

Sustainable Design Framework for the Anthropocene

Preliminary research of integrating the urban data with building information

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In terms of the efficiency and informatization in the architecture and construction industry, the Fourth Industrial Revolution presents positive aspects of technological development, but we need to discuss the expanded concept, the Anthropocene. The era of the human-made environment having a powerful influence on the global system is called Anthropocene. Since the 1950s, many indicators representing human activity and earth system have shown the 'Great acceleration'. Currently, lots of urban data including building information, construction waste, and GHG emission ratio is indicating how much the urban area was contaminated with artifacts. So, the integrated planning and design approach are needed for sustainable design with data integration. This paper examines the GIS, LCA and BIM tools focusing on building information and environmental load. With the literature review, the computational system for sustainable design is demonstrated to integrate into one holistic framework for the Anthropocene. There were some limitations that data was simplified during the statistical processing, and the framework has limitations that must be demonstrated by actual data in the future. However, this could be an early approach to integrating geospatial and environmental analysis with the design framework. And it can be applied to another urban area for sustainable urban models for the Anthropocene

Keywords: *Anthropocene, Sustainable Design Framework, Urban Data Analysis, GIS, LCA, BIM*

INTRODUCTION

In recent years, enormous environmental problems have occurred around the world. Rapid changes in temperature and excessive levels of fine dust are affecting human lives and their health. To address these issues, the United Nations passed the

Paris Agreement in 2015 to reduce greenhouse-gas-emissions (GHG), which is being used as a key indicator of environmental issues. The agreement warns that a rise of more than 2 degrees to the average temperature before industrialization would pose a serious threat to mankind, and regulates that the

countries should submit a greenhouse gas reduction target report. Also, the academic world produced evidence that these unexpected and uncontrollable events of the Earth's system were generated from human's activity. For example, rapid industrialization and urbanization conducted by humans have had a negative impact on the environments. Paul Crutzen (Crutzen 2006; Steffen et al 2011; 2015), the Nobel Prize-winning atmospheric chemist, claimed that a new epoch of human, 'the Anthropocene', has begun. At the same time, Will Steffen (Steffen 2011) put forward various indicators to provide a basis for Anthropocene, which is divided into human activity and earth system. The indicators starting with the Industrial Revolution represent a sharp rise since World War 2, called the Great Acceleration in 1950, and some scholars claimed this period as the starting point of the Anthropocene. To mitigate the risks and impact of this human-made epoch and to come up with the alternative, many discussions are going on in academia. Especially, in the architecture and construction field, we have been making efforts to develop sustainable building and city that have little impact on environmental pollution while reducing the carbon dioxide emission. These efforts led to the development of various computational tools such as BIM or LCA. Many construction projects use BIM (Building Information Modeling) tools in the design phase and environmental simulation is conducted in this phase by calculating environmental impacts. LCA (Life Cycle Assessment) tools that can calculate an environmental load of materials in the construction process also have been done for environmental assessment. However, each methodology is not integrated as one and separated by the building design process. It means BIM tools are reducing construction errors and improving economic efficiency without providing a solution to the environmental assessment. Also, the assessment from LCA tools is not integrated into the design process. Also, the assessment process is mainly focused on the early stages of the building life cycle from the production of building materials to the completion of the building. The envi-

ronmental loads from the construction waste are also considered in the process, but still, lack consideration of environmental load until they are completely exhausted. Therefore, this study proposes a framework for the sustainable design of the entire process from the design stage of a new building to the process of obsolescence and destruction in the Anthropocene point of view. To achieve the goal, we collected and analyzed various urbanization data in South Korea based on the assumption that this country which has achieved rapid industrialization since 1950 could serve as an example of the Anthropocene. Especially, here we focused on the buildings and infrastructures in urban areas and tried to analyze the correlations of the indicators which can represent how much the area is polluted. By defining the correlation between urban indicators and environmental data, we estimate and modeling the future urban area and visualize the data on the GIS-based map. We expect that urban planners and policymakers can use this estimated urban model for the decision-making process. It also can support the Anthropocene, beyond the 4th industrial revolution.

RELATED WORK

In this chapter, we will look through the tools related to computational design for building and infrastructure in the city. Those were developed independently and played individually, so it is needed to be integrated into the sustainable design framework.

GIS tools and Open data for urban data analysis (city scale)

Geographical Information System (GIS) is a system based on geographical data to analyze the condition of cities or country. It is including a polygon vector with attached attributes of city components. Currently, a variety of government-initiated open data related to the country is easy to access, and free GIS software allows spatial and statistical data analysis. The system provides the opportunity to manage the information on a larger scale, taking into account spatial dimensions. Recently, it has been used for var-

ious predictive models. We looked through the related research that introducing GIS-based case studies which is using open data to analyze and estimate the condition of the city. Many of the case studies were focused on the distinct area and they are shown that GIS and LCA can be integrated for an environmental impact assessment on a large scale. Mastrucci(Mastrucci et al 2015, Mastrucci et al 2017) shown that geospatial data can be used for the life cycle environmental impact assessment of building stocks at the urban scale. The aim of his study is to develop a geospatial data model for the life cycle assessment of environmental impacts of building stocks at the urban scale. The methodology includes geospatial processing of building-related data to characterize urban building stocks; a spatiotemporal database to store and manage data; life cycle assessment to estimate potential environmental impacts. We identified the possibilities of integration in that research, and we collected the open data that the Korean Statistical Institute provide, which is containing administrative district data of the city, and building information including gross area, land area, year, and materials. After collecting the data, we did statistical analysis by using QGIS which is free software for geospatial data analysis.[1]

LCA tools for Environmental Analysis of Building (Environmental, Construction level)

Life Cycle Assessment(LCA) is a tool for systematically analyzing the environmental performance of a product or process over its entire life, including the acquisition of raw materials to be discarded. In the case of a building, LCA tools are used to evaluate the life cycle including production phase(e.g. extraction, production, transport, and construction), usage and maintenance phase, and disposal phase(destruction and disposal). Now, LCA is considered one of the most suitable methodologies for assessing the environmental impact as a comprehensive approach to investigate the environmental impact of the building as a whole by quantifying and evaluating the mate-

rial and energy flow of the building system. But, most of LCA tools were developed for the general application to all industrial products, not specialized for LCA of building materials. For this reason, the use of different LCA tools, even for the same purpose, may result in a lack of repeatability of the results and objectivity. So, Kim(Kim and Tae 2016) developed an LCA system specialized for concrete in order for concrete-related experts to easily assess the environmental loading of concrete and actively apply the results to the green concrete industry. According to his research, the results of LCA varied in accordance with input and output, and hence focus-based research on concrete was required. Also, most of the previous LCA models developed in South Korea considered only the GHG emissions generated from the combustion of energy sources used in the material manufacturing, transportation, and construction phases(Tae et al 2011). Tae(Tae et al 2011) tried to develop a simple CO₂ assessment system that can assess the life cycle CO₂ of apartment buildings even without data pertaining to a quantity of construction material and the results of energy simulation analysis of the operation stage. But for the Anthropocene, we need more integrated environmental impact assessment in the life cycle of a building. Due to the enormous environmental impact, Jang(Jang et al 2015) aims to develop a hybrid LCA model that can evaluate the inherent environmental impact of buildings more comprehensively. Out of the various environmental factors, the results are classified and calculated into six types of environmental impact categories(e.g. global warming, ozone depletion, nitrification, and acidification) For the framework of sustainable design, we choose those six environmental impact categories. These indicators become transient connections of six indicators, including GWP and ODP, which are used as indicators of the Anthropocene. In the process of LCA, a database which is including the information of material and its coefficient is necessary. The Korean Ministry of Land, Infrastructure, and Transport provides the LCI DB for Korean industry and also globally recognized 'Ecoinvent' tools that can be calcu-

lated and provided by Switzerland can be used. After that LCA process can be done with equations below described in the methodology part (T. Ramesh et al 2010; Jeong et al 2015)

BIM tools for Sustainable and Eco-design Modelling(Building Scale)

BIM serves as the most important tool for designing the entire process of design, which is the first step in the building's life cycle. Based on the field of computer design, it is being used to automate architectural design and to automate eco-friendly design. However, due to the variety of BIM tools, the lack of compatibility has led to the need for integrated management. IFC, a file format created to enhance interoperability among BIM tools, has been introduced for data exchange between different BIM applications. The BIM software provides the ability to exchange modeled building information between the parties by input and output in the form of an IFC file. Lee (Lee et al. 2012) conducted a preliminary survey that provided clear ideas on how IFC should be used to maintain BIM data on the building's lifecycle. And today BIM not only provides technical benefits to the development process but also provides an innovative and integrated working platform to improve productivity and sustainability throughout the project's life cycle. (Elmualim and Gilder 2014) and is now mature and integrated into interoperable data(Porwal and Hewage 2013)

From the related work review, we could find that the systems should be integrated into one holistic framework and there was some approach to integrate them. Therefore, we focused on Anthropocene and developed an early study to develop a framework for sustainable design.

METHODOLOGY

To develop the sustainable design framework, we analyzed the building cycle from the stage of planning and to the stage of reconstruction including construction waste disposal process. The stages that affect the cycle of buildings were defined as follows. (1) Design, (2) Construction, (3) Usage/Maintenance, (4) Destruction, (5) Reconstruction. We draw the entire conceptual framework to integrate the systems that we reviewed in related work chapter. After that, to estimate the potential environmental effect of the urban situation, we list up the data and equations which are required for the sustainable framework.

Conceptual Framework

We draw the conceptual framework based on the data utilized in each system of building and city planning. The data list was devised by considering the indicators of the Anthropocene(Figure 1). We have checked the international organization for standardization of the system and found that IFC format is corresponding with the ISO standard 16739 and the technical framework for life cycle assessment(LCA) was defined by ISO standard 14042[2]. The flow of sustainable design framework is that selection of impact categories, category indicators, and models and assigns the LCI results which are classification process. After that characterization process is done with the calculation of category indicator results. At the final process, by doing normalization the values are being grouped and weighted for data analysis. In this research, we focused on an apartment which is the typical resident of Korea for the analysis of Anthropocene evidence in Korea. And as we mentioned in the related chapter, we used the equation of LCA for simplified assessment of concrete. Using the collected data, we visualized the evidence of Anthropocene in Korea by using QGIS tools. (Figure2).

LCA equations

The equations were used for the entire life cycle assessment of building in the sustainable framework for the Anthropocene and were referenced from the research of Jeong (Jeong et al 2015).

Figure 1
Conceptual
framework of
sustainable design
for the
Anthropocene.

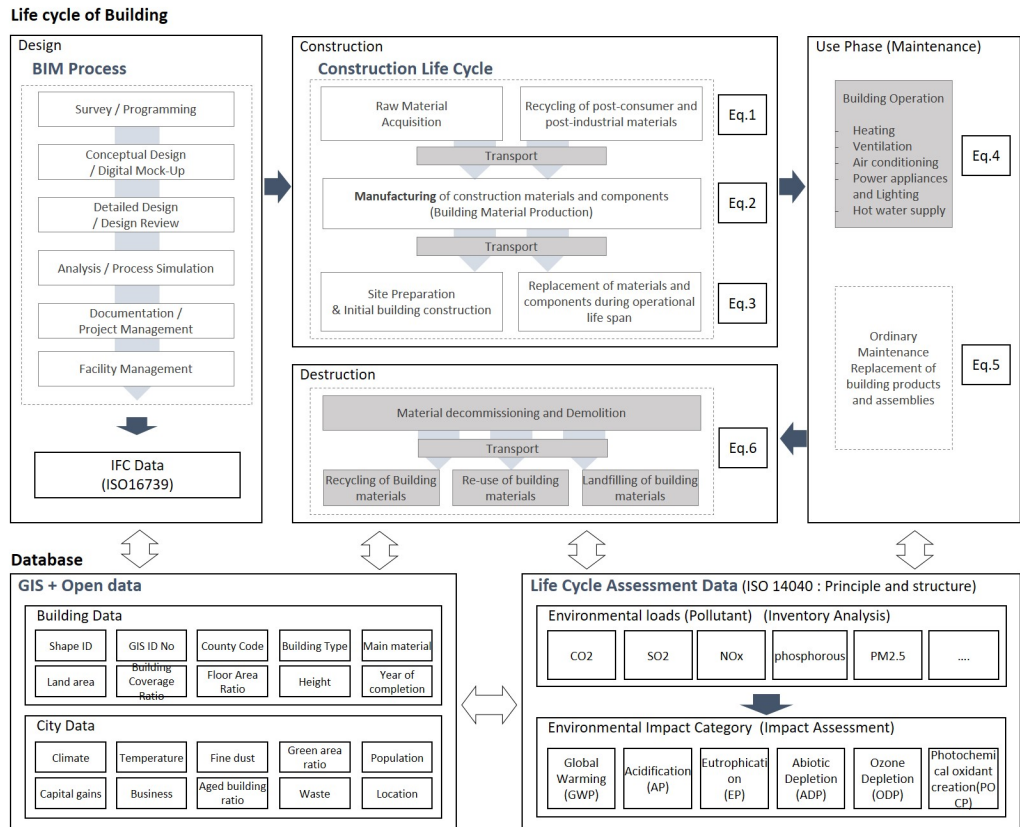


Figure 2
Distribution Map of
Apartment Location
in South Korea
(QGIS)

• Material Manufacturing

$$QE_k = \sum_j \frac{CD_j \cdot PIC_{k,j}}{UP_k}$$

QE_k

is the quantity of the consumed energy (k),

CD_j

is the cost data of the construction material (j) in the bill of quantity,

$PIC_{k,j}$

is the production inducement coefficient of the energy source (k) required to manufacture the material (j) and

UP_k

is the unit price of the energy source (k).

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• **Material Transportation and On-site Construction**

$$QE_k = 2 \sum_m \cdot \sum_j \left(\frac{QD_j}{C_j^m} \cdot \frac{TD_j^m}{SM_j^m} \cdot FC_k^m \right) \quad (2)$$

$$QE_k = \sum_n \cdot \sum_j \left(\frac{QD_j}{C_j^m} \cdot FC_k^m \right) \quad (3)$$

QD_j is the quantity data of material (j), C_j^m is the capacity of vehicle (m) that is Operation and maintenance phase used to transport material (j), TD_j^m is the transportation distance of the construction material (j) from the plant to the construction site using vehicle (m), SM_j^m is the standard movement of vehicle (m) for an hour and FC_k^m is the fuel (k) consumption per unit hour of vehicle (m), C_j^n is the capacity of work per unit hour of equipment (n) that was used to construct the building materials (j) and FC_k^n is the fuel (k) consumption per unit hour of construction equipment (n).

• **Operation and Maintenance phase**

$$QE_k = QAE_k \cdot (ServiceYear) \quad (4)$$

QAE_k is the quantity of annual energy consumption.

• **Demolition and Disposal Phase**

$$QE_k = QW_j \cdot QES_{j,k}^m \quad (5)$$

QW_j is the quantity of waste material (j) generated in each stage, $QES_{j,k}^m$ is the quantity of the energy source (k) that the equipment (m), which is used to process the waste material (j), uses during the processing of a unit amount of the waste material

• **Calculation of the environmental impact substances from energy combustion**

$$E_i = \sum_k (QE_k \cdot EP_{i,k} + QE_k \cdot EC_{i,k}) \quad (6)$$

E_i is the emission of substance (i), QE_k is the quantity of consumed energy (k), $EP_{i,k}$ is the emission factor of substance (i) that was emitted in the production of one unit of energy source (k), and $EC_{i,k}$ is the emission factor of substance (i) that was emitted in the combustion of one unit of the energy source (k).

Life Cycle Impact Assessment

$$CI_l = \sum_i (E_i \cdot CF_{l,i}) \quad (7)$$

$$QE_k = QW_j \cdot QES_{j,k}^m \quad (8)$$

CI_l is the characterized impact of impact category (l); E_i is the emission of substance (i); $CF_{l,i}$ is the characterization factor of substance (i) to impact category (l).

Environmental Impact Categories

Several impact categories and impact assessment methods were used in the Life Cycle Impact Assessment. Those six categories are mostly used categories and recommended by the standard EN15643-2[4]. In the environmental impact assessment for the concrete, concrete size of $1m^3$ was selected as the functional unit. The classified indicators went through the process of characterization and normalization and lastly weighted for integrated life cycle assessment. (Kim et al 2016)

GWP(Global Warming Potential) : CO_{2eq}/m^3

ODP(Ozone-layer Depletion Potential) : CFC_{11eq}/m^3

AP(Acidification Potential) : SO_{2eq}/m^3

EP(Eutrophication Potential) : PO_{4eq}/m^3

POCP(Photochemical Ozone Creation Potential) : $Ethyl_{eq}/m^3$

ADP(Abiotic Depletion Potential) : $1/m^3$

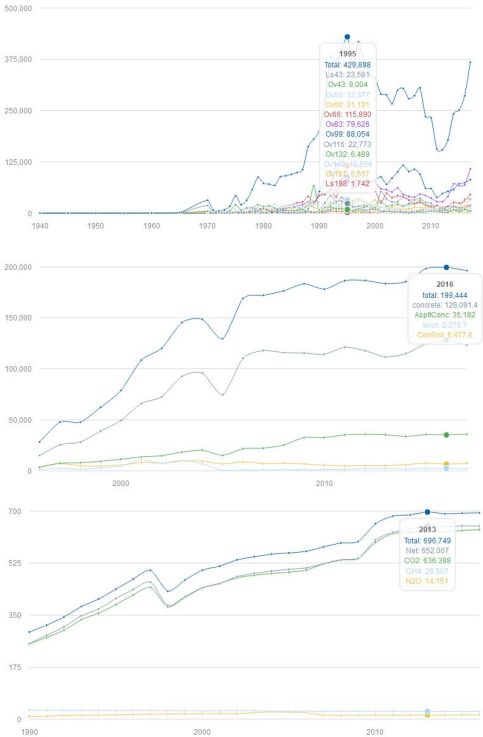
Figure 3
Completion year of
Apartment in Korea
(Household)

Figure 4
Quantity of
Construction Waste
in Korea(1996~2016)

Figure 5
Emission trends of
Environmental
Impact (GHG
Emission)

DISCUSSIONS AND CONCLUSION

This study was for a preliminary study of the entire life cycle framework for sustainable design from city to building. Many computational tools were developed for a specific purpose. With a holistic point of view, these tools need to be integrated. We collected open data which can be related to Anthropocene in Korea where rapid urbanization was conducted[3]. We analyzed the completion year of the apartment with a quantity of construction waste and GHG emissions. Figure3 shows that the completion year of the apartment(unit= household) picked at 1995 with 429,898. The life cycle of an apartment building in Korea is 25 years to 50 years. We compared the quantity of construction waste is picked in 2016 with a total 199,444 ton and most of those components are concrete and asphalt concrete. We reached the conclusion that we researched and analyzed the relationship between construction waste occurred from urban artifacts. With the GHG emission rate from 1990 shown in figure4, we found that the conceptual framework should be more developed in advance for sustainable design. So, the spatial analysis integrated with environmental impacts would play an important role in the sustainable design framework for Anthropocene and can be a basis for decision making for city planning in the future. This research is meaningful in the development of a preliminary sustainable design methodology by integrating the life cycle of a building and spatial data. This framework tried to propose a methodology to enable designer or decision maker can recognize the environmental impact of it. We would research the results that to design artifacts for sustainable cities, the forecasting process of the potential environmental impact of cities (N years later) should take place in the design or planning phase. And the next step is to apply the framework developed in this study to the actual construction process so that realistic data can be demonstrated. And we expect that this sustainable design methodologies adapted to climate change can be used in international sustainable design guidelines.



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REFERENCES

Crutzen, PJ 2006, 'The Anthropocene', in Krafft, EET (eds) 2006, *Earth system science in the Anthropocene*, Springer, New York, pp. 13-18

Elmualim, A and Gilder, J 2014, 'BIM: innovation in design management, influence and challenges of implementation', *Architectural Engineering and Design Management*, 10:3-4, pp. 183-199

Jeong, KB, Ji, CG, Koo, CW, Hong, TH and Park, HS 2015, 'A model for predicting the environmental impacts of educational facilities in the project planning phase', *Journal of Cleaner Production*, 107, pp. 538-549

- Kim, TH and Tae, SH 2016, 'Proposal of Environmental Impact Assessment Method for Concrete in South Korea: An Application in LCA(Life Cycle Assessment)', *International Journal of Environmental Research and Public Health*, 13, p. 1074
- Kim, TH, Tae, SH and Chae, CU 2016, 'Analysis of Environmental Impact for Concrete Using LCA by Varying the Recycling Components, the Compressive Strength and the Admixture Material Mixing', *Sustainability*, 8, p. 389
- Lee, JH, Smith, J and Kang, J 2011 'The Role of IFC for Sustainable BIM Data Management', *Proceedings of the 28th ISARC*, Seoul
- Mastrucci, A, Marvuglia, A, Leopold, U and Benetto, E 2017, 'Life Cycle Assessment of building stocks from urban to transnational scales: A review', *Renewable and Sustainable Energy Reviews*, 74, pp. 316-332
- Mastrucci, A, Popovici, E, Marvuglia, A, Sousa, LD, Benetto, E and Leopold, U 2015 'GIS-based Life Cycle Assessment of urban building stocks retrofitting', *EnvironInfo 2015 and ICT4S 2015*
- Porwal, A and Hewage, KN 2013, 'Building Information Modeling(BIM) partnering framework for public construction projects', *Automation in Construction*, 31, pp. 204-214
- Steffen, W, Broadgate, W, Deutsch, L, Gaffney, O and Ludwig, C 2015, 'The trajectory of the Anthropocene: The Great Acceleration', *The Anthropocene Review*, 2(1), pp. 81-98
- Steffen, W, Grinevald, J, Crutzen, P and McNeill, J 2011, 'The Anthropocene: conceptual and historical perspectives', *Philosophical Transactions of the Royal Society A*, 369, p. 1938
- T, Ramesh, Prakash, R and K, KS 2010, 'Life cycle energy analysis of buildings:An overview', *Energy and Buildings*, 42, pp. 1592-1600
- Tae, SH, Shin, SW, Woo, JH and Roh, SJ 2011, 'The development of apartment house life cycle CO2 simple assessment system using standard apartment houses of South Korea', *Renewable and Sustainable Energy Reviews*, 15, pp. 1454-1467
- [1] <https://www.qgis.org/ko/site/>
- [2] <https://www.iso.org/standard/23153.html>
- [3] http://kosis.kr/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ZTITLE&parmTabId=M_01_01
- [4] <https://www.en-standard.eu/une-en-15643-2-2012-sustainability-of-construction-works-assessment-of-buildings-part-2-framework-for-the-assessment-of-environmental-performance/?gclid=Cj0KCQjwocPnBRDFARlsAJJcf96FhYcJoiM-dvIOHUIoIR8UbQio01l-FRFyG0MNGR>