Life cycle costing for obtaining concrete credits in green star rating system in Australia

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Abstract
Cement is one of the widely used materials in construction. Due to the adverse impacts towards the environment from cement manufacturing, green building rating tools always give a significant consideration towards concrete usage in green buildings. Irrespective of its significance in green buildings, there is a clear lack of research on life-cycle cost (LCC) impact of using supplementary cementitious materials (SCMs) in cement as required by green building rating tools. Therefore, this research analyses the life cycle costs of concrete using SCMs in obtaining concrete credits according to Green Star rating system in Australia. This research used fly ash, slag and silica fume as SCM for concrete. The SCM replacement percentage in concrete ranges from 10% to 60% as higher than 60% substitution is impractical. This research calculated LCC for each replacement percentage and specific building elements in different strength categories. LCC of concrete decreases with higher SCM replacement percentages. Further, there are only slight differences in LCC when comparing the three SCMs. In LCC, the contribution from the initial material cost is approximately 85%–87%, and in an exceptional situation such as in columns, this lowers to 66%. In larger columns, the cost of demolition is greater than that of the initial cost whereas it contributed to 61%–68% of the LCC.

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1. Introduction

Construction industry plays a major role in any country's economy. However, the construction sector has a significant impact on the environment and social well-being (Baloi, 2003). When considering the environmental impact, building and construction around the world consume about 40 percent of raw stone, gravel and sand, about 25 percent of virgin wood, about 40 percent of energy and about 16 percent of water annually (World Watch Institute, 2015). Due to these many adverse impacts, the construction industry needs to move towards sustainable development.

Abidin (2010) stated that sustainable construction is the way for the construction industry to contribute towards sustainable development. Increasing adverse impact on nature through construction lead to a wider recognition to create environmentally efficient buildings, commonly known as green buildings (Ali and Al Nsairat, 2009). Cassidy, Wright, and Flynn (2003) identified green buildings as buildings which increase the efficiency of sites use, energy, water, and materials, and reduce building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal throughout the complete building life cycle. One of the most important facts is that, when considering a green building, environmental, health and well-being and economic aspects are considered throughout the life cycle of the building and not just for the construction phase.

Although green buildings have many benefits and have gained wider recognition, initial costs of green building have always been one of the most highlighted topics. There are many misconceptions and myths attached to this concept. There is a basic idea that cost for green buildings is quite high compared to conventional buildings and there are also many other counter-arguments. Many researchers argue on the first cost premium of green buildings and illustrate that it acts as a barrier to the green building development (Ahn et al., 2013; Davis and Langdon, 2007; Gabay et al., 2014; Hwang and Tan, 2012; Pearce, 2008; Qualk and McCown, 2009; Tatari and Kucukvar, 2011; Zhang, 2014; Zhang et al., 2011). According to Dwaikat and Ali (2016), more than 90% of the reported...
green cost premiums through empirical investigations fall within a range from $-0.4\%$ to $21\%$. However, other researchers are arguing that the savings within the life cycle of green buildings are not well informed within the construction industry and it is necessary to look to into the green building in a life-cycle cost perspective rather than focusing on the initial cost premium. (Bartlett and Howard, 2000; Bond, 2011; Kim et al., 2014).

Concrete is one of the main building materials. In most of the green building rating tools there is a requirement to use less volume of cement, and substitute it with the supplementary cementitious material (SCM) for concrete (Green Building Council of Australia, 2015; Green Building Index, 2013; United States Green Building Council, 2014). In the literature, there are many types of research focusing on durability, modulus, compressive strength, creep and structural properties in using SCM in concrete (Dassetan and Bai, 2017; He et al., 2017). Wu and Ye (2017) identified the influences of the carbonation on the pore structure of SCMs blended cement paste. Mo, Lingle, Ayengar, Yap, and Yuen (2017), illustrated that higher content and better quality of cement paste in lightweight aggregate concrete increase the overall cost of production. Therefore, the possibility of utilising supplementary cementitious material (SCM), especially at higher volume is desirable to reduce the cement consumption and carbon footprint (Mo et al., 2017). However, in most of these studies on concrete, the cost is not discussed. Therefore, there is a clear lack of research on life cycle cost impact of using SCM in concrete.

Obtaining green certification from green building rating tools is becoming increasingly important. Unfortunately, lack of detailed LCC cost information focusing on the green credits has become a constraint to the development of green buildings. According to Wong (2010), research must be carried out on sustainable materials and methods of determining the most viable solution considering the whole life cycle. Although there is much research conducted regarding the concrete focusing on its properties, life cycle cost is rarely discussed. Therefore, this research aims to analyse the life-cycle cost impact of using SCM for concrete in green buildings.

1.1. Life cycle costing

According to Australian National Audit Office (2001), the process of LCC fundamentally involves assessing costs arising from an asset over its lifecycle and evaluating alternatives that have an impact on this cost of ownership. Further, in assessing costs over the life cycle, it is necessary to identify the different stages and types of costs related to the assets, or the buildings. According to Australian National Audit Office (2001), there are five main phases which trigger different types of costs which are design, purchase and construction, operational, maintenance, development and disposal.

In LCC, capital cost is the initial investment made for the project. Usually, there are three sub-categories to capital cost, namely; purchase costs, acquisition/finance costs and installation/commissioning/training costs (Woodward, 1997). Operational costs are the expenses incurred in the operation phase of the buildings. The ‘residual value’ of a structure depends on the decision to demolish, where the material can be recycled, or more carefully deconstructed to allow structural components to be reused (Gardner et al., 2007). Ascertaining costs for each variable in the formula can be difficult. Each of these given costs must be identified to calculate LCC.

Certain costs such as operational and maintenance costs are not available at the time of LCC calculation, and therefore, it is necessary to predict based on solid data. This involves a high degree of uncertainty. Many essential parts of the LCC calculation have to be determined, often by only scant evidence, and some of this information is of such crucial nature that high quality professional judgement and forecasting is necessary (Ashworth, 1989).

These costs incur in different periods of the life cycle. Since the timing of costs is different, it is necessary to reflect this in the LCC calculation (Gluch and Baumann, 2004). For this purpose, the most commonly used technique is the use of net present value and the time value of money, expressed as a discount rate, which depends on inflation, cost of capital, investment opportunities and personal consumption preferences (Gluch and Baumann, 2004). The discount rate controls the present value of costs over the life cycle and variation of the discount rate changes the impact of costs associated with maintenance, operation and end-of-life costs which span over the building life cycle (Gardner et al., 2007). Therefore, identifying the discounting rate is crucial for the calculation. According to Goh and Sun (2016), deciding the correct discounting rate is one of the limitations of an LCC study. The LCC significantly changes to the changes in discounting rate. This discounting method is commonly used in LCC calculations with costs occurring in many intervals.

However, cost indices can also be used to adjust the cost data according to the time period is used. According to Goh (2016) using cost indices overcome existing limitations in the building industry where there is a general lack of cost information and accepted standards for describing the life cycle behaviour of facilities and their operating systems.

1.2. LCC to assist in obtaining Green Star concrete credits

In the Green Star rating tool, there are eight main categories available. From these categories, “Material” category includes 14% of the credits (Green Building Council of Australia, 2015). This represents a significant proportion of the credit allocation. Therefore, when considering green certification using Green Star rating tool, it is essential to concentrate on the “Material” category. In these credit points, Green Star focuses on concrete, steel and timber. This category allocated up to 7 credits for the less usage of concrete, steel and building reuse. Further reduction of concrete can receive a maximum of 3 credits (Green Building Council of Australia, 2015). This is a significant portion of the credit allocation contributing to a 3% of the overall score of the total credit allocation. Concrete is the widely used construction material in the industry (Aitcin, 2000). Portland cement manufacturing industry is under scrutiny these days because of the large volumes of carbon dioxide emitted in the manufacture of Portland cement clinker (Gartner, 2004). Therefore, the significance of concrete credits allocated in the green building rating tools is widely discussed.

One of the options to achieve these credits is to use SCMs. According to Gartner (2004), the cement industry is currently responding rapidly to the demands by using SCMs principally derived from industrial by-products, such as blast-furnace slags and coal combustion fly ashes. Meyer (2009) also identified the increasing use of SCMs which can serve as partial substitutes to Portland cement such as fly ash, ground granulated blast furnace slag and silica fume. These SCMs are widely used worldwide, and it changes with the extent, these particular by-products produced within the countries. According to Gjorv and Sakai (1999), the utilisation rates of fly ash varied greatly among countries, from as low as 3.5% for India to as high as 93.7% for Hong Kong.

When considering these SCMs, those derive many economic and environmental benefits. Meyer (2009) argued that the most significant advantage of using fly ash is that it is a by-product of coal combustion, which otherwise would be a waste product to be disposed of at high cost. Moreover, concrete produced with fly ash can have better strength and durability properties than concrete produced without it and also as a bonus in addition to all other advantages it offers, fly ash is less expensive than Portland cement (Meyer, 2009). Slag is a by-product of the steel industry. However,
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