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A life cycle assessment model for evaluating the environmental impacts of building construction in Hong Kong

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ABSTRACT

Building construction consumes large amount of energy and material. Despite that, not much effort has been directed to examine the environmental impact of the construction phase, and this is particularly relevant to Hong Kong where the demand for building construction is ever increasing. In this study, a life cycle assessment (LCA) model namely the Environmental Model of Construction (EMoC) is developed to help decision-makers assess the environmental performance of building construction projects in Hong Kong from cradle to end of construction. The model provides comprehensive analyses of 18 environmental impact categories at the midpoint and endpoint levels. By inputting project specific data to EMoC, it can generate results of over two-hundred detailed processes. A public rental housing (PRH) project is fed into EMoC to examine the environmental performance of this type of projects. The results indicate that material is the major contributor to environmental impacts of the upstream stages of public housing construction. The carbon emissions of the studied project amount to 637 kg carbon dioxide equivalent per square meter of the gross floor area. Sensitivity analysis reveals that the environmental pollution can be significantly reduced by adopting a higher proportion of precast concrete components. The model should help support decision-makers identifying pragmatic solutions to reduce the environmental burden of a building project at the design, procurement and construction stages.

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1. Introduction

While economic development can lead to an improvement in the quality of life, the corresponding environmental damages to our pristine planet may affect human health and ultimately undermine the economic growth. Notable environmental issues include global warming, energy crisis, ozone depletion, etc. In order to control environmental pollution and sustain the development, the term ‘sustainable development’ was proposed by the World Commission on Environment and Development (or the Brundtland Commission), with the well-known definition being ‘the development that meets the need of present without compromising the ability of future generations to meet their own needs’ [1]. Environmental protection forums, such as Kyoto Protocol, Montreal Protocol, Agenda 21, etc., have played an important role in decreasing and preventing the environmental pollutions in specific impact categories like global warming and ozone depletion. Regional and national environmental strategies are consequently formulated. For instance, the China's 12th Five Year Plan aims at a 40–45% reduction in carbon intensity (carbon emission per GDP) from 2005 to 2020 [2].

Fulfilling the goal of sustainable development necessitates the control of the environmental impacts arising from the massive construction activities, since construction consumes large amount of materials and generates considerable pollutions. It was reported that civil and construction works are responsible for 60% of raw material consumption [3], and of which 40% is attributed to building construction [4]. The production rate of concrete is about 1 ton per capita per year [5,6]. As an essential component in concrete, cement is a carbon-intensive material that contributes about 5–7% to the global anthropogenic carbon emissions [7]. Construction consumes 16% of the total iron and steel production annually [8], while the steel and iron industry is responsible for 6.7% of the world carbon emissions [9].

To estimate the environmental impacts generated during building construction is, therefore, imperative to the industry. Currently, the building environmental assessment schemes, such as the Leadership in Energy and Environment Design (LEED) [10] by

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the U.S. Green Building Council (USGBC) and the Building Environment Assessment Method (BEAM) [11] by the BEAM Society in Hong Kong, are widely applied and recognized as the assessment method to evaluate the environmental performance of buildings. These rating systems provide evaluation through a semi-quantitative scoring method, while the emitted substances cannot be systematically quantified. In addition, the assessment is focused on certain impact areas, e.g. indoor air quality, energy consumption, ozone depletion, water consumption, etc. Therefore, those impact categories which are beyond the evaluation scope are neglected, despite that emissions generated during construction may also be influential to those categories.

As an alternative to the building environmental assessment schemes, life cycle assessment (LCA) can quantitatively evaluate the environmental impacts of a product based on a large number of recognized impact categories. Because of its comprehensive coverage on environmental impacts and effectiveness of calculation, LCA has been intensively adopted as a decision support tool in both the business and political levels. Some studies applied LCA to estimate the environmental performance of construction materials [12,13], building operation [14], demolition methods [15], etc. In Hong Kong, an LCA model was established to assess the energy consumption of commercial buildings [16]. Moreover, an LCA study was conducted to evaluate the environmental impacts of construction materials used in public housing projects in Hong Kong [17]. Despite several studies [18–21] were focusing on the construction phase, none were specifically designed for Hong Kong. With limited storage space on site and in order to meet the continuous demand for housing facilities in Hong Kong, precast concrete is becoming increasingly popular, in particular in public housing estate construction. However, previous research studies have not paid enough attention to the adoption of precast concrete components in particular the processes within the precast yard where precast concrete products are manufactured. A holistic LCA model covering the processes of manufacturing and on-site installation of precast components is lacking.

To bridge the research gap and to help uncover the environmental impacts of construction projects, an LCA model known as the Environmental Model of Construction (EMoC) is developed to estimate the upstream life cycle stages of building construction up to the end of construction in a quantitative manner. Developed in Microsoft Excel, EMoC consists of a series of functional worksheets to facilitate environmental analyses on the construction activities according to a detailed breakdown of material, transportation, energy, waste treatment, etc. This enables, for instance, the adoption of precast and cast-in-situ concrete be analyzed in a transparent and structured basis. Besides, impact assessment is provided using both the midpoint and endpoint approaches so that the model results can be interpreted at different levels. This paper provides a step-by-step introduction of EMoC by exemplifying the model structure, assessment scope, collection of background data, calculation methods, as well as the model inputs and outputs. Finally, a case study of a public housing project in Hong Kong is presented to test the model performance.

2. Model development

2.1. Model scope

EMoC[1] is designed to provide assessment for high-rise concrete framed buildings, in particular for those residential buildings adopting precast concrete elements. The model can be applied in Hong Kong, and potentially be used in mainland China as well as other regions with further development needed. EMoC covers the ‘cradle-to-end of construction’ activities, which include the processes on or before the construction process, i.e. from raw material extraction, through material manufacturing, transportation, to the on-site construction (Fig. 1). Moreover, waste treatment of construction materials is also involved in the scope of the model.

Four types of resources are considered in EMoC, i.e. energy, material, equipment and labor. In terms of energy, the model analyzes three energy resources *viz.* electricity, diesel and gasoline. The production and usage of energy resources are embraced in the model while the transportation and combustion of fuels are also evaluated.

Construction materials refer to both the permanent and temporary materials whereby the environmental pollutions generated from material manufacturing and transportation as well as the waste treatment of materials are estimated in EMoC. Besides, the delivery of equipment and the fuel consumed by equipment on-site along with the environmental impacts resulted from labor transportation are also scrutinized.

On-site construction activities are the primary focus of EMoC. The model is capable of calculating the environmental impacts of over 200 construction activities, in particular those related to the concrete work. The environmental impacts of precast and cast-in-situ concrete can be evaluated independently. Apart from concrete, the model can be used for evaluating other construction activities such as ground work and masonry.

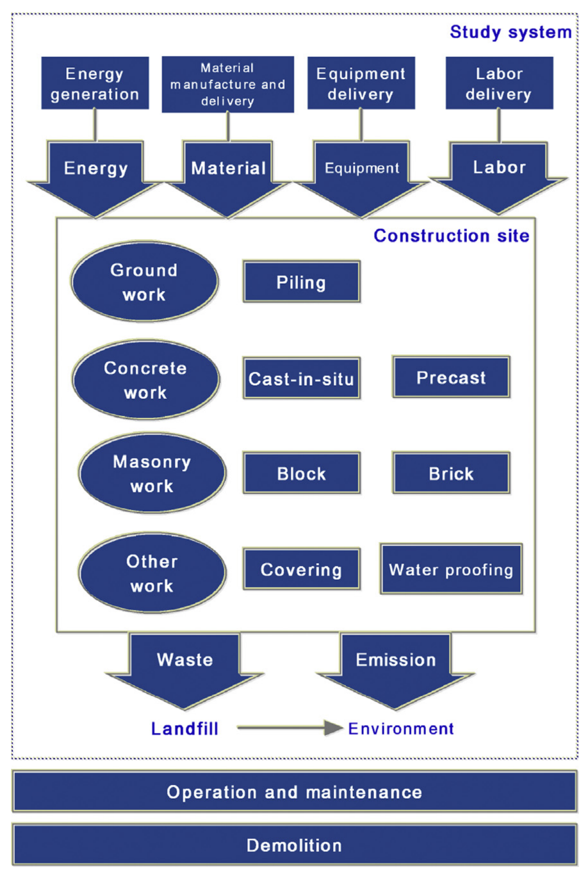

Fig. 1. Schematic illustration of the processes considered in EMoC.

[1] The intended users who are interested in EMoC can approach the first author Y.H. Dong (yhdonghk@gmail.com) for a copy of the model EMoC.

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