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Green Template for Life Cycle Assessment of Buildings Based on Building Information Modeling: Focus on Embodied Environmental Impact

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Abstract: The increased popularity of building information modeling (BIM) for application in the construction of eco-friendly green buildings has given rise to techniques for evaluating green buildings constructed using BIM features. Existing BIM-based green building evaluation techniques mostly rely on externally provided evaluation tools, which pose problems associated with interoperability, including a lack of data compatibility and the amount of time required for format conversion. To overcome these problems, this study sets out to develop a template (the "green template") for evaluating the embodied environmental impact of using a BIM design tool as part of BIM-based building life-cycle assessment (LCA) technology development. Firstly, the BIM level of detail (LOD) was determined to evaluate the embodied environmental impact, and constructed a database of the impact factors of the embodied environmental impact of the major building materials, thereby adopting an LCA-based approach. The libraries of major building elements were developed by using the established databases and compiled evaluation table of the embodied environmental impact of the building materials. Finally, the green template was developed as an embodied environmental impact evaluation tool and a case study was performed to test its applicability. The results of the green template-based embodied environmental impact evaluation of a test building were validated against those of its actual quantity takeoff (2D takeoff), and its reliability was confirmed by an effective error rate of ⩽5%. This study aims to develop a system for assessing the impact of the substances discharged from concrete production process on six environmental impact categories, *i.e.*, global warming (GWP), acidification (AP), eutrophication (EP), abiotic depletion (ADP), ozone depletion (ODP), and photochemical oxidant creation (POCP), using the life a cycle assessment (LCA) method. To achieve this, we proposed an LCA method specifically applicable to concrete and tailored to the Korean concrete industry by adapting the ISO standards to suit the Korean situations.

Keywords: green template; building information modeling (BIM); life cycle assessment; embodied environmental impact; building

1. Introduction

Since the mid-2000s, building information modeling (BIM) has increasingly been used for architectural design because it offers not only 3D building components for architectural drawing but also the detailed elements and attribute information necessary for quantity takeoff, cost reduction, and process management [1,2]. Along with the growing popularity of BIM, various technologies have been developed to support work processes using the salient features of BIM across the construction and building industry (e.g., architectural design, construction, and interior design), such that tools developed using these technologies are now used in related work processes. The number of BIM-based green building design cases is on the increase [3]. BIM-based energy simulation tools are used for predicting energy savings at the design phase of low-energy buildings [4–6]. In particular, Cofaigh *et al.* configured the shape and orientation of a low-energy building by using BIM, achieving a 40% reduction in the environmental load and financial burden relative to a conventional building shape and orientation [7]. Wang and Zmeureanu used a BIM-based energy analysis simulation tool to analyze the environmental impacts of different building materials and established parameters that were optimized for environmental impact evaluation [8].

BIM supports the individual input of attribute data for the major and auxiliary materials required for environmental impact evaluation. Using this salient feature of BIM, an increasing number of BIM-based studies are being undertaken to develop technologies for evaluating the embodied environmental impact of buildings, embracing the entire process of building materials production, construction, and demolition. IMPACT, developed by the UK Building Research Establishment (BRE) is representative of these technologies. IMPACT was designed to evaluate a range of environmental impacts by extracting BIM-implemented building structures in the standard Industry Foundation Classes(IFC) and gbXML BIM data formats. However, currently available embodied environmental impact evaluation tools, including IMPACT, lack the inter-data compatibility required during work sessions despite the use of the IFC and gbXML formats, while some of the standard data formats are entirely unsupported, which lowers the reliability of the results of an embodied environmental impact evaluation and increases the processing time, given the need for format conversion to ensure interoperability [9].

Against this background, this study was undertaken with the aim of developing a green template capable of evaluating embodied environmental impacts through the use of BIM tools, as part of life-cycle assessment (LCA) technology R&D.

2. Literature Review

2.1. BIM-Based Evaluation of Environmental Performance of a Building

BIM enables the highly efficient management of building material inventory by inputting a range of attribute data for each classified unit of the materials required for the environmental performance evaluation of a building. Simulations of building energy analysis were performed after implementing software interoperability, using international industrial standard formats such as IFC and gbXML [10].

The Korea Land and Housing Corporation and Public Procurement launched a design competition based on the outcomes of BIM-based building energy simulation [11]. The Korea Land and Housing Corporation called a design competition and evaluated eco-friendly design, insolation duration analysis, and energy analysis using IES/VE which is a building energy evaluation program and calculated an optimal layout from a range of building block layout plans. Additionally, using the Revit table feature, a quantity takeoff for each building block was derived, which was used to determine the CO_2 emission and energy efficiency grades [12,13].

The Norwegian government is promoting the application of BIM in the construction sector by providing a BIM manual. Architectural designers are selected via a two-step evaluation of their architectural designs. The first step involves a basic BIM model examination including a building concept and structural overview. Then, Step 2 requires the submission of CO_2 emission calculations along with a detailed BIM model [14]. BuildingSMART International implemented building modeling using ArchiCAD and performed building block layout and window planning using the results of Ecotect energy simulations such as insolation analysis based on the annual mean insolation and a daylight and shadow pattern analysis [15]. Project Chicago is a representative academia-industry collaboration initiated by the Autodesk Green Building Research Team in 2007 to deal with building modeling in the design process, an energy performance evaluation, and sustainable test methods, whereby a collaboration user interface was developed for building energy performance evaluation by introducing a multi-touch screen and using an instant feedback scenario [16]. Sutter Medical Center acquired LEED Silver for healthcare rating with a BIM energy simulation for the BIM-based reconstruction project commissioned by the State Government of California. The design team was granted financial support from the State Government upon the approval of the environmental impact report (EIR) on the building operational stage [17].

A review of the BIM-based building environmental performance evaluation methods revealed that most focus on energy simulation at the operational stage of a building with specific software tools.

2.2. Use of Template in BIM

A BIM template is an input form with a predetermined structure and is intended for repeated use, being uniformly configured to obtain output values suitable for a specific evaluation scope and purpose, with the ultimate goal of acquiring the necessary BIM modeling information [18]. The user can acquire the desired outcomes by entering the data requested by the template. BIM templates are directly applied to work processes, and library-related data standardization helps designers to derive standardized information and outcomes in a consistent work environment. BIM templates can be classified according to the purpose of using BIM and their formats can vary greatly according to the purpose of the development.

The spatial BIM template developed by the U.S. General Services Administration (GSA) is utilized at the planning and design stage to check whether the design elements satisfy the space requirements. It uses IFC parameters to enhance the system coordination [19]. The Revit Start Kit developed by Japanese Autodesk also supports legal administrative affairs at an early stage of the design process by providing guidelines for checking the basic design elements against the graphic standards and construction-related laws and regulations, in addition to the template. The Korea Architecture BIM (KABIM) developed by a Korean architectural design company helps build up a coordination system within a company using Revit Architecture, which is a BIM program for small- and medium-size architectural companies. The Green BIM Template (GBT), also developed in Korea, helps satisfy the requirements of the Green Building Certification criteria by offering features for environmental analysis and simulation. Specifically, it offers a data input/output environment for the template-based checking of a certificate program [20].

3. Research Methods

This chapter describes the process of generating the library and overview table for the main building elements for the evaluation of the embodied environmental impact of buildings within the scope of the BIM-based tools. Its application is limited to Autodesk Revit, the most frequently used BIM authoring tool in Korea. The major building materials for the embodied environmental impact evaluation include ready-mixed concrete, steel, glass, concrete block, insulation material, and gypsum board, based on the analysis results of a previous study [21].

3.1. Generation of Major Building Element Library

3.1.1. Determination of LOD of BIM for the Embodied Environmental Impact Evaluation

Figure 1 depicts the results of analyzing major building materials for which the environmental impacts can be derived according to the level of detail (LOD). The level of BIM was defined by the American Institute of Architects (AIA) to establish evaluation standards for the embodied environmental impact evaluation [22].

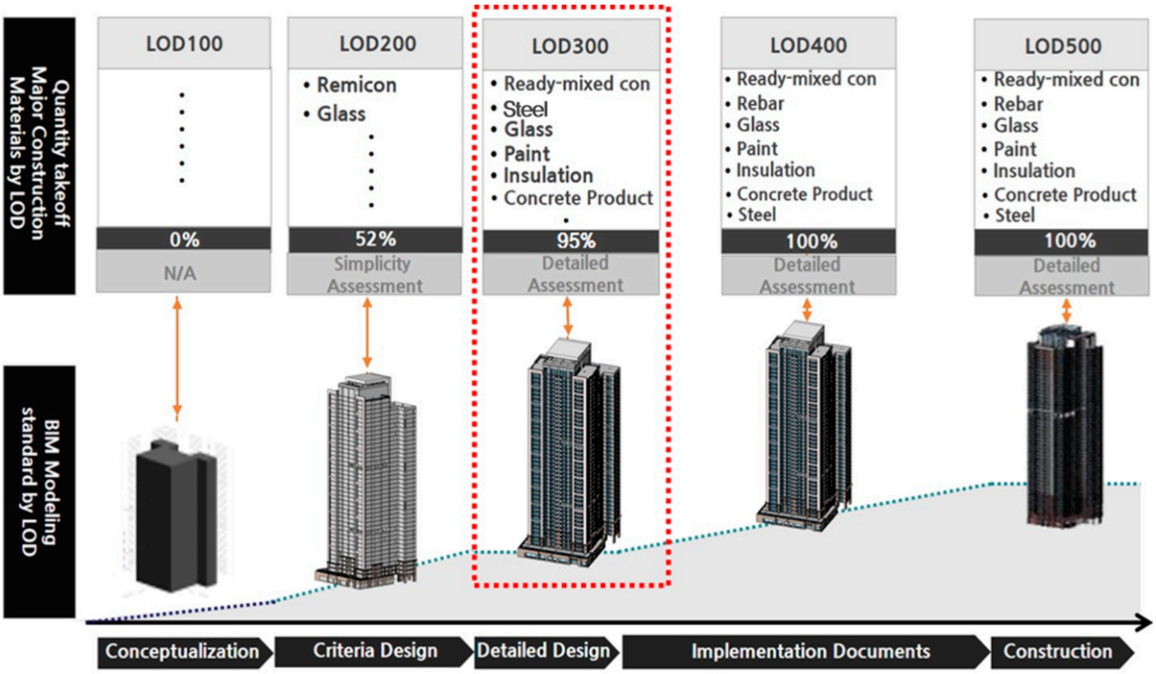

Figure 1. Material selection for library using AIA BIM guideline.

It has been shown therein that, of the main building materials for the embodied environmental impact evaluation (ready-mixed concrete, steel, glass, concrete block, insulation material, and gypsum board), the environmental impacts of five of those materials (except for steel) could be calculated at LOD 300 [23]. Therefore, this study set LOD 300 as the reference LOD for the evaluation of the embodied environmental impact of a building.

3.1.2. Generation of a Database for the Embodied Environmental Impact Factor of Major Building Materials

Table 1 outlines the impact factors of major building materials by impact category (global warming potential (GWP), abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), ozone depletion potential (ODP), and photochemical ozone creation potential (POCP)) as derived from analyses of the Korea life-cycle inventory (LCI) databases, compiled by the Ministry of Knowledge Economy and the Ministry of Environment and the national database for environmental assessment of building materials, compiled by the Ministry of Land, Infrastructure and Transport [24–26].

Additionally, the scenarios were applied for all stages of the life-cycles of the six major building materials and established by a calculation process for determining the environmental impact factor as a basis for evaluating the embodied environmental impact. This process involves the input of LCI databases, transportation information, and the fuel efficiency of the major building materials and the output of the embodied environmental impact factor databases of the major building materials according to preconfigured scenarios.

3.1.3. Determination of Conversion Factor for Impact Factor

Since the quantity takeoff information for building materials provided by the Revit BIM authoring tool is obtained in units of volume or surface area, a unit conversion factor should be set to enable the evaluation of their embodied environmental impact. In this study, the unit conversion factor was calculated by analyzing the material-specific size and density information, based on the Korean Industrial Standard (KS) certification specifications (Table 1).

Table 1. Impact factors of major building materials by impact category.

Major Materials	Units	Environmental Impact Database						Unit Conversion Factor		
		GWP (kg-CO_{2eq})	ADP (kg)	AP (kg-SO_{2eq})	EP (kg-$PO_4{}^{3-}{}_{eq}$)	ODP (kg-CFC-11_{eq})	POCP (kg-$Ethylene_{eq}$)	Revit	6EI	Factor
Concrete	m^2	419	1.56	0.6940	0.0818	0.0000461	1.13	m^3	m^3	1
Rebar	ton	352	2.79	2.3100	0.3480	0.0000104	0.3410	m^3	ton	7.85
Steel	ton	405	1.12	0.6450	0.1170	0.0000226	0.2930	m^3	ton	7.85
Glass	ton	788	6.97	3.6700	0.0523	0.0003040	0.8950	m^3	ton	3.45
Concrete block	EA	246	0.292	0.3140	0.0454	0.0000094	0.0262	m^2	1000EA	75
Insulation	ton	2060	174.000	40.50	2.75	0.0000289	6.390	m^3	ton	0.03
Gypsum board	ton	0.192	0.016	0.0313	0.00528	0.000000567	0.00761	m^3	ton	2.3

GWP: Global warming potential; POCP: Photochemical ozone creation potential; EP: Eutrophication potential; ODP: Ozone depletion potential; AP: Acidification potential; ADP: Abiotic depletion potential.

3.1.4. Building Materials Classification System for Library Construction

A library of the major building materials was established in line with the construction information standard classification system that is internationally applied to construction, civil engineering, and plant classification [27].

Table 2 presents the classification system used in this study to systemize the building element library composition. The building materials were first divided into basic and secondary structural materials at Level 1. The Level 1 elements were then broken down into Level 2 elements (columns, beams, walls, slabs, and wall framings) depending on the component parts. Each Level 2 element was further broken down into Level 3 elements (concrete, steel, steel reinforced concrete, load-bearing walls, non-load-bearing walls, partitions, floors, and windows). By subdividing the Level 3 elements by individual input materials, a library of 34 building elements was constructed for standardized use. For example, by classifying walls as a Level 2 elements belonging to the basic structure and breaking these walls down into load-bearing and non-load-bearing walls at Level 3, a standard classification of building materials by element was implemented.

Table 2. Building materials classification system.

Building Materials Classification System			Library Items
Level 1	Level 2	Level 3	Individual materials
Basic structure	Column	Concrete	Rectangular RC column Square RC column Round RC for column
		Steel	H-shaped steel for column Square steel for column Round steel for column
		SRC	Square SRC column Rectangular SRC column Round SRC column
	Beam	Concrete	H-shaped steel beam Square steel beam Round steel beam I-shaped steel beam L-shaped steel beam (equal legs) L-shaped steel beam (uneq. legs) L-shaped steel beam (thickness) C-shaped steel beam T-shaped steel beam
		SRC	Rectangular SRC beam
	Wall	Load-bearing wall	Outer wall RC Inner wall RC
		Non-load-bearing wall	Outer wall concrete block Inner wall concrete block Outer wall clay brick Inner wall clay brick Outer wall concrete block Inner wall concrete block Outer wall RC + concrete block Outer wall RC + clay brick Insulation
	Slab	Floor	Slab
Secondary structure	Wall framing	Partition	Secondary lightweight partition
		Window	Single-hung window Double-hung window

3.1.5. Development of a Parametric Building Element Library

Parametric modeling is a BIM modeling technique for defining the inter-object relationships and operating data according to those relationships [28]. Accordingly, if the size of a structure changes, all of the information associated with the structure through relationship definition changes automatically [29]. This enables an instant output check for each aspect of the embodied environmental impact evaluation data whenever a design parameter changes, regardless of the complexity of the drawings.

For the construction of the building element library, the Revit content library and component library writing methods were used. A component library can be configured as a library file (*rfa), which can be reused in a different project and shared with other designers. A system library exists only in a template file as a library that is graphically associated with the predefined parametric set. Consequently, we applied the system library writing method to the wall and slab elements.

The component library writing method to the beam, column, and secondary wall-framing elements. Additionally, to match the information necessary for LCA with the library content, we utilized a shared parameter input method that is identical to that for the BIM data input method. Figure 2 illustrates an example of a parametric building element library developed as part of this study.

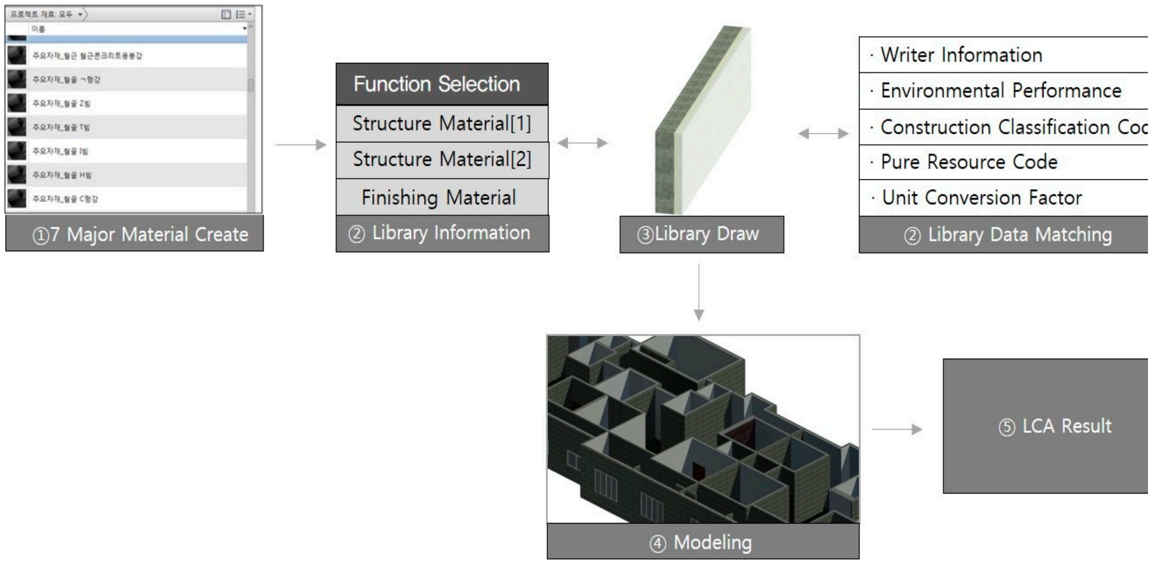

Figure 2. Parametric building element library Library production process(example : wall).

3.2. Embodied Environmental Impact Evaluation Results Overview Table

Figure 3 shows the overview tables for the evaluated environmental impact of the major building materials modeled by the user on the basis of the major building element library. The overview table was integrated into the green template so that the embodied environmental impact evaluation results can be extracted in Revit without being linked to other programs used for the structure. This enables the user to directly check the evaluated values of the environmental impacts by the modeled building structure using the major building element library.

To sum up, the major building library evaluation result overview table provided in the green template presents the evaluated embodied environmental impacts of building elements (wall, floor, beam, column, and window). These two overview tables enable the user to directly check the embodied environmental impact of any given building element depending on its material composition, so that building contractors can use these two overview tables as the basis for efficient decision-making when selecting eco-friendly building materials [30]. First and foremost, along with the conventional building LCA technology, the evaluation result overview table of all the major building elements of a building structure can be efficiently used for quantity takeoff and material selection for building elements at the design stage, and it offers the great advantage of user convenience in terms of access.

Column Environmetal Impact Assessment Result

Library Name	Type	Volume	Structure Material	U C F	GWP	GWP R	ADP	ADP R	AP	AP R	EP	EP R	ODP	ODP R	POCP	POCP R
Major element Lbrary Column RC	600*60	1.44M3	Major Mateial_Remicon_21MPa	1	410	590.4	1.87	2.69	0.68	0.98	0.08	0.12	4.7E-05	6.8E-05	1.02	1.47
Major element Lbrary Column RC	600*60	1.44M3	Major Mateial_Remicon_21MPa	1	410	590.4	1.87	2.69	0.68	0.98	0.08	0.12	4.7E-05	6.8E-05	1.02	1.47
Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
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Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
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Major element Lbrary Column RC	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49	0.08	0.06	4.7E-05	3.4E-05	1.02	0.73
TOTAL						7084.8		32.31		11.75		1.38		0.00081		17.63

(**a**)

Green Template_Building Environmental Impact Assessment

Building LCA Result

Library Name	Type	Volume	Structure Material	U C F	GWP	GWP R	ADP	ADP R	AP	AP R
Major element Lbrary Column RC	600*60	1.44M3	Major Mateial_Remicon_21MPa	1	410	590.4	1.87	2.69	0.68	0.98
Major element Lbrary Beam Rebar H	150*105	1.44M3	Major Mateial_Remicon_21MPa	1	410	590.4	1.87	2.69	0.68	0.98
Major element Lbrary Window	1000*1000	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Window	1000*1000	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Window	1000*1000	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Column Rebar	600*60	0.72M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
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Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
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Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
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Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
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Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
Major element Lbrary Wall RC	1500*1500*200	2.5M3	Major Mateial_Remicon_21MPa	1	410	295.2	1.87	1.35	0.68	0.49
TOTAL						943.54		5.77		1.77

(**b**)

Figure 3. Overview tables of the LCA by building element. (**a**) Overview table of the building element library evaluation results; (**b**) Overview table of the embodied environmental impact evaluation results.

On the other hand, the embodied environmental impact evaluation result overview table was configured to allow the user to check the embodied environmental impacts of the individual elements of the building [31].

4. Development of the Green Template

Figure 4 illustrates the composition of the green template developed in this study with a standard input form predefined in BIM software to enable the extraction of results suitable for the evaluation scope and purpose. In other words, the green template provides databases for the embodied environmental impact evaluation of a building at each modeling level, using Revit as the BIM authoring software. The designer can perform preliminary modeling for a building design using the green template guide, as shown in Figure 4. Furthermore, the green template guide contains instructions on how to construct a library and environmental information databases for major building elements. Using these features, the designer can develop a required building element library in addition to the existing libraries.

A designer can proceed to modeling using the building element library, thereby checking the evaluated embodied environmental impacts by impact category and LOD stage embedded in the green template. The green template-based modeling of a building structure should be implemented at the LOD 300 or a higher level, according to the BIM classification. The detail level here refers to the maturity of the information regarding the designations of the elements and materials used for the structure (ready-mixed concrete, glass, concrete block, insulation material, and gypsum board) as well as their respective volumes.

Furthermore, data on major building materials provided in the building element library of the green template can be modified or reconstructed using the shared parameter input method used in Revit Architecture.

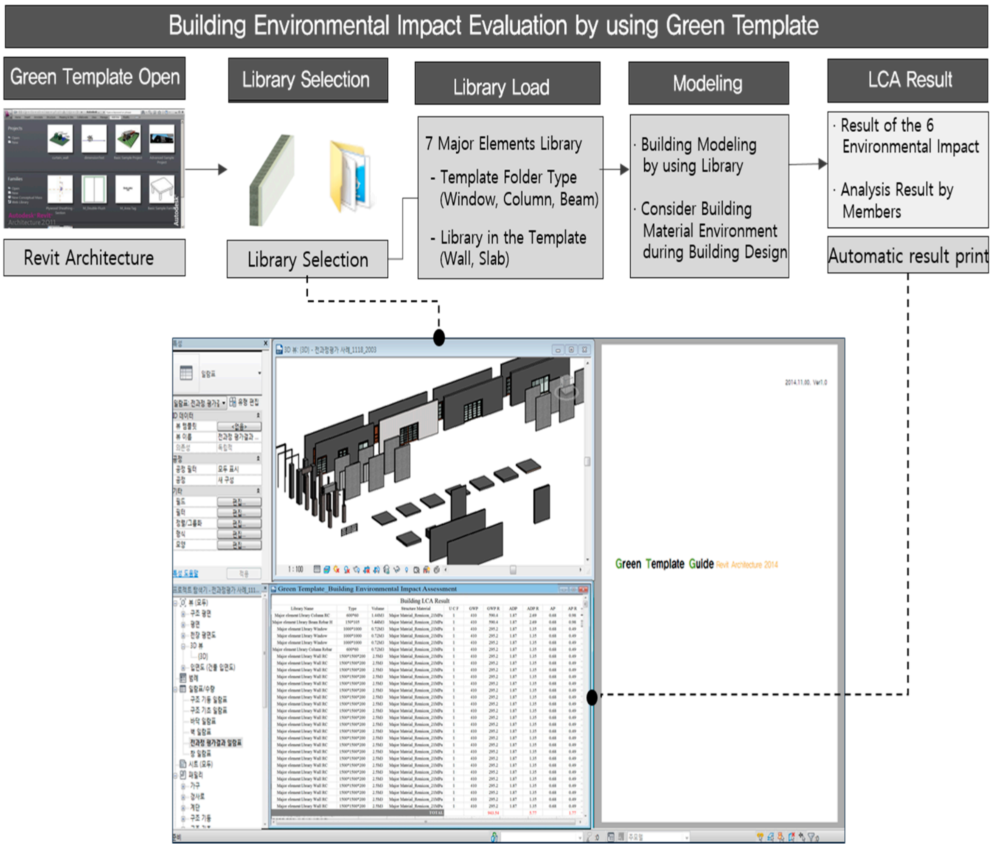

Figure 4. Modeling with the green template using the major element library and result output.

5. Case Study

A case study analysis was performed to test the applicability of the green template developed in this study. Table 3 outlines the specifications of the test building (a standard Korean apartment building) that was used for the case study. We performed the modeling of this building using the green template at the LOD 300 level using the Revit Architecture 2014 BIM modeling tool.

Table 3. Specifications of test building used for case analysis.

	**Project Name**	**Reconstruction of Busan Jugong Apartment Building**			
	Structure	RC	Total floor area	Above ground	4581.94 m^2
				Under ground	732.06 m^2
	Scale	18 floors			
	Expected service life	40 years		Total	5313.90 m^2
Green template –based modeling	Heating method	Local heating method	Floor area ratio		282.95%

5.1. Evaluation Method

A case study analysis was performed to compare the values of the embodied environmental impacts evaluated using the green template with those calculated from the quantity takeoff of the major building materials used for the test building. First, we extracted the quantity takeoff for the building elements of the test building using the major element library embedded in the green template, and then performed an evaluation of the embodied environmental impacts of the building materials. The embodied environmental impact evaluation was performed for all of the major building materials except steel which is not considered at Revit architecture 2014 (ready-mixed concrete, glass, concrete block, insulation material, and gypsum board) for each of the six environmental impact categories.

5.2. Evaluation Results

Table 4 compares the actual quantity takeoff (2D takeoff) of the building elements and the green template-based embodied environmental impact evaluation results.

The values yielded by 2D takeoff and the green template and the error rates were 3055 m^3 and 2946 m^3, respectively, for ready-mixed concrete with an error of 3.49%, and 23.99 m^3 and 23.02 m^3 (3.98%) for glass. For concrete products, both the green template and 2D takeoff yielded 1832 m^2 (n = 139961). The values obtained after changing the number of concrete blocks to 130,432, using the unit conversion factor, revealed an error rate of 5.1%. A relatively higher error rate was yielded by the insulation material (52.1901 m^3 *vs.* 48.9390 m^3; 6.17%), presumably because premiums were not considered in the BIM. The error rate for gypsum board between the 2D takeoff and green template was 4.66% (534.41 m^3 *vs.* 509.1324 m^3).

A comparison was made between the 2D takeoff and green template results for the embodied environmental impact evaluation for the category of environmental impact, as shown in Figure 5, to analyze the contribution of major building materials to each of the environmental impact categories. The comparative analysis yielded an average error rate of about 5%, presumably ascribable to the quantity takeoff for steel that was excluded from the LOD 300 modeling with the green template.

Table 4. 2D takeoff and the embodied environmental impacts evaluated using green template.

Division	Material Name	Material Quantity	Unit	GWP	ADP	AP	EP	ODP	POCP
				(kg-CO_{2eq}/Unit)	(kg/Unit)	(kg-SO_{2eq}/Unit)	(kg-$PO_4{}^{3-}{}_{eq}$/Unit)	(kg-CFC-11_{eq}/Unit)	(kg-$Ethylene_{eq}$/Unit)
2D Takeoff	Ready-mixed concrete	3055.733	m^3	904	4.12	1.51	0.176	0.000103	2.25
	Rebar	389.04	Ton	98.80	0.78	0.65	0.098	0.000003	0.09570
	Glass	23.996	m^3	47.10	0.42	0.22	0.003	0.000018	0.05350
	Concrete block	139,961.52	m^3	24.80	0.03	0.03	0.005	0.000001	0.00265
	Insulation material	52.19051	m^3	2.33	0.20	0.05	0.003	0.0000000326	0.00722
	Gypsum board	534.41	m^3	0.17	0.01	0.03	0.005	0.000001	0.00675
Green Template	Ready-mixed concrete	2946.9489	m^3	872	5.15	1.46	0.170	0.000099	2.17
	Glass	23.026562	m^3	45.20	0.40	0.21	0.003	0.000017	0.05130
	Concrete block	130,542.11	m^2	24.00	0.03	0.03	0.004	0.000001	0.00255
	Insulation material	48.939041	m^3	2.18	0.18	0.04	0.003	0.000000	0.00677
	Gypsum board	509.13241	m^3	0.16	0.01	0.03	0.004	0.000000	0.00643

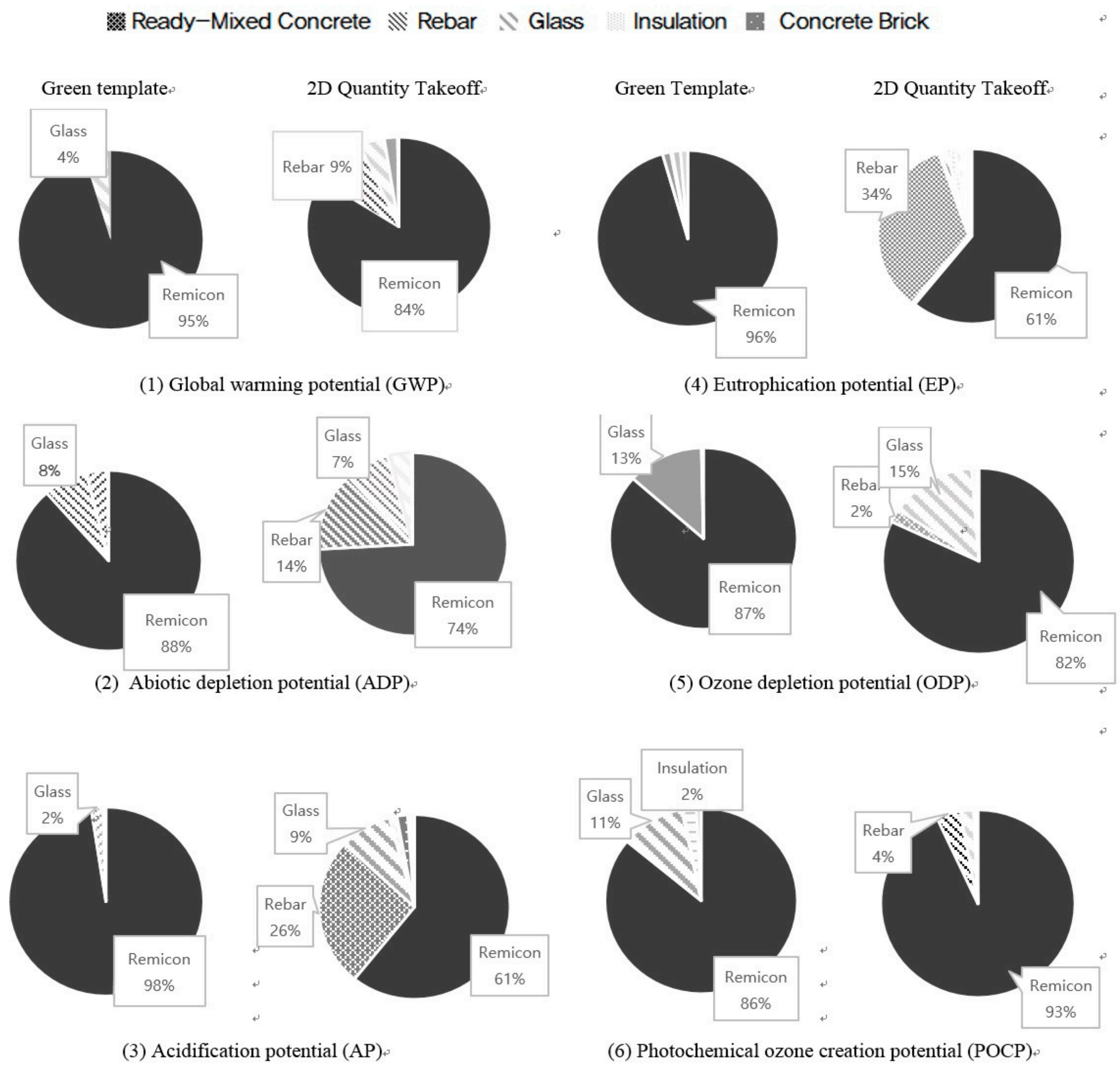

Figure 5. Comparison between green template and 2D takeoff for environmental impact category.

6. Discussion

The green template was developed to support users in the efficient production of an embodied environmental impact evaluation of a building based on BIM. In particular, six major building materials were proposed as evaluation targets, and six environmental impact categories, including greenhouse gases, were considered to enable consideration at a professional level. User convenience and the easy production of an embodied environmental impact evaluation were ensured by the building element library and evaluation result overview table.

This study has two limitations. First, the lack of steel in the Revit Architecture environment may lower the reliability of the evaluation results, especially because steel accounts for over 20% of the overall embodied environmental impact of a building. Therefore, to improve the performance of the green template, steel and the premium rates for major building materials should be reflected in each LOD stage of the building modeling. Second, the system developed in this study is based on a standard Korean apartment building, without reflecting the current trend for using green technologies and materials to reduce the environmental impact of a building. Therefore, to enhance the applicability and reliability of the green template, future studies will have to include steel as a major building material, as well as premium rates for the building materials and also examine the comprehensive environmental impacts of buildings constructed using green technologies.

7. Conclusions

This study resulted in the development of a green template, for use with a BIM authoring tool to evaluate the embodied environmental impacts, as part of BIM-based building LCA technology R&D project. The following outlines the results of this study.

1. The green template developed in this study for embodied environmental impact evaluation using a BIM authoring tool consists of a major building material library, an evaluation result overview table, and the green template guideline.
2. The impact factors of the six environmental impact categories, unit conversion factors, and the green template major building materials library reflecting them were established.
3. An embodied environmental impact evaluation result overview table was constructed to allow a user to check the embodied environmental impacts in real time while designing a building using the building element library of the green template.
4. The green template's applicability was verified by the small average error rate ($\leqslant$5%) between the results of the green template-based embodied environmental impact evaluation and the 2D takeoff.

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