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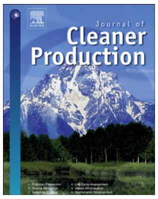

Economic sustainability, environmental sustainability and constructability indicators related to concrete- and steel-projects

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ABSTRACT

Due to an increased awareness of sustainable development and constructability, the construction industry is now facing challenges to reduce energy consumption, carbon emissions and other negative environmental impacts while maintaining high economic sustainability and constructability performance. This study investigates the performance of reinforced concrete framed (RC-framed) and structural steel framed (SS-framed) buildings on economic sustainability, environmental sustainability and constructability performance indicators in Singapore. The results suggest that economic sustainability, environmental sustainability and constructability performance are important in the decision making process for the selection of structural materials. While RC-framed buildings outperform SS-framed buildings in structural costs, maintenance costs and financial costs, SS-framed buildings outperform RC-framed buildings in increased area, flexibility of internal space, recycling rate, recyclability, waste rate, water consumption, labour saving, construction duration and construction quality. Both RC-framed buildings and SS-framed buildings performed on the same level in noise pollution and construction safety. The present study also provides a good guidance of selecting structural materials based on economic, environmental and constructable considerations.

1. Introduction

The way that the world has been using global natural resources in the past has placed a tremendous strain on the environment – depleting natural resources, polluting the environment, causing global warming, raising sea levels, and endangering biodiversity. For example, as a result of global warming, the global average sea level has risen at an average rate of 1.8 mm/year since 1960 and at 3.1 mm/year since 1993 (Intergovernmental Panel on Climate Change, 2007). A widely accepted cause of global warming is the increase of greenhouse gas (GHG) emissions, which come from both natural and man-made sources (Wu and Low, 2012).

The building and construction industry contributes to the increase of carbon emissions level in many aspects, such as manufacturing of raw materials and transportation of finished products. The cement section alone accounts for 5% of global man-made CO_2 emissions (Worrell et al., 2001a). Manufacturing of raw materials (e.g. cement and steel) and chemicals have considerable impact on CO_2 emissions (Worrell et al., 2001b). Transportation of raw construction materials is also energy intensive, especially for countries like Singapore which heavily relies on the import of raw materials (Wu and Low, 2011). Additionally, on-site construction of building is not always effective and may generate unnecessary carbon emissions (Wu et al., 2013). As one of the largest sources of emissions, the building and construction industry is facing increasing pressure to reduce greenhouse gas (GHG) emissions (Wu et al., 2014). Building also represents 24% of global extractions (Bribián et al., 2011). The manufacture, transport and installation in a building made of materials from the extractions, such as steel, concrete and glass, require a large quantity of energy (Bribián et al., 2011). According to Yohanis and Norton (2002), the initial embodied energy from building materials in a single-storey office building could account up to 67% of its operating energy over a 25 years period. Construction and demolition waste is also among the primary sources of waste (Coronado et al., 2011). According to Rodríguez et al. (2015), the European Union produced approximately

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530 million tonnes of construction and demolition waste, which accounted for 25–30% of the total solid waste generated.

In order to address these environmental issues, especially global climate change, the construction industry has begun to work towards achieving sustainability. For example, various technologies have been developed to mitigate carbon emissions during cement production (Huntzinger and Eatmon, 2009). In the construction industry, two of the main construction materials, concrete and steel, are considered as materials with high embodied energy. The appropriately selection from these two construction materials may help the industry to minimize the environmental impacts.

Following the global trend towards achieving sustainability, a systematic decision support system is needed because the traditional budget-oriented selection process is no longer suitable. However, the development of such decision support system may be problematic. For example, most of the green building assessment tools, such as the Building Research Establishment Environmental Assessment Method (BREEAM), the Leadership in Energy and Environmental Design (LEED) and the Singapore Green Mark (GM) Scheme, are applied to evaluate the environmental performance of a whole building from the life cycle perspective. The rating systems require comprehensive project information that may restrict engineers from using these systems due to not having adequate project information. Many studies have been initiated to develop a simplified model to incorporate sustainability issues in the decision making process for selecting structural materials. For example, Castro-Lacouture et al. (2008) and Paya-Zaforteza et al. (2009) have developed two models for selecting structural materials by integrating environmental and cost goals. However, constructability issues have also been recognized by the construction industry since the 1980s. According to Pulaski et al. (2006), "constructability" is an established concept in which changes to design are made to improve the efficiency of construction. It shows the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building (CIRIA, 1983). Recent studies have shown that by giving consideration to constructability in early design phase, significant improvements in the performance of green building projects can be achieved (Pulaski et al., 2006; Son and Kim, 2014). For countries that adopt progressive tightening on the supply of foreign workers and demand for better quality, increased constructability can be obtained by using labour-efficient designs and more pre-assembled products. According to Booth (1999), a key measure to improve constructability and productivity is to select structural building materials in a scientific way because the construction speed, labour-saving, and other associated performance vary depending on the structural materials used. Lindahl et al. (2014) also argue that appropriate material selection has the potential to not only reduce ecological impacts, but also link to future actions to move towards the full scope of sustainability. This paper therefore aims to: (1) identify the sustainability and constructability factors in the decision support system for the selection of structural materials between reinforced concrete (RC) and structural steel (SS); and (2) compare the performance of RC-framed and SS-framed buildings on these sustainability and constructability factors.

2. Methodology

2.1. Identification of indicators

Sustainability has been represented by a set of triangular concepts, which involves a comprehensive and integrated approach to economic, social, and environmental processes, i.e. the triple-bottom-line of sustainability. As a subset of sustainable development, sustainable construction is of great importance because half of the total raw materials extracted from the planet is used by construction and more than half of the waste comes from the construction sector (Mourão and Pedro, 2007).

The goal of sustainable construction is to create and operate a healthy built environment based on resource efficiency and ecological design (Kibert, 2008). The Conseil International du Batiment (CIB) (2004) established seven principles for sustainable construction, including:

- Reducing resource consumption;
- Reuse resources;
- Use recyclable resources;
- Protection from toxic substances;
- Apply life cycle costing; and
- Focus on quality.

The concept implies that resource-conscious design is central to sustainable construction and sustainable construction should at least focus on environmental and economic sustainability. As social sustainability can be difficult to quantify, many studies and tools, e.g. the Building for Environmental and Economic Sustainability (BEES), use environmental and economic sustainability as sustainability indicators.

2.1.1. Economic sustainability indicators

To achieve economic sustainability, the construction industry must shift the use of resources from non-renewable to renewable forms, from waste production to reuse and recycling, from an emphasis on first costs to life cycle costs and full-cost accounting, where all costs such as waste, emission, and pollution are factored into the price of materials (Kibert, 2008). Although traditional cost-accounting methods, e.g. internal rate of return and return of investment, can still be used in the decision making processes, these methods have been challenged for leading to incorrect decisions concerning environmental costs (Hamner and Stinson, 1995). Life cycle costing (LCC) is a useful tool to address these issues. According to British Standards Institution (2008), life cycle cost is the cost of an asset, or its parts throughout its life cycle, while fulfilling the performance requirements. The components in life cycle cost include construction costs, maintenance costs, operational costs, occupancy costs, end-of-life costs and non-construction costs (BSI, 2008). These factors have been selected as economic sustainability indicators in various studies on the performance of RC- and SS-framed buildings, which are shown in Table 1.

2.1.2. Environmental sustainability indicators

Due to the importance of environmental sustainability in the construction industry, there is a growing awareness regarding environmental sustainability (De Medeiros et al., 2014). Various environmental building assessment methods have been developed in the construction industry, using a wide range of environmental sustainability indicators. For example, the Leadership in Energy and Environmental Design (LEED) uses sustainable sites, water efficiency, energy and atmosphere, material and resources, as well as indoor air quality as the indicators while the Singapore Green Mark uses energy efficiency, water efficiency, environmental protection and indoor air quality as the indicators. According to Čuček et al. (2012), moving towards sustainability requires the redesigning of production and construction, which is built on a complete environmental building assessment. No matter what assessment methods are chosen, the primary role of an environmental building assessment method is to provide a comprehensive assessment of the environmental characteristics of a building using a common and verifiable set of criteria and targets for building owners and designers to achieve higher environmental standards (Cole, 1999).

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