carbon Emission

NO.	Major Building Materials Information		Carbon Emission	
	Building Materials	Detailed Building Materials	Gloss Amount (kg-CO_2)	By Unit Area (kg-CO_2/m²)
1	Ready-mixed Concrete	Less than 18MPa	6,048,498.66	34.60
		21MPa	0.00	0.00
		24MPa	41,583,335.30	237.89
		27MPa	7,134,755.28	40.82
		30MPa	7,132,111.84	40.80
		35MPa	0.00	0.00
		40MPa	0.00	0.00
		45MPa	0.00	0.00
2	Rebar	Rebar	22,331,528.40	110.64
3	Section Steel	Angle, Channel, H Section Steel, I Section Steel	88,909.65	0.45
4	Glass	Plate Glass, Colored Glass	0.00	0.00
		Tempered Glass, Tempered Low-E Glass	3,791.68	0.02
		Multi-layer Glass, Multi-layer Low-E Glass	66,001.26	0.32
5	Concrete Brick	Concrete Brick	652,785.60	3.69
6	Insulation	Urethane Plate	0.00	0.00
		Glass Wool, Mineral Wool	0.00	0.00
		Expanded Polystyrene Foam	866,868.80	4.21
7	Plaster Board	Waterproofing Plaster Board, Fireproofing Plaster Board	5,209.45	0.05

- Operational Carbon Emission

NO.	Part	Carbon Emission	
		Gloss Amount (kg-CO_2)	By Unit Area (kg-CO_2/m²)
1	Cooling	0.00	0.00
2	Heating	190,004,000.00	911.76
3	Hot Water Heating	76,001,600.00	364.70
4	Lighting	45,600,960.00	218.82
5	Ventilation	11,400,240.00	54.71

Fig. 5. Assessment Result Screen.

5.3. Evaluation Results

Table 7 and Fig. 6 present the results of evaluating life cycle carbon emissions using the existing evaluation method and BEGAS 2.0. The amount of life cycle carbon emissions calculated with the existing evaluation method is 2,048.69 kg-CO_2/m^2, which is very similar to that derived by BEGAS 2.0, 2,023.48 kg-CO_2/m^2, with an error rate of 1.23% (see Table 7). The amount of embodied carbon emissions of a building, calculated with both the existing evaluation method and BEGAS 2.0 (except carbon emissions from operations, which had the same value), was determined to be very similar: 498.70 kg-CO_2/m^2 and 473.49 kg-CO_2/m^2, respectively, with an error rate of approximately 5%. This result is very close to the cut-off criteria of 95% for major building materials as established in this study. Given that efficiency and validity of the carbon emissions evaluation method based on major building materials, which is applied as a core technology in BEGAS 2.0, were confirmed, BEGAS 2.0 could effectively be used to support evaluation of life cycle carbon emissions in the GBI certification system.

6. Discussion

This section discusses the final result of this study, including the definition, limitations, and future development of BEGAS 2.0. Recently, the building life cycle carbon emissions assessment programs were actively developed according to the building carbon emissions reduction policies and the establishment and the reinforcement of the building LCA certification standard of the green building certification system. However, the previous building LCA program was developed to be suitable for the environments of North America and Europe, where the volume of building supplies is mainly documented in the unit of the building members of the framework. Hence, there have been many limitations and difficulties in applying it to sustainable building practices in Korea, where the volume of supply of building materials is documented in the unit of the building materials. In addition, the building materials and the carbon emission unit of the energy source(s) do not consider the environmental characteristics of the region. Many LCA guidelines recommend the usage of LCI DB and LCA program developed for a specific country, and BEGAS 2.0 was developed in this context.

BEGAS 2.0 is a new governmental program developed in this study to support Korea's GBI certification system. The governmental program requires that non-eco-friendly buildings be regulated, and thus it is important to ensure that many users can easily perform LCA of a building. In addition, the application of the carbon emission unit, taking into account the environmental characteristics of Korea, is mandatory. By constructing an efficient LCA structure into BEGAS 2.0, many users can easily perform the LCA of the building. Also, the building LCA method in the units of the building materials has been applied by reflecting the current state of the Korean building industry. In other words, the production process suggests the seven major building materials as the target of evaluation. For the processes that are directly connected with the volume of building materials, such as transportation, maintenance, and disposal, it has been designed so that the carbon emission quantity is automatically evaluated based on the volume of the major building materials input from the production process. The connecting system has been constructed between the carbon

Table 5
Architecture Scheme.

Certification Division	Preliminary Certification
Title of the Business	Seoul M District 7 Complex
Purpose	Apartment Housing
Structure	RC Structure Column Type
Gross Floor Area	208,393 m^2
Lot Area	51,184 m^2
Exclusive Use Area	95,002 m^2
Life Span	40 years

Table 6
Evaluation Methods of Life Cycle Carbon Emissions by the Existing Evaluation Method and BEGAS 2.0.

Classification		**Existing Evaluation Method**	**BEGAS 2.0**
Construction Stage	Production	Carbon emissions evaluation of 426 specific building materials based on the bill of quantities	Carbon emissions evaluation based on seven major building materials
	Transport	Carbon emissions evaluation of 426 specific building materials using established scenario	Carbon emissions evaluation of seven major building materials using established scenario
Operation Stage	Use	Carbon emissions evaluation based on the building energy efficiency rating certificate	Carbon emissions evaluation based on the building energy efficiency rating certificate
	Maintenance	Carbon emissions evaluation of 426 specific building materials using established scenario	Carbon emissions evaluation of seven major building materials using established scenario
Disposal Stage	Transport Landfill Recycling		

Table 7
Results of Evaluating Life Cycle Carbon Emissions.

Classification		Existing Method ($kg\text{-}CO_2/m^2$)	BEGAS 2.0 ($kg\text{-}CO_2/m^2$)	Error Rate (%)
Construction Stage	Production	454.42	433.46	4.61
	Transport	20.11	18.27	9.15
	Sub-total	474.53	451.73	4.80
Operation Stage	Use	1,549.99	1,549.99	0.00
	Maintenance	0.12	0.02	83.33
	Sub-total	1,550.11	1,550.01	0.01
Disposal Stage	Transport	18.46	17.39	5.80
	Landfill	5.59	4.34	22.36
	Sub-total	24.05	21.73	9.65
Total		2,048.69	2,023.48	1.23

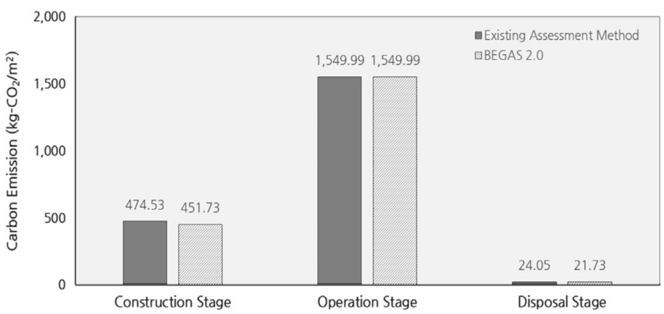


Fig. 6. Results of Evaluating Life Cycle Carbon Emissions.

footprint labeling certification system performed in Korea and the energy efficiency rating certification system. It can produce a synergy effect that prevents the systemic existence from overlapping with the evaluation range. According to the DB selection standard of LCA, the DB has been established by analyzing the carbon emission unit in an order of territorial correlation, temporal correlation, and technological correlation. This is specialized in the Korean environment and is a building life cycle carbon emissions assessment program that can support the GBI certification system (G-SEED, the current Korea green building certification system, is also supportable.).

However, additional research that analyzes the standard carbon emission levels in accordance with the purpose and the division of the area of the buildings in Korea is required in order to improve the quality of BEGAS 2.0. There is also a need to compensate for the fact that it only considers the carbon emission level without evaluating various environmental effect indexes compared to the other building LCA programs. Therefore, future studies need to develop a building LCA program that can evaluate the comprehensive environmental performance by computing various environmental effect indexes. On the other hand, development and maintenance of LCI DB need to be continuously accomplished by the government for the promotion of building LCA research targeting various building materials. Additionally, it needs to consistently accompany the institutional practice along with the policy studies reflecting building LCA with various certification systems.

7. Conclusions

This study aimed to develop BEGAS 2.0 to support the GBI certification system of Korea, with the following conclusions:

1. BEGAS 2.0 was developed by establishing a method and scenario used to evaluate the life cycle carbon emissions of a building, taking into consideration the guidelines of the GBI certification system and the state of the construction industry in Korea.
2. An efficient carbon emissions evaluation method based on seven major building materials was suggested to explore the construction stage as well as an operations evaluation method that is divided into a carbon emissions input method and an energy consumption input method according to the available information at the time of evaluation.
3. In addition, a database of the life cycle carbon emission unit of a building reflecting environmental characteristics of Korean regions as well as LCA guidelines was determined.
4. The result of performing a case study on one apartment complex indicated that the amount of life cycle carbon emissions evaluated by BEGAS 2.0 and by the existing life cycle carbon emissions evaluation method were very similar: 2023.48 $kg\text{-}CO_2/m^2$ and 2048.69 $kg\text{-}CO_2/m^2$, respectively.
5. The fact that the embodied carbon emissions of a building calculated by BEGAS 2.0 and existing evaluation methods were also similar, 473.49 $kg\text{-}CO_2/m^2$ and 498.70 $kg\text{-}CO_2/m^2$, respectively, with an error rate of approximately 5%, confirmed the validity of the carbon emissions evaluation method based on seven major building materials. Therefore, it is presumed that BEGAS 2.0, as developed in this study, will effectively support evaluation of life cycle carbon emissions within the GBI certification system.

Additional research that analyzes the standard carbon emission levels in accordance with the purpose and the division of the area of the buildings in Korea is required in order to improve the quality of BEGAS 2.0, but the aims of the study have been largely achieved. Further work in this area will hopefully strengthen the framework of the research provided in this paper.

Acknowledgments

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