Environmental Impact Assessment Review 54 (2015) 9–21

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

A program-level management system for the life cycle environmental and economic assessment of complex building projects

Chan-Joong Kim [a], Jimin Kim [b], Taehoon Hong [b,*], Choongwan Koo [b], Kwangbok Jeong [b], Hyo Seon Park [b]

[a] Parsons Brinckerhoff, Seoul 135-763, Republic of Korea
[b] Department of Architectural Engineering, Yonsei University, Seoul 120-749, Republic of Korea

ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form 30 April 2015
Accepted 30 April 2015
Available online 16 May 2015

Keywords:
Program management
Life cycle assessment
Life cycle cost
Complex building

ABSTRACT

Climate change has become one of the most significant environmental issues, of which about 40% come from the building sector. In particular, complex building projects with various functions have increased, which should be managed from a program-level perspective. Therefore, this study aimed to develop a program-level management system for the life-cycle environmental and economic assessment of complex building projects. The developed system consists of three parts: (i) input part: database server and input data; (ii) analysis part: life cycle assessment and life cycle cost; and (iii) result part: microscopic analysis and macroscopic analysis. To analyze the applicability of the developed system, this study selected 'U' University, a complex building project consisting of research facility and residential facility. Through value engineering with experts, a total of 137 design alternatives were established. Based on these alternatives, the macroscopic analysis results were as follows: (i) at the program-level, the life-cycle environmental and economic cost in 'U' University were reduced by 6.22% and 2.11%, respectively; (ii) at the project-level, the life-cycle environmental and economic cost in research facility were reduced 6.01% and 1.87%, respectively; and those in residential facility, 12.01% and 3.83%, respective; and (iii) for the mechanical work at the work-type-level, the initial cost was increased 2.9%; but the operation and maintenance phase was reduced by 20.0%. As a result, the developed system can allow the facility managers to establish the operation and maintenance strategies for the environmental and economic aspects from a program-level perspective.

1. Introduction

The Kyoto Protocol, which was established at the 3rd Conference of the Parties of the United Nations Framework Convention on Climate Change in 1997, became effective as an international agreement in February 2005 (Albino et al., 2009; Jeswani et al., 2008). The Kyoto Protocol recommended that the developed countries included in Annex I establish a national carbon emission reduction target (CERT) (Pan, 2005). South Korea is currently included in Non-Annex I under the Post-Kyoto Protocol (2013–2020), but it is expected that South Korea will have the responsibility for the greenhouse gas emissions reduction. Accordingly, the South Korean government established its national CERT as 30% below business-as-usual by 2020 (Hong et al., 2012a; Kim et al., 2012; Koo et al., 2014a). In particular, the South Korean government follows the global trend of greenhouse gas emissions reduction by establishing the "Act on the Allocation and Trading of Greenhouse Gas Emission Allowances" and enacting the "emissions trading scheme" (18th Korean Congress, 2012; Hong et al., 2012b, 2013, 2014; Koo et al., 2014b).

Meanwhile, as the construction industry depends on the energy-consuming industries such as steel, cement, and power-generation, it will not be able to avoid the direct and indirect effects of the Kyoto Protocol. Thus, for the transition towards an eco-friendly industry system, it is required to conduct the environmental and economic assessments throughout the whole life cycle of a building construction project. Fragmentary approach to the environmental and economic aspects of building projects, however, may not be linked to the operational and maintenance strategies for the environmental and economic aspects from a program-level perspective (Nässén et al., 2007; Ramesh et al., 2010; Rebitzer and Hunkeler, 2003; Thormark, 2006). In addition, as complex building projects with various functions have increased, a program-level management system should be developed.

Under such circumstances, several previous studies were conducted on the environmental impact assessment and life cycle assessment in the civil and construction industry, all the take together, which can be divided into three categories (Cabeza et al., 2014; Ortiz et al., 2009): (i) LCA tools and databases related to the civil and construction industry (Fiksel and Wapman, 1994; Norris, 2001; Paggio et al., 1999; Shokravi et al., 2014); (ii) LCA applications for civil and construction products' selection (Keoleian and Volk, 2005; Lloyd and Lave, 2003; Zhang et al., 2009) and (iii) LCA applications for civil and construction systems and

* Corresponding author at: Yonsei University, 50 Yonsei-ro, Seodaemun-gun, Seoul 120-749, Republic of Korea.

http://dx.doi.org/10.1016/j.eiar.2015.04.005
0195-9255/

process evaluation (Hong et al., 2009; Jeong et al., in press; Lim and Park, 2007; Schaltegger and Synnestvedt, 2002; Steen, 2005).

- (i) Some studies were conducted on LCA tools and databases, which provided standardized assessment models and inventory data at multiple scales (Haapio and Viitaniemi, 2008; Singh et al., 2011). The scales range from industry-wide and sector-wide data down to product- and even brand-specific data as the following three levels (refer to Table 1) (Hong et al., 2014): (i) level-1 software (BEES, National Renewable Energy Laboratory's (NREL) U.S. life cycle inventory database, Simapro, and the Life cycle Explorer) (Lippiatt, 2000, 2007); (ii) level-2 software (whole-building decision support tools like Athena Eco-Calculator, and Envest 2); and (iii) level-3 software (whole-building assessment systems and frameworks such as Athena Impact Estimator, SUSB-LCA, BRE environmental assessment method, and the LEED rating system) (Lee et al., 2009).
- (ii) Other studies were conducted on LCA applications for civil and construction products' selection. Aforementioned tools were considered highly effective in the environmental impact assessment for a single industrial product (Boehm et al., 1995; Durairaj et al., 2002; Forsberg and Von Malmborg, 2004; Gluch and Baumann, 2004; Hischier et al., 2014; Li, 2006; Salhofer et al., 2007). In applying the tools to the construction industry, however, it was limited to provide only a simple summation of the life-cycle environmental impact assessment (Jeong et al., in press; Mateus and Bragança, 2011; Norris and Yost, 2001; Yu-rong et al., 2009).
- (iii) Other studies were conducted on LCA applications for civil and construction systems and process. Basically, in evaluating the environmental impacts of construction and buildings, it is required to consider more than a simple summation of individual product and material assessment (Cabeza et al., 2014). However, most of previous studies focused on the specific buildings in assessing the environmental impacts of construction industry (Blengini, 2009; Fay et al., 2000; Hacker et al., 2008; Keoleian et al., 2000; Monahan and Powell, 2011; Petersen and Solberg, 2002, 2005; Sartori and Hestnes, 2007; Scheuer et al., 2003; Thormark, 2002; Yohanis and Norton, 2002). Hacker et al. (2008) compared embodied and operational CO_2 emissions from the only one domestic residential building by considering passive and active designs. Monahan and Powell (2011) conduct a partial LCA from cradle to the construction of a low energy house by considering an off-site panelized modular timber frame system.

Based on the aforementioned previous studies, there were two kinds of limitations. First, some studies analyzed the various types of buildings, however, they evaluated the specific environmental impacts (e.g., global warming potential) (Kalogirou, 2009; Keoleian et al., 2005; Norman et al., 2006; Van der Lugt et al., 2006; Venkatarama Reddy and Jagadish, 2003; Zabalza Bribián et al., 2009). Norman et al. (2006) compared high- and low-populated buildings for their energy use and GHG emissions. The results showed that the choice of functional unit was highly related to the urban density effects. Zabalza Bribián et al. (2009) presented the main potential users who could apply the LCA tools in the early design phases of a building, but they only estimated global warming potential and energy consumption. Second, other studies evaluated the various types of environmental impacts, however, they did not apply the program-level management approach but conducted the design alternative analysis (Carlsson Reich, 2005; Cuéllar-Franca and Azapagic, 2014, 2012; Ding, 2008; Hu et al., 2004; Junnila et al., 2006; Khasreen et al., 2009; Malmqvist et al., 2011; Peuportier et al., 2013; Peuportier, 2001). Cuéllar-Franca and Azapagic (2012) used LCC and LCA to assess several environmental impacts for the life cycle of houses. Peuportier (2001) conducted the comparative analysis of single family houses using LCA for all life cycle phases and Peuportier et al. (2013) evaluated the energy and environmental benefit for the attached two-story passive houses.

To address these challenges, this study defined the research scope as follows: (i) the scope of environmental impact assessment was defined from cradle to grave; and (ii) the scope of application scale was defined from microscopic (e.g., design alternatives) to macroscopic (e.g., program-level, project-level, and work-type-level). Based on the defined research scope, this study aimed to develop a program-level management system for the life-cycle environmental and economic assessment of complex building projects.

The developed system would be innovative LCA practice and categorized into LCA methodological developments related to the building projects because it can be used to conduct the life-cycle environmental and economic assessment from two perspectives: (i) microscopic analysis (e.g., design alternatives): the individual analysis on various design alternatives which can be established through value engineering with architectural and engineering experts; and (ii) macroscopic analysis (e.g., program-level, project-level, and work-type-level): the multilateral analysis of integrating the microscopic analysis results into the work-type-level, project-level, and program-level, which can be used for establishing the operation and maintenance strategies from the environmental and economic perspective. To verify the applicability of the developed system, this study selected “U” University, which is a complex building project consisting of a research facility and a residential facility.

Table 1
Comparison of the LCA tools based on ATHENA classification.

Class	ATHENA classification	Level 1	Level 2	Level 3
	Definition	Product comparison tools and information sources	Whole building design or decision support tools	Whole building assessment frameworks or systems
	Assessment tools (representatives)	BEES 4.0	ATHENA™	LEED®
Acceptable building type	New building	–	●	●
	Building product/component	●	–	–
	Residential building (multi-unit)	–	●	●
Users of the tools	AEC professionals	●	●	●
	Producers of building products	●	–	●
	Investors, building owners	–	–	●
	Consultants	●	●	●
	Researchers	●	●	●
	Authorities	–	–	●
Phases of the life cycle	Production	●	●	●
	Construction	–	●	●
Tool developer		NIST; USA	ATHENA® Institute; Canada	U.S. GBC; USA
Databases of the tools		Generic data and brand specific	ATHENA Institute	No database included

Source: Hong et al. (2014) (License number: 3580550680968; License date: Mar. 1, 2015; Licensed content publisher: Elsevier; and Licensed content publication: Applied Energy. This is a License Agreement provided by Copyright Clearance Center (CCC)).