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EMBODIED ENVIRONMENTAL IMPACTS OF HIGH-RISE RESIDENTIAL BUILDING IN SOUTH KOREA

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Abstract - This study aims to evaluate the embodied environmental impacts of high-rise residential building in South Korea, with focus on main building materials, as part of analytic research on a building's life cycle environmental impact. To this end, a high-rise residential building constructed in Bus an metro city, South Korea, was selected as an evaluation target, and the quantity of five main building materials (i.e. ready-mixed concrete, rebar, concrete brick, cement, aluminum products) were taken off. The embodied environmental impact factors of main building materials were established using a life cycle impact assessment model. Then the embodied environmental impact of high-rise residential building was evaluated and analyzed the evaluation results.

Index Terms - Embodied Environmental Impact, High-rise Residential Building, Life Cycle Assessment, Main Building Material

I. INTRODUCTION

Drastic growth in population and rapid technology-focused industrial development that started from the 20th century caused an international environmental issue such as global warming, acidification, and ozone depletion [1]. As a result, all industries are trying in many ways to prevent environment [2]. Recent years have seen the building industry working towards reducing potential environmental impacts of buildings throughout their life cycles in line with the ideology of sustainable development [3], [4]. Especially, the building industry has put much work into reducing a building's environmental impact during its life cycle, focusing on its operational environmental impact, given its higher proportion attributable to the extremely long service life and huge energy demand of buildings compared with general consumer products [5], [6].

With the advent of new technologies geared towards radical reduction of operational energy along with the commercialization of energy efficiency building with operational energy demand close to zero, there is a need for research focus shift from operational to embodied environmental impact in response to the increasing demand for evaluating and reducing a building's embodied environmental impact of [7], [8].Embodied environmental impact equals the sum of all environmental impacts associated with building materials [9]. To meet this demand of time, developed countries such as the US, the UK, Germany, and South Korea are evaluating a building's embodied environmental impact associated with building materials according to the criteria stipulated in their respective Building Codes and Green Building Certification Systems [10]–[13]. Alongside this, some dedicated researchers have presented new approaches to effective evaluation of a building's embodied environmental impacts and performed various case studies in an attempt to reduce them [14]–[18]. The results of these studies are used as basic data for quantitative analysis of a building's life cycle environmental impacts and for research and policy geared towards reducing them efficiently.

This study aims to evaluate the embodied environmental impacts of high-rise residential building in South Korea, with focus on main building materials, as part of analytic research on a building's life cycle environmental impact.

II. MATERIAL

In this study, the 60 stories 208 m high-rise residential building with 40,636.36m^2 above ground floors gross area that complies with the high-rise building designing guideline and is located in Bus an metro city, South Korea, was selected as an evaluation target. This building is composed as 4 floor plan types which are 118 m^2, 121 m^2, 165.32 m^2 and 178 m^2 with 280 households in total, and has 2.9 m story height. Fig. 1 and Fig. 2 show the floor plan and elevation of the high-rise residential building selected in this study.

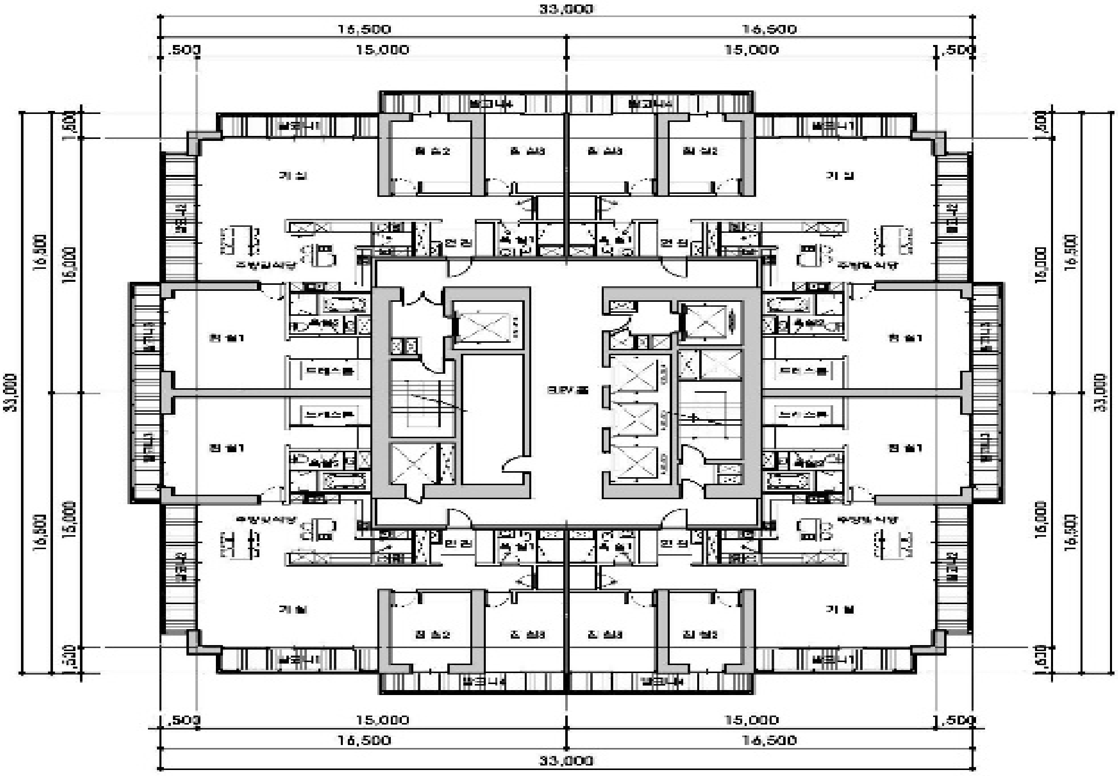


Fig.1. Floor of the high-rise residential building.

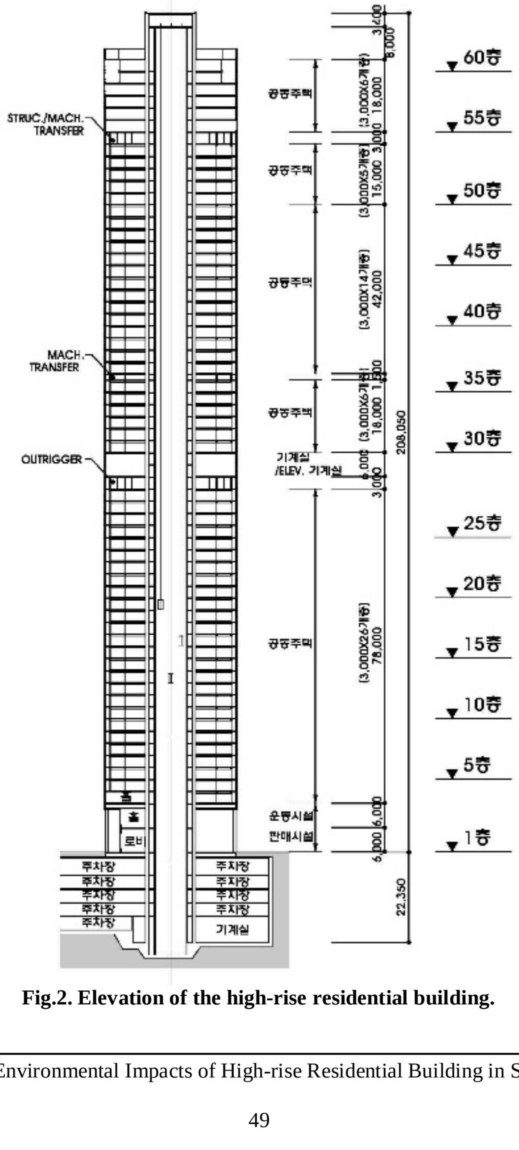


Fig.2. Elevation of the high-rise residential building.

III. METHODOLOGY

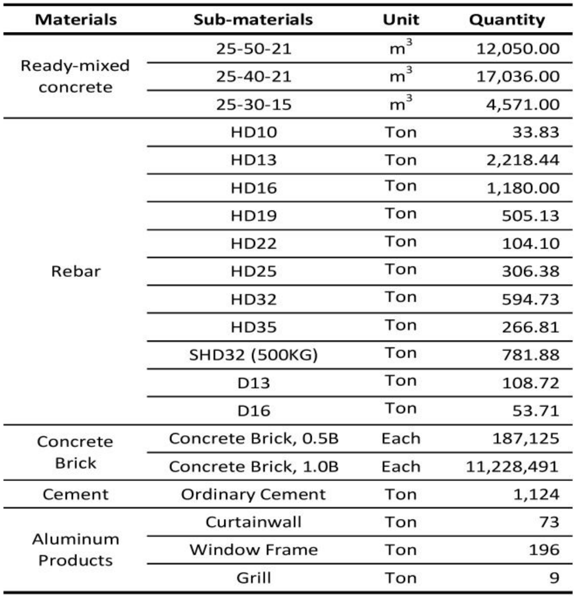
This chapter describes the process of embodied environmental impact evaluation of high-rise residential building.The embodied environmental impacts can be evaluated by multiplying the quantity of material and their environmental impact factor [19].This study, therefore, takes off the quantity of main building materials of high-rise residential building selected in this study and then evaluates three kinds of embodied environmental impacts, i.e. six environmental impact categories, four safety guard and environmental damage index, and environmental cost, based on the life cycle impact assessment (LCIA) methodology.

A. Quantity of Main Building Materials

This study was selected five kinds of building materials,i.e. ready-mixed concrete, rebar, concrete brick, cement, aluminum products, as main building materials, and then taken off them.

When the main building material quantities were estimated per group, the main building materials were selected, and then the itemized unit costs provided in the Standard Estimating System of the construction work [20] were applied to the selected building materials so that other sub-materials were all estimated. The number of the estimated materials is 20. Especially, the building incorporated a wall column structure with a core wall of reinforced concrete, and the strength of the concrete varied according to the zoning per floor. The strength of the core wall was 50 MPa from the first to 45th floors and 30 MPa from the 46th to the 60th floors. The strength of the structures was 40 MPa from the first to the 45th floors and 30 MPa from the 46th to the 60th floors.Table 1 represents the quantity of main building materials of the high-rise residential building selected in this study.

Table 1. Quantity of main building materials ofthe high-rise residential building



Materials	Sub-materials	Unit	Quantity
Ready-mixed concrete	25-50-21	m^3	12,050.00
	25-40-21	m^3	17,036.00
	25-30-15	m^3	4,571.00
Rebar	HD10	Ton	33.83
	HD13	Ton	2,218.44
	HD16	Ton	1,180.00
	HD19	Ton	505.13
	HD22	Ton	104.10
	HD25	Ton	306.38
	HD32	Ton	594.73
	HD35	Ton	266.81
	SHD32 (500KG)	Ton	781.88
	D13	Ton	108.72
	D16	Ton	53.71
Concrete Brick	Concrete Brick, 0.5B	Each	187,125
	Concrete Brick, 1.0B	Each	11,228,491
Cement	Ordinary Cement	Ton	1,124
Aluminum Products	Curtainwall	Ton	73
	Window Frame	Ton	196
	Grill	Ton	9

B. Environmental Impact Category

Environmental impact categories are the list of the global environmental changes caused by human behavior or technology. Global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), ozone layer depletion potential (ODP), photochemical oxidation potential (POCP), and abiotic depletion potential (ADP) are representative environmental impact categories, which can be assessed quantitatively through various LCIA methodologies [21].

GWP is the abnormal weather in which the average temperature on the surface of the earth rises, and causes the environmental problems of changing ecosystems in soil or water or rising sea levels. AP is an environmental problem in which the ocean and soil are acidified mainly by the circulation of the air pollutants, and threatens the survival of living organisms such as fishes, plants, and animals due to the elution of heavy metals. EP causes harmful impacts on the marine environment, such as the red tide, due to the amount of nutrients abnormally increased by the introduction of chemical fertilizers or sewage. ODP is a phenomenon in which the ozone in the ozone layer, which is located in the stratosphere 15-30km above from the ground, is destroyed and its density decreases. It causes diseases such as skin cancer due to the increase in ultraviolet rays. POCP is a reaction between the pollutants in the air and sunlight in which chemical compounds such as ozone (O_3) are created, and causes ecosystem losses such as damage to human health and crop growth inhibition. ADP acts as the cause of ecosystem balance destruction and environmental pollution due to excessive collection and consumption of resources [22].

Table 2. Environmental impact factor of main building materials

Materials	FU	GWP	AP	EP
RMC$^{1)}$	m^3	4.14×10^{2}	6.79×10^{-1}	8.08×10^{-2}
Rebar$^{1)}$	kg	4.38×10^{-1}	1.40×10^{-3}	1.79×10^{-4}
Concrete Brick$^{2)}$	Each	2.46×10^{-1}	3.12×10^{-4}	4.52×10^{-5}
Cement$^{1)}$	kg	1.06×10^{0}	1.30×10^{-3}	1.86×10^{-4}
Aluminum$^{3)}$	kg	1.13×10^{1}	5.89×10^{-2}	2.76×10^{-3}

Note) RMC: Ready-mixed Concrete; FU: Functional Unit; GWP's Unit: kg-CO_{2eq}/FU; AP's Unit: kg-SO_{2eq}/FU; EP's Unit: kg-$PO_4^{3-}{}_{eq}$/FU; 1) Korean LCI DB; 2) National Database on Environmental Information of Building Materials; 3) Oekobaudat.

In this study, the environmental impact factor of the functional unit of main building materials was established in compliance with the life cycle inventory database (LCI DB) selection criteria specified in ISO 14044 [23], namely geographical correlation, temporal correlation, and technological correlation. Korean LCI DB provided by the Ministry of Commerce, Industry and Energy and the Ministry of Environment [24], National Database on Environmental Information of Building Materials provided by Korea Institute of Civil Engineering and Building Technology [25], and Oekobaudat of Germany [26] were applied in descending order of prioritization.Table 2 represents the environmental impact factor of main building materials established in this study.

C. Safety Guard and Environmental Damage Index

The safety guard means the environment that the human race must protect from an environmental ethics perspective and can be classified into human and ecosystem items. The human items are divided into human health, which is required for humans to live a healthy life, and social assets, which support human society. The ecosystem items can be subdivided into biodiversity, which means the preservation of animals and plants, and primary production, which is essential to maintain biodiversity [27].

The damage index quantifies the damage to the aforementioned safety guard (human health, social assets, biodiversity, and primary production) by environmental impacts. In other words, human health uses the disability adjusted life year (DALY), which means death or the period of disabilities and diseases that do not lead to death, as the damage index, and social assets mean the economic cost (USD) for suppression and depletion of crops, fishery resources, forest resources, mineral resources, and fossil fuels. In addition, biodiversity assesses the expected increase in number of extinct species (EINES), which are expectations for the extinct species of vascular plants and aquatic plants, as the damage index, and the primary production uses the net primary production (NPP), which assesses the amount ($kg/m^2 \cdot year$) of the organic matters created by the photosynthesis of land plants and marine plankton, as the damage index. The damage index for each safety guard can be assessed through the end-point-level LCIA methodology, which systematized the damage index for each safety guard using natural science research results [27].

This study established the environmental damage index of each building material using the LCI DB, and Korean life cycle impact assessment method based on a damage oriented modeling (KOLID) [27], a monetary valuation-based damage cost LCIA model developed by the Ministry of Environment of South Korea. KOLID quantifies 16 endpoint damages, such as cancer, heat stress, infectious disease, skin cancer, cataract and respiratory diseases, attributable to the six environmental impact categories (GWP, AP, EP, ODP, POCP, and ADP), and evaluates the four safety guards consisting of human health, social assets, biodiversity, and primary production. Fig. 3 shows the concept of KOLID.Table 3 represents the environmental damage index of main building materials established in this study.

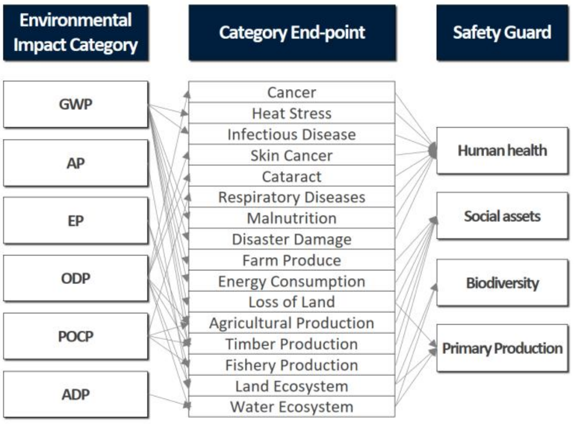


Fig.3. Concept of KOLID.

Table 3. Environmental damage index of main building materials

Materials	FU	HH	SA	BD	PP
RMC	m^3	2.47×10^{-4}	4.94×10^{0}	2.54×10^{-1}	4.61×10^{1}
Rebar	kg	3.98×10^{-7}	7.88×10^{-3}	4.27×10^{-4}	4.58×10^{-2}
Concrete Brick	Each	1.07×10^{-7}	2.12×10^{-3}	9.24×10^{-5}	1.02×10^{-2}
Cement	kg	4.50×10^{-7}	8.89×10^{-3}	3.67×10^{-4}	4.21×10^{-2}
Aluminum	kg	1.55×10^{-5}	2.96×10^{-1}	7.06×10^{-7}	1.64×10^{0}

Note) RMC: Ready-mixed Concrete; FU: Functional Unit; HH: Human Health; SA: Social Assets; BD: Biodiversity; PP: Primary Production; HH’s Unit: DALY/FU; SA’s Unit: USD/FU; BD’s Unit: EINES/FU; PP’s Unit: kg/FU.

D. Environmental Cost

Embodied environmental cost refers to the cost of an environmental impact converted into an economic value by quantifying the related environmental issues at endpoint level and categorizing the corresponding area of protection as a safety guard from environmental ethical viewpoint.It can be computed using economic valuation-based damage cost life cycle evaluation model.

Table 4. Environmental cost unit of main building materials

Materials	FU	Environmental Cost Unit (USD/FU)
RMC	m^3	1.40×10^{1}
Rebar	kg	2.11×10^{-2}
Concrete Brick	Each	5.57×10^{-3}
Cement	kg	2.34×10^{-2}
Aluminum	kg	8.02×10^{-1}

Note) RMC: Ready-mixed Concrete; FU: Functional Unit.

This study established the environmental cost unit of each building material using KOLID [27]. In the KOLID, the environmental cost is derived as the final evaluation outcome computed through the marginal willingness to pay (MWTP) for these damage indicators.Table 4 represents the environmental cost unit of main building materials established in this study.

IV. RESULTS

In this chapter, the embodied environmental impacts of high-rise residential buildings were assessed, and the quantitative assessment results were analyzed from the perspectives of environmental impacts, safety guards, and environmental costs.

A. Environmental Impact Category

Table 5 and Fig. 4 show the results of the embodied environmental impact assessment and percentage of the environmental impact assessment results of high-rise residential building performed in this study.
According to Table 5 and Fig. 4, for the embodied environment impacts of high-rise residential building, the impacts of ready-mixed concrete was the highest for all environmental impact categories while those of the cement was the lowest for almost environmental impact categories. In particular, among the overall embodied environmental effects assessed in this study, the percentage of the embodied environmental impacts caused by ready-mixed concrete ranged from 43.23% (AP) to 89.38% (POCP), indicating that reducing the embodied environmental impacts of ready-mixed concrete is the most important to decrease the embodied environmental impacts of high-rise residential building.

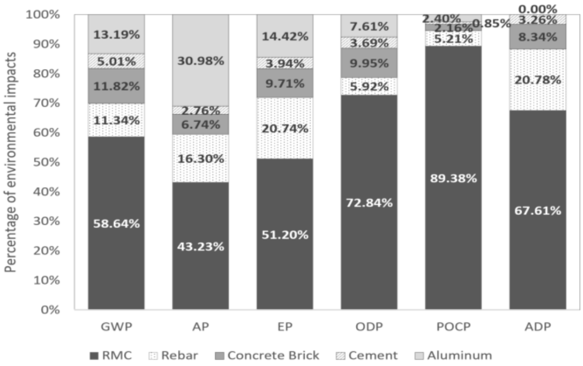


Fig.4. Percentage of the environmental impacts assessment results.

Table 5. Results of the environmental impact assessment

Classification	Unit	Safety Guards
Human Health	DALY	1.68×10^{1}
Social Assets	USD	3.31×10^{5}
Biodiversity	EINES	1.26×10^{4}
Primary Production	kg	2.45×10^{6}

B. Safety Guard

Table 6 and Fig. 5 show the results of the embodied environmental damage index(safety guards) assessment and percentage of the safety guard assessment results of high-rise residential building performed in this study.

According to Table 6 and Fig. 5, for the safety guards of high-rise residential building, the safety guards of ready-mixed concrete was the highest for all safety guards while those of the cement was the lowest for almost safety guards. In particular, among the overall safety guards assessed in this study, the percentage of the safety guards caused by ready-mixed concrete ranged from 49.47% (Human Health) to 67.61% (Biodiversity), indicating that reducing the safety guardsof ready-mixed concrete is the most important to decrease the safety guards of high-rise residential building.

Table 6. Results of the safety guard assessment

Classification	Unit	Safety Guards
Human Health	DALY	1.68×10^{1}
Social Assets	USD	3.31×10^{5}
Biodiversity	EINES	1.26×10^{4}
Primary Production	kg	2.45×10^{6}

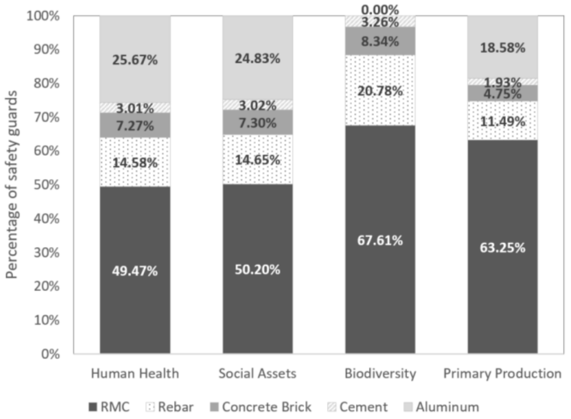


Fig.5. Percentage of the safety guard assessment results.

C. Environmental Cost

Table 7 and Fig. 6 show the results of the embodied environmental cost assessment and percentage of the environmental cost assessment results of high-rise residential building performed in this study.

According to Table 7 and Fig. 6, for the environmental cost of high-rise residential building, the environmental cost of ready-mixed concrete was the highest for environmental cost while those of the cement was the lowest. In particular, the percentage of the environmental cost caused by ready-mixed concretewas51.47%, indicating that reducing the environmental costof ready-mixed concrete is the most important to decrease the environmental cost of high-rise residential building.

Table 7. Results of the environmental cost assessment

Classification	Unit	Safety Guards
Environmental Cost	USD	9.12×10^5

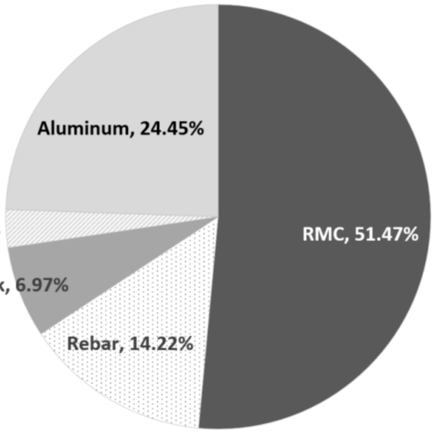


Fig.6. Percentage of the environmental cost assessment results.

CONCLUSIONS

This study aims to evaluate the embodied environmental impacts of high-rise residential building in South Korea, with focus on main building materials, as part of analytic research on a building's life cycle environmental impact. The results are summarized as follows.

1. The embodied environmental impacts of high-rise residential building were assessed, and the results were analyzed from the perspectives of environmental impacts, safety guards and environmental cost.
2. The embodied environmental impacts caused by ready-mixed concrete was the highest for all environmental impact categories, such as the maximum percentage of 89.38% of POCP.
3. The safety guards caused by ready-mixed concrete was the highest for all safety guards, such as the maximum percentage of 67.61% of biodiversity.
4. The environmental cost caused by ready-mixed concrete was the highest, 51.47%, while those of the cement was the lowest.
5. Reducing the quantityof ready-mixed concrete is the most important to decrease the embodied environmental impacts, the safety guards, and the environmental cost of high-rise residential building.

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