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Embodied carbon of building products during their supply chains: Case study of aluminium window in Australia

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ABSTRACT

This study aims to provide a reliable approach to quantifying the embodied carbon in building products during their supply chains in Australia. For embodied carbon quantification, the cradle-to-factory gate system boundary includes all stages in the product's life cycle from extraction of materials, through processing, transportation and manufacturing. For performing hot spot analysis on the production of the product, the method restricts embodied carbon modelling and analysis to the realm of influence in which production related activities can be directly controlled or influenced by the manufacturer of the final product. The approach was quantitatively demonstrated by showing how embodied carbon in an aluminium window brand is calculated and how the embodied carbon can be reduced in the final product design with the various design contexts. Through this study, we found that the window manufacturing process contributes 11% of total carbon emission. Transportation contributes only a small amount (0.45%) of the total. The supplied aluminium extrusions exhibit a high contribution to the total carbon emissions. This study also shows interesting scenario results by applying alternate design options for the purpose of reducing carbon in the final product.

1. Introduction

With an increasing awareness of climate change, the building industry sector becomes increasingly concerned about energy use, carbon emissions and their allocations to buildings and building products. The running of buildings contributes 23% to Australia's total GHG emissions. Of these emissions, approximately 10% are from operating commercial buildings and 13% from residential buildings (Colonial First State, 2011; Bond, 2010; API, 2011). The carbon emission due to running of building, which is called operational carbon, is a significant contributor to a building's total life cycle carbon emissions, but it is only a part of it. The other part, which is called embodied carbon is also important. Embodied carbon is generally defined as the carbon emissions (as kg of CO_2eq) which comes from the process of extraction of raw materials, manufacturing of building products, transportation to the site, building construction, maintenance and demolition of building (Dixit et al., 2014; Treloar et al., 2000).

For the life cycle of a typical building, about 80% of carbon comes from running of building (e.g., lighting, heating, cooling, etc.) and the rest are relevant with embodied emissions (Wuppertal Institute, 2011). Due to increase of energy efficiency of building, however, the existing ratio of embodied to operational carbon has changed from 20:80 to 40:60 for an average building (Lane, 2007; Seo et al., 2012; Sturgis and Roberts, 2010; Wuppertal Institute, 2011). The share of embodied carbon will steadily increase over time since zero (operative) carbon emission buildings become popular. Thus, the carbon emissions of the elements that go into buildings will be our key concern in carbon reduction (Chau et al., 2012; Ortiz et al., 2010; Seo et al., 2012). The knowledge of carbon emissions attributed to building products should help us target where and what innovations can be prioritised to reduce carbon.

Embodied carbon and related assessments for building industry are getting interest but have not been extensively applied and used in the building product sector, particularly considering for their supply chain. Embodied carbon assessment is being used

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for carbon reporting by companies (meaning reporting what has happened), but it has not been integrated into the design and management processes of the building product companies. RIBA (2009) identified a number of skills necessary for creating low carbon buildings: Client skills (knowledge of climate change, communicating the importance of low carbon design, negotiations with authorities), design skills (regulation and standards, thermal characteristics, building services and renewable energy systems, low carbon design, energy assessment), procurement skills (carbon impacts of design and construction, capital and in use costs, funding mechanisms, economics of low carbon technologies), construction skills (commissioning, ensuring delivery of low carbon design, metering and monitoring). Of these skills only one is relevant to embodied carbon assessments–regulations and standards, and it requires every stakeholder to share some basic understanding.

Considering this context, in this paper aluminium window product was selected in building products as a case study. This paper intended (1) to promote understanding of the carbon impact of the quarrying and processing of building products and (2) to provide a process-based method to quantify the embodied carbon of a building product and provide hot spot analysis in the product production of aluminium window. In this paper, we present the importance of understanding embodied carbon in buildings and building products. This paper also suggests a method of evaluating embodied carbon in aluminium window building product considering their supply chains. As an illustrative example, a case study shows how to use the method to reduce embodied carbon in the supply chain of aluminium window.

2. Evaluation of embodied carbon of building product

2.1. Definition of embodied carbon

Embodied carbon impact is part of life cycle assessment (LCA). LCA includes the systematic evaluation of the environmental aspects of a product, system or service through its life cycle (i.e. from extraction, processing, manufacturing, transport and distribution, use, maintenance, recycling and disposal). Angelini and Nawar (2008) define embodied energy as the total energy consumed during the whole life of a product. Recently, Dixit et al. (2012) discussed parameters causing problems in embodied data analysis. In their study, embodied energy is defined as energy consumption during the processes of building material production, on-site delivery, construction, maintenance, renovation and final demolition. UKWIR (2008) defines the embodied carbon of a product as the total carbon dioxide equivalent (CO_2eq) that is emitted during the life cycle stages of extract, processing, use and disposal of the product. While Jones (2011) describes embodied carbon as mainly coming from the use of fossil fuel resources to heat and power production processes and transportation activities. Many studies (Fay et al., 2000; Haynes, 2010; Crawford and Treloar, 2005; Scheckels, 2005; Oztas and Ipekci, 2013; Venkatarama and Jagadish, 2003) define the embodied energy of a product as the energy consumed by all the process associated with its production. Thus, embodied carbon can be defined as the carbon dioxide emitted into the atmosphere as a result of all the associated energy used in the production of a product.

For building construction, the embodied carbon consists of the initial embodied carbon, the construction carbon and the recurring embodied carbon (Jones, 2011; Holtzhausen, 2007; Cole and Kernan, 1996). The initial embodied carbon is the product-based carbon emissions before the construction of the building, including the extraction of raw materials, manufacturing of products and transportation to the construction site. The construction carbon is the emissions associated with the construction phase of the building, i.e. assembly on site. The recurring embodied carbon is the emissions associated with the maintenance, replacement, disassembly and demolition of the building. The total embodied carbon of a building is the sum of all three. However, in this study, the embodied carbon is confined to initial embodied carbon only. This is because this study only focuses on the embodied carbon emissions for building products before the construction of the building.

The measurement of carbon emissions (embodied carbon and/or operational carbon) is represented by a measure of "global warming potential" (GWP) of any greenhouse gas, which is the ratio of heat trapped by one unit mass of the greenhouse gas to that of one unit mass of CO_2 over a specified time period.

2.2. Embodied carbon intensity of power

2.2.1. Importance of embodied carbon

Recently, many researchers (e.g. Crawford and Treloar, 2003; Crowther, 1999; Pullen et al., 2006; Cabeza et al., 2013; Hammond and Jones, 2008) demonstrated that the embodied impacts of energy and carbon are increasing and occupy a significant proportion of the life cycle impacts of buildings. Chen et al. (2001) analysed embodied energy of residential building in Hong Kong and reported it can contribute up to 40% of total energy consumption. Similarly, Thormark (2002) evaluates embodied energy of an efficient apartment in Sweden and estimated embodied energy as 45% of total energy during the 50 year life span.

Following the effect of decreasing operational energy and carbon over time, the proportion and concern regarding embodied carbon in buildings has increased. Typical Australian commercial buildings with 3 star energy rating show roughly 12% of total carbon emissions during the 50 years life span (Crawford and Treloar, 2003). When the building energy efficiency is increased to 5 stars, the share of embodied carbon is increased to 22%. In either case, the operational carbon is still a significant contributor to the whole of life carbon emissions. However, when net zero carbon buildings become more prominent in the future, there will be no operational carbon for these buildings; and all carbon emissions will be attributed to embodied carbon.

2.2.2. Overestimation of operational carbon

Generally, embodied carbon takes up 20–25% of total carbon emissions in conventional commercial buildings in Australia (Seo et al., 2012). Recently, Darby (2011) argued the importance of embodied carbon of building by showing different weight of time for embodied and operational carbon. For a typical building, operational carbon is generally larger than embodied carbon. But, operational carbon occurs over the life time of a building (about 50 years), while most of embodied carbon occurs at the start of the building's life. Thus, Darby (2011) suggests that embodied carbon needs a weighting to reflect the fact that carbon savings made at the early stage (start of building's life) could be more valuable than the projected savings in the future, when considering the time frame of carbon reduction.

In addition, in the conventional carbon assessment, operational carbon of buildings might have been overestimated. Buildings consume large amounts of electricity for their day-to-day running. When calculating operational carbon, we apply the static value for carbon intensity of electricity over the life time of the building, which assumes no improvement in carbon intensity from electricity generation over time. However, carbon emissions from electricity generation are decreasing steadily due to increasing natural gas usage as well as renewable energy supply in the electricity generation mix. (See Green Energy Markets (2011) for more details.)

Australian Government (The Treasury) (2011) released carbon price modelling (entitled Strong Growth Low Pollution, SGLP) to