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Quantitative assessment of carbon dioxide emissions in construction projects: A case study in Shenzhen

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ABSTRACT

Construction management in China has embraced a new practice encompassing the evaluation criteria of green construction. Thus, greenhouse gas emissions produced during the construction period should not be overlooked anymore. The greenhouse gas emissions from construction projects are evaluated based on life cycle assessment theory, and on green construction evaluation and management techniques. A procedure for assessing the greenhouse gas emissions from construction projects is developed using the unit construction process, and by classifying and integrating the different components of construction projects. A segregation-integration method was established for calculating the greenhouse gas emissions of construction project. A mathematical model and framework to calculate the greenhouse gas emissions from construction projects have been established. The energy consumption and carbon dioxide emissions for earthwork, foundation work, masonry, and reinforced concrete during construction are calculated based on the example of a commercial building in a large-scale residential complex in the Pingshan New District of Shenzhen City. The greenhouse gas emissions were calculated as equivalent carbon dioxide emissions. High-rise buildings and villas have the highest unit carbon emissions of 54.51 kg/m^2, and account for 84% of the carbon dioxide emissions produced during the construction of the residential community. The unit carbon emissions for construction of the entire residential community are approximately 54.18 kg/m^2. The scientific value of this paper is that the carbon emissions during the construction stage of a residential community were quantitatively assessed. The unit carbon emissions of the buildings during construction can be used to calculate unit energy consumption of buildings during construction, which should be useful in realising energy savings, and can therefore provide management guidance for reducing energy consumption during the life cycle of building, especially consumption during construction.

1. Introduction

Large quantities of greenhouse gases (GHGs) are emitted during construction projects. The carbon dioxide emissions (termed carbon emissions hereafter) arising during construction are an important component of the carbon emissions over a building's life cycle. Global warming caused by excess emissions of GHGs has become a major international focus. Climate change and its social, environmental, economic and ethical consequences are widely recognized as the principal set of interconnected problems facing human societies. The impacts and costs will be enormous, profound, and unevenly spread across the globe for decades (Huisingh et al., 2015). Since the Copenhagen Conference in 2009, most countries have undertaken specific actions to mitigate GHG emissions and global warming. Buildings produce and emit large quantities of GHGs over their entire life cycle, which extends from the production of raw materials to transportation, construction and installation, operation and use, and eventual demolition. Buildings are responsible for more than 40% of global energy usage, and as much as 33% of global GHG emissions in both developed and developing countries. The construction industry is responsible for a number of complex environmental effects, particularly carbon emissions. Construction has been a major source of energy consumption and carbon emissions globally (Allouhi et al., 2015).

An investigation by Peng (2016) showed that the construction, operational, and demolition stages of the life cycle of a building produce 12.6%, 85.4%, and 2% of the total CO_2 emissions, respectively. In the past decade, reductions in carbon emissions in the

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construction industry have focused on the operational stage. In recent years however, researchers have realized the importance of the construction stage in reducing carbon emissions (Chou and Yeh, 2015). The GHG emissions during construction and installation are the most important component of the emissions from the entire life cycle of buildings (Hong et al., 2015). Energy consumption keeps increasing in China's construction sector, with the constant growth of the urban population, and with more and more large-scale mixed commercial-residential communities being built in cities across China. In order to achieve the co-benefits of effectively reducing energy use and costs, and GHG emissions, all aspects related to energy performance in the construction stage need to be addressed (Jiang et al., 2013). Despite the fact that over 80% of total energy use in a building's lifecycle is contributed by the operational stage, the focus of this study is placed on the construction stage, as a proper understanding of the energy consumption and carbon emissions will enable an exploration of effective approaches to achieving the above co-benefits. Building construction consumes large quantities of resources, uses many types of construction and transportation equipment, and emits large amounts of GHGs over a relatively short time period. Thus, the emissions during construction are intense and concentrated. The calculation of GHG emissions from construction processes is also important for the assessment of carbon emissions during the life cycle of a building. The unit carbon dioxide emissions of buildings can be used to calculate unit energy consumption of the buildings in construction, and therefore it can provide management guidance for reducing energy consumption in the life cycle, especially during construction (Jiang et al., 2014). The same is applicable in large-scale mixed commercial-residential complexes. The purpose of this paper is to develop a quantitative assessment method of greenhouse gas emissions on effective building construction stage only. The emissions from material production and transportation were not considered in the construction stage in this research.

Based on life cycle assessment (LCA) theory, and a life cycle inventory (LCI) analysis of construction processes, this paper develops a complete model for the calculation and assessment of carbon emissions during construction. The energy embodied in building materials are not considered in this stage. The main contents of the paper include: (1) establishment of a framework to calculate the GHG emissions during construction; and (2) calculation of GHG emissions during construction of a large-scale residential community in Shenzhen City.

2. Life cycle assessment (LCA)

The concept of LCA originated from the analysis of resource utilization and the environmental impact of packaging by the Coca-Cola Company in the 1960s and 1970s. The Society of Environmental Toxicology and Chemistry (SETAC) first scientifically introduced the concept of LCA assessment in 1990, and defined it as the entire life cycle of a product, process or activity, including the excavation and processing of raw materials, product manufacturing, transport and distribution, usage, maintenance, recycled use or disposal (Fava, 1993; Guinée et al., 1993). The International Organization for Standardization (ISO) has performed in-depth research on this theory and defined the LCA concept as the collection and assessment of the input, output and potential environmental impacts of product systems during their entire life cycles (British Standards Institution, 2006). The LCA concept was included in the ISO 14000 series. Although different organizations have different definitions of LCA, the core content is the same, in that they all agree that the main function of LCA, as a scientific and systematic assessment method, is to assess the environmental impact of the entire course of a process, a product or a service from the production of raw materials to its final disposal (Hoxha et al., 2014; Oyarzo and Peuportier, 2014). This theory was introduced to the construction industry in 1990, and has gradually become an important tool in the assessment of the environmental impacts of construction (Fong et al., 2008; Wallhagen et al., 2011). The framework of LCA (Umetsu et al., 2002; British Standards Institution, 2006) is shown in Fig. 1.

To apply the LCA theory to the construction industry, the life cycle of a building must be classified. The classification of life cycle stages is used to accurately define the aim and scope of studies. Shang and Zhang (2010) showed that the building life cycle covers the excavation of raw materials, the production of construction materials and equipment, the processing and manufacturing of components, maintenance during operation, and demolition. The calculation of carbon emissions for a building project should be based on the entire life cycle of the project, which includes the life cycle “from cradle to grave”. However, Shang and Zhang (2010) more clearly classified the life cycle into four stages: the preparation of construction materials, construction, use and maintenance of buildings, and demolition. This paper does not quantitatively assess the GHG emissions for the entire life cycle of a building project, but only for the construction stage. The LCA theory and framework will be used to assess the GHG emissions from construction activities and the related consumption of energy and materials based on the construction plans and processes provided by the construction company. The carbon emissions embodied in the building materials, and generated during use and maintenance of the building, and demolition, will not be addressed.

3. Scope and goal

The scope or boundaries of any given project are defined based on the goal of the assessment (Takemi et al., 1995), which is the first step of studying the life cycle of a project. The building life cycle is normally divided to several stages using time sequences as shown in Fig. 2, i.e., the production of construction materials, transportation, construction and installation, use and maintenance, and demolition and clean-up. In this paper, the research scope of greenhouse gas emissions was limited to the construction and implementation phase, namely the “construction and installation” phase.

From the perspective of project management, the life cycle of construction projects includes the entire period from the project conception to completion, acceptance, use, and demolition. The life cycle can be classified into four stages: (1) conception; (2) planning; (3) execution; and (4) finishing. The construction stage represents the project execution, and extends from the start of the project to

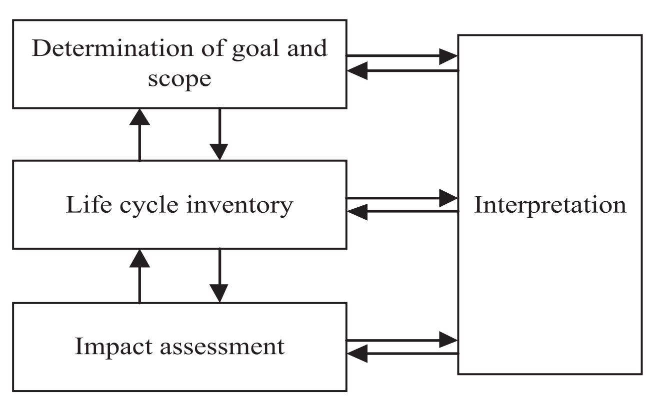

Fig. 1. Theoretical framework of LCA.