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Greenhouse gas emissions during timber and concrete building construction —A scenario based comparative case study

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ABSTRACT

Greenhouse gas (GHG) is a major air emission pollutant that creates environmental burden in buildings. Timber buildings are gaining notable popularity in the building industry due to life cycle environmental and economic benefits over conventional buildings. However, little or no studies have made attempts to compare greenhouse gas emission variations in timber and concrete buildings during the construction stage. Knowledge of emission at the construction stage is critical for passionate contractors who wants to maintain an environmental friendly built environment. The study presented in this paper aims to compare GHG emissions and energy consumptions during timber and concrete building construction. A process based quantitative assessment is conducted for evaluating emissions from materials, equipment and transportation stages. The comparative results of the study indicated that use of timber can reduce embodied emissions as well as transportation emissions during the construction stage. Scenario analyses results comprehends that recycling of materials and use of regional materials influence GHG emissions the most while transportation distance has medium effect on total GHG emissions at the construction stage of timber building. The results of the study are important in aggregate level decision making of timber and concrete buildings. Further studies are encouraged on conducting comprehensive assessment of different timber usages in a building to investigate the GHG emission variation.

1. Introduction

Buildings are known to be one of the major contributors of environmental emissions and impacts and resource consumers over its life cycle (Sandanayake, Zhang, Setunge, Li, & Fang, 2016; Zhang & Wang, 2016). Recent research findings have indicated that buildings contribution for world's top third of the greenhouse gas (GHG) emissions and one fifth of the worlds' resource consumptions (Guggemos & Horvath, 2005; Guggemos and Horvath, 2006; Sandanayake, Zhang, & Setunge, 2016). These statistics have been escalating at a rapid pace and various researches have made numerous attempts to minimise environmental impacts from buildings (Dixit, Fernandez-Solis, Lavy, & Culp, 2012; Kneifel, 2010; Xing, Xu, & Jun, 2008a). There are two major research focuses currently being adopted to minimise environmental impacts of buildings. One is the material usage and the other is energy optimisation during the service life of a building (Alcorn, 2003; Bribián, Uson, & Scarpellini, 2009; González & García Navarro, 2006; Huberman & Pearlmutter, 2008; Malmqvist et al., 2011; Shipworth, 2002; Treloar, Gupta, Love, & Nguyen, 2003; Watson, Mitchell, & Jones, 2004; Zabalza Bribián, Valero Capilla, & Aranda Usón, 2011). With the invention of energy user friendly techniques and processes in buildings, the latest research focus has been to minimise emissions and environmental impacts at construction stage of a building (Orabi, Zhu, & Ozcan-Deniz, 2012; Sandanayake, Zhang, Setunge, & Thomas, 2015; Singh, Berghorn, Joshi, & Syal, 2011; Yan, Shen, Fan, Wang, & Zhang, 2010; Zhang & Wang, 2016).

Use of timber instead of concrete is one of the current research emphases that have gained popularity over the past few years. Factors such as advantages in construction techniques, life cycle cost and energy savings have persuaded Architectural, Engineering and Construction (AEC) stakeholders to consent to timber buildings; especially in case of mid-rise buildings (Asif, Muneer, & Kelley, 2007; Buchanan, Deam, Fragiacomo, Pampanin, & Palermo, 2008 ; Ip & Miller, 2012). Despite these advantages, no research has been conducted on detailed comparison of environmental emissions at timber compared to concrete building construction. Knowledge of emissions and impacts savings during the construction stage of timber buildings will aid the contractors to maintain sustainable construction practices.

Thus, the study aims to assess greenhouse emissions associated with the construction stage of a timber building compared to a concrete

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building. Based on the results, a scenario analysis is conducted to examine the possible methods of reduction of emissions during timber building construction. The results of the study are expected to enhance knowledge of greenhouse emission profile and reduction capabilities at the construction stage of a timber building.

2. Background

Life Cycle Assessment (LCA) is a powerful tool used by many researchers to evaluate environmental impacts of a product or process over its life cycle (Klöpffer, 1997). Thus, LCA provides a comprehensive analysis of environmental impacts from material extraction to final disposal. It provides the practitioner an excellent foundation to analyse all the environmental impacts along the entire system of unit processes of the product or process.

Several studies have conducted LCA studies on timber and concrete buildings. A study comparing environmental impacts of steel and concrete revealed that lesser material stage emissions are observed for steel building and high use phase emissions are recorded for concrete building (Xing, Xu, & Jun, 2008b). Another study estimated GHG emissions in a concrete building and compared different sources of GHG emissions during building construction (Yan et al., 2010).

LCA study of wooden products in building revealed that timber tends to offer better environmental performance in terms of GHG emissions and construction waste reduction (Werner & Richter, 2007). LCA on a building in Australia which has cross laminated timber panels as the main structural material indicates that the building has 22% lower global warming potential and the operation of the building contributes the most towards the life cycle impacts. More recently, LCA study conducted to evaluate the replacement of reinforced concrete with Engineered Wood Products by considering mid-rise buildings, concludes that 100% replacement of reinforced concrete in a residential building by 100% Engineered Wood Products result in a saving of 26 $MtCO_2$-eq by 2050. Another comparative study examined the GHG emissions in building with wood substitution (Gustavsson, Pingoud, & Sathre, 2006). The results indicated that a net reduction of CO_2 emissions can be achieved by using timber in buildings. Observations from Table 1 exemplify that concrete buildings have been researched enormously for GHG emissions as compared to timber buildings. The observations are based on a Google Scholar search with the keywords, *"Timber", "Concrete", "Buildings" "Construction"* and *"GHG emissions"*.

The brief review on LCA studies on both timber and concrete buildings revealed that GHG emissions have been the major emission focus in past studies. This is mainly due to the huge environmental impacts from GHG emissions at global environment (Sandanayake, Zhang et al., 2016). Moreover, none of the studies have considered a detailed GHG emission assessment to compare the emission distribution during construction stage of timber and concrete/steel buildings.

3. Methodology

The following research methodology is developed based on the review findings and the objectives of the study.

3.1. Research gap

Literature review in the preceding section suggests that despite whole life cycle GHG emission studies on timber studies construction stage is not given enough due consideration. The emissions at the construction stage is often critical for designers and contractors who seek to maintain a vibrant construction environment and sustainable construction practices (Sandanayake et al., 2016). Therefore the current study aims to address the research gap of evaluating GHG emissions at the construction stage of timber building. Further sensitivity analysis is conducted to investigate the different variations of material and transportation usage and compositions.

3.2. Functional unit, objectives and emissions scope

Numerous studies have highlighted the significance of GHG emissions over other air emissions in building construction (Hong, Shen, Feng, Lau, & Mao, 2015; Mao, Shen, Shen, & Tang, 2013; Sandanayake et al., 2015; Yan et al., 2010). Therefore, the study sets an emission scope to evaluate GHG emissions of timber and concrete building construction. According to the Kyoto protocol, GHG emissions include carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O), Fluoro Carbons (FC) and sulphur hexafluoride (SF_6) (Iwata & Okada, 2014). However, construction stage GHG emissions are due to fossil fuel combustion, and therefore CO_2, CH_4 and N_2O are the dominant air pollutants. Herein, GHG emissions in the study refers to CO_2, CH_4 and N_2O emissions.

Timber and Concrete may incur different advantages and disadvantages over its implementation, materials characteristics and structural stability. With subsequent research confirming the capability of both concrete and timber as a building material, research have been directed towards investigating the environmental sustainability. However little or no research has been conducted on exploring and comparing the emission variation during the construction stage of both. The assessment and investigation of GHG emissions at the construction stage is critical for designers and contractors in maintaining sustainable designs and construction environment.

Thus, the objective of the study is to compare GHG emissions in timber and concrete building constructions. It also aims to identify the potential positive and negative drives in adopting timber construction from GHG emissions point of view. The functional unit of the study is set to GHG emissions per square metre (m^2) to attain a realistic comparison of GHG emissions between the two types of buildings.

3.3. System boundary

3.3.1. System boundary for emission sources

An ideal LCA study should consider all the life cycle stages in its system boundary to draw more conclusive results (Li, Zhu, & Zhang, 2010; Xing et al., 2008b). With the intention of comprehensive assessment of specific life stage, different life cycle stages such as cradle-to-gate, gate-to gate and well-to wheel (Tillman, Ekvall, Baumann, & Rydberg, 1994). Selection of a system boundary is often influenced by

Table 1
LCA studies on concrete and timber buildings (Based on search on Google scholar).

Study focus	Emission Scope	
	Material	Construction and other life cycle
Concrete/Steel	Zabalza Bribián et al., (2011); González and García Navarro, (2006); Yan et al., (2010); Xing et al., (2008b); Omar et al., (2013); Hong et al., 2015; Karan et al., (2016); Gerilla et al., (2007); Gustavsson and Sathre, (2006); Li et al., (2010)	Sandanayake et al., (2016); Guggemos and Horvath, (2006); Sandanayake, Zhang et al., (2016); Yan et al., (2010); Gerilla et al., (2007); Sandanayake, (2016); Junnila et al., (2006); Sandanayake, Zhang, Setunge, Luo, & Li, 2017; Robertson et al., (2012)
Timber	Werner and Richter, (2007); Gustavsson et al., (2006); Upton, Miner, Spinney, & Heath, 2008 ; Bribián et al., (2011)	Gerilla et al., (2007) ; Cole, (1998)