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An Activity-Based Costing decision model for life cycle assessment in green building projects

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ABSTRACT

Carbon emissions are an increasingly important consideration in sustainable environmental development. In the green building industry, green construction cost controls and low-carbon construction methods are considered to be the key barriers encountered. Based on Corporate Social Responsibility (CSR) policy, management of carbon emissions from green building projects contributes to the acquisition of accurate building cost information and to a reduction in the environmental impact of these projects. This study focuses on the CO_2 emission costs and low-carbon construction methods, and proposes a 0–1 mixed integer programming (0–1 MIP) decision model for integrated green building projects, using an Activity-Based Cost (ABC) and life cycle assessment (LCA) approach. The major contributions of this study are as follows: (1) the integrated model can help construction company managers to more accurately understand how to allocate resources and funding for energy saving activities to each green building through appropriate cost drivers; (2) this model provides a pre-construction decision-making tool which will assist management in bidding on environmentally-friendly construction projects; and (3) this study contributes to the innovation operation research (OR) literature, especially in regard to incorporating the life cycle assessment measurement into construction cost management by utilizing a mixed decision model for green building projects.

1. Introduction

Recent natural disasters resulting from global climate change have caused significant damage to both life and property. Governments have proactively begun developing environmental pollution policies, and the protection of air quality has become a prime concern. In 2012, Taiwan passed the indoor air quality management act; it requires managers or employers to be responsible for managing and maintaining the indoor air quality of their premises in order to protect public health. Taiwan became the second country to implement these regulations, following South Korea. This act was promulgated because of the fourth assessment report of the Intergovernmental Panel on Climate Change, which indicated that carbon dioxide (CO_2) in greenhouse gases (GHGs) has increased as a result of human activities, such as the use of fossil fuels in transportation, manufacturing industries, and in the heating and cooling of buildings (IPCC, 2007). Construction of new buildings is responsible for significant greenhouse gas emissions (GHGs), particularly of CO_2. Many countries are now attempting to promote Green Building development in order to reduce or at least slow down global climate warming due to CO_2 emissions.

A carbon tax is highly recommended by economists and international organizations as a cost-effective method (EEA, 1996) for reducing greenhouse gas emissions. Many countries, including: Denmark, Sweden, Norway, the Netherlands and Finland have already adopted carbon taxes to reduce CO_2 emissions. In addition, the carbon tax policy promotes the development of renewable energy (Lin & Li, 2011), encourages environmental management applications (Kunsch & Springael, 2008) and assists in creating a foundation for developing economies (Thomas, John, Laura, & Richard, 2013). On the other hand, the levying of carbon taxes also increases building costs for construction companies. With heightened awareness of Corporate Social Responsibility (CSR), construction companies must consider carbon emission costs to help accurately predict building costs and reduce a building project's overall impact on the environment.

Life-cycle assessment (LCA) is an evaluation of the environmental load and energy consumption of goods and services during their total life cycle (ISO, 2006). LCA has been applied in assessing construction costs, and has become an important technique for improving construction sustainability (Ortiz, Castells, & Sonnemann, 2009).

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As emphasis on the measurement of building costs and economic benefits is used to enhance operating profits within the construction industry, green building is often perceived as having high construction costs. However, Activity-Based Costing (ABC) could improve the accuracy of cost-related data and further control project costs (Rahman, Omar, & Abidin, 2003; Tsai & Hung, 2009a, 2009b). This approach results in a more accurate estimation of the constuction costs for each buildings compared to traditional cost systems since the former represents a closer reflection of the real construction cost. Many studies have applied a Mathematical Programming (MP) model to provide energy management solutions in order to minimize costs, such as: greenhouse gas studies, green airline fleet planning, energy saving selection, carbon emission constraint problems, optimizing airline network design and green manufacturing technologies (Abanda, Tah, & Cheung, 2013; Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, & Rapine, 2013; Antunes, Martins, & Brito, 2004; Derigs & Illing, 2013; George, Danae, Kostas, & Paraskevas, 2008; Liu, Pistikopoulos, & Li, 2010; Tsai, Chen, Leu, Chang, & Lin, 2013; Tsai et al., 2012a). From the viewpoint of construction building cost evaluation, little research to date has combined the MP and construction cost models in consideration of the environmental factors. Hoinka and Zie¸bik (2010) applied a mathematical method to assess the energy management of complex buildings, and pointed out that energy management is an essential aspect in the preliminary design of complex buildings. Favre and Citherlet (2008) presented the features of Eco-Bat, a computer program developed to assess the environmental impact of buildings, including construction materials and energy consumed, and to evaluate environmental impact based on the LCA approach. Yan, Shen, Fan, Wang, and Zhang (2010) identified the scope and sources of GHG emissions in building construction, including: the manufacture and transportation of building materials, and energy consumption of construction equipment, as well as in processing resources and disposing of construction waste. While previous relevant researches mainly focus on the energy management measurement of building construction, this paper employs the ABC approach to identify the construction process activities of a green building project life cycle, following which, a cost estimate is prepared for each activity individually.

Differing from the previous researches introduced above, the aim of this study is to develop an integrated decision model for construction companies to use in selecting green building projects, without sacrificing profit margins. The relevant entire life cycle of green building construction resources and activities will be incorporated within an ABC decision model, and both low-carbon construction method and CO_2 emission cost can be analyzed simultaneously. In addition, the features of capacity expansion features and price elasticity are incorporated into an ABC decision model by using a mathematical programming approach. The remainder of the study is organized as follows: Section 2 introduces LCA in green buildings, ABC concepts and CO_2 emission costs. An illustration of integrated MP and ABC decision-making models follows in Section 3, while Section 4 contains a short description of a case study and a discussion of the results. Section 5 presents concluding remarks.

2. Research background

The construction industry today is facing unprecedented and growing pressures from global economic problems, increasing natural disasters, rising material costs, and other political and environmental issues. The construction industry has been motivated to develop "green" building projects and to re-evaluate related construction costs (Kubba, 2010). This section presents recent relevant literature on the LCA of green buildings, CO_2 emission costs and Activity-Based Costing concepts.

2.1. Life cycle assessment of green building

Green building is a sustainable form of building that incorporates the life cycle concept, including green building plans and designs, production and transportation of building materials, construction, use and maintenance, and disposal processes, which minimize resource consumption and waste production. The LCA methodology has been widely applied in assessing the environmental burden of products and services during their life cycle; in particular, the construction industry has extended this concept to the selection of appropriate building materials and construction elements (Ortiz et al., 2009). Many previous studies have conducted an LCA of buildings in terms of energy management and environment impact issues (Chang, Ries, & Wang, 2010; Maria, Theophilus, & Peter, 2012). The life cycle point of view becomes increasingly important as green buildings use renewable building materials and efficient energy systems to achieve sustainable development. This study attempts to incorporate life cycle thinking into the cost measurement for green building projects; therefore it includes an assessment of the energy consumption of a building and the carbon emissions created during the construction process.

According to ISO 14040, stage one of any LCA study is clearly defining its purpose, scope and system boundaries. This study includes four main stages in the life cycle of green building.

(1) *Green design phase:* Green design strategies foster sustainability by considering occupant health and environmental resource depletion during construction. This phase includes green design consultant fees (e.g., construction site selection and renewable energy source adoption) (Arena & Rosa, 2003).
(2) *Construction phase:* Differing from the traditional construction process, an environmental impact assessment must be included in the green building construction process. This phase covers the transportation of building materials and low-carbon construction methods; it includes environment loads resulting from the use of heavy equipment or machines at the construction site (Li, Zhu, & Zhang, 2010).
(3) *Operation phase:* Energy consumption during the operation phase is separated into operational uses (cooking, electricity, heating and ventilating) and maintenance and building refurbishing (repair) activities (Blengini & Carlo, 2010).
(4) *Decommissioning phase:* This phase includes the dismantling of the building structure shell and the final disposal activities: landfill use, waste recycling and reuse (Zheng, Jing, Huang, Zhang, & Gao, 2009).

2.2. Carbon tax policy and CO_2 emission costs for green building projects

With increasing concerns about global warming and climate change, it is imperative for world governments to impose effective policy instruments to promote energy saving and reduce carbon emissions. Johansson (2006) theoretically evaluated the policy instruments used to contribute to reduction of CO_2 emissions, while preserving the competitiveness of the construction industry. Lee, Lin, and Lewis (2008) proposed that incorporating flexible price mechanisms into carbon tax rates was a useful policy tool for encouraging the reduction of carbon emissions.

With construction activities covering both machine operation and maintenance activity, the construction industry has traditionally produced the highest carbon emissions of various industry sectors. As an incentive-based policy instrument aimed at reducing emissions of carbon dioxide, carbon and energy taxation have had economic effects on construction companies. Joshua (2010) and Lu, Zhu, and Cui (2012) indicated that carbon emission costs