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Comparing carbon emissions of precast and cast-in-situ construction methods – A case study of high-rise private building

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HIGHLIGHTS

- Adoption of precast concrete can reduce the carbon emissions.
- The carbon emission of 1 m^3 cast-in-situ concrete is 692 kg CO_2 eq.
- For 1 m^3 concrete, precasting can lead to 10% reduction of carbon emission.
- Adoption of precast façade can reduce 2.1 kg CO_2 eq per m^2 floor area.
- It is highly recommended to adopt precast concrete in building construction.

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ABSTRACT

Buildings are one of the primary contributors to carbon emissions. Given the small size of construction site and increasing housing demand in Hong Kong, precast concrete has been frequently adopted in not only public residential buildings, but also the private sector. This study compares the carbon emissions of precast and traditional cast-in-situ construction methods based on a case study of a private residential building in Hong Kong. Life cycle assessment (LCA) model is established to consider the system processes from cradle to end of construction. The comparison is conducted based on eight scenarios at four levels, i.e. cubic meter concrete, precast facade, group of façade elements, and an apartment. It is found that the carbon emission of the studied residential apartment is 669 kg carbon dioxide equivalent per one square meter floor area. Precasting can lead to 10% carbon reduction for one cubic meter concrete. Steel formwork for precasting performs better than timber formwork used in cast-in-situ concrete. Adopting more precast concrete can lead to less carbon emission. Based on the research findings, it is highly recommended to adopt precast concrete in building construction. The building industry should consider the carbon reduction as a benefit of implementing precast concrete.

1. Introduction

Rapid economic development consumes large amount of resources and degrades the environment. One of the primary concerns of environmental impacts is climate change being most likely attributed to the emissions of greenhouse gases (GHGs). The temperature growth is correlated with increased atmospheric concentration of GHGs, while carbon dioxide is the most important anthropogenic GHG [1]. In recent years, auditing and controlling carbon emissions have become a key strategy to achieve sustainable development. In Kyoto Protocol, 37 industrialized countries and the European Community committed to reduce GHG emissions by 18% below the 1990's level from 2013 to 2020 [2]. The China's 12th Five-year Plan aimed at a 40–45% reduction in carbon intensity from 2005 to 2020. In the meantime, Hong Kong formulated a carbon reduction strategy with 50–60% from 2005 to 2020 [3].

Buildings are contributors to carbon emissions, not only due to the energy consumption in building operation and maintenance, but also caused by the significant material use and intensive on-site construction processes. It has been reported that buildings account for 40% of the global material flow [4]. Concrete is an indispensable construction material with the worldwide annual consumption of 1 ton per capita [5], and this figure is even four-time higher in Hong Kong [6]. Concrete has been recognized as a carbon intensive material, and cement being the key ingredient of concrete is responsible for 5–7% of the world's anthropogenic carbon emission [7]. The on-site construction method is another source

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of carbon emission, mainly contributed from fuel consumption in heavy equipment and material transportation, embodied carbon in temporary materials, and waste treatment management.

Hong Kong is a concrete jungle with over 40,000 buildings [8] and most of the building stocks are built with reinforced concrete. Of the limited area of 1108 km^2, only 6.9% is used as the residential land and more than 66% are protected forest or wet lands [9]. The scarcity of available land imposes challenges on building construction in Hong Kong. To accommodate 7 million people, construction of high-rise residential buildings is the only choice for this compact city. Given the small size of construction site and increasing housing demand, precast concrete has been adopted to construct residential buildings. The history of precast concrete in Hong Kong can be dated back to the mid-1980s, and it was mainly used in public residential buildings developed by the Hong Kong Housing Authority (HKHA) [10]. Over the years, precast concrete has become more prevalent in terms of the precasting percentage and the types of precast elements, while it has only been introduced to the private sector in the last decade [11]. In Hong Kong, the public and private residential housing both hold about 50% population. In the private sector, the precast components are generally tailor-made for a specific building design and specific site; on the contrary, standardization across building projects is mostly adopted in public housing projects [12]. The elements that adopt precast concrete for the public sector include façade, staircase, refuse chute, slab, balcony, kitchen, etc., whereas precast concrete is mostly used for façade in the private sector. The gross floor area (GFA) concession of precast concrete was introduced in 2002, and this encouraged the private sector to adopt precast [13,14].

Prefabrication is a sustainable construction method of improved quality control, improved environmental performance, improved site safety, reduction of labor demand and construction time [15]. Jaillon et al. [16] reported the use of precasting method can lead to 52% of waste reduction and 70% of timber formwork reduction. Wong and Tang [17] compared the precast and cast-in-situ concrete with the system boundary from ‘cradle to site’ and concluded that precasting method can reduce carbon emissions. If ‘cradle to end of construction’ processes are considered, environmental benefits of precast concrete can also be detected [18]. Although the two studies have compared the carbon emissions between precast and cast-in-situ methods, they only focused on the public sector. The private sector that increasingly adopts precast concrete should not be excluded. The influence of precast concrete on the carbon emissions should be studied to provide proof of the carbon reduction due to precast concrete in the private sector, and hence encourage the adoption of precast concrete in terms of environmental benefits. Moreover, a comprehensive research to investigate the carbon reduction of using precast concrete based on the unit of a precast element or an apartment is still lacking.

To bridge the research gaps, this study compares the carbon emissions of precast and cast-in-situ construction methods through a case study of a private residential building in Hong Kong. Life cycle assessment (LCA) is applied to calculate carbon emissions with the upstream processes from ‘cradle to end of construction’ being considered. The comparison is conducted based on eight scenarios at four levels, i.e. a cubic meter concrete, a precast concrete element, a group of façade elements, and an apartment. The results are further discussed to deepen the understanding on the environmental performance of precast and cast-in-situ methods, as well as to provide suggestions for the building industry.

2. Methods

In this study, LCA is implemented to calculate carbon emissions of precast and cast-in-situ concrete. LCA is a widely used method to estimate environmental performance throughout a product’s life cycle. As described in ISO 14040/14044 [19,20], a LCA study is composed of four interactive phases, i.e. (i) goal and scope definition, (ii) life cycle inventory, (iii) impact assessment and (iv) interpretation. In the first phase, the key items in a LCA study are defined, such as study aim, system boundary, target audience, etc. The second phase is to collect essential data, establish the LCA model and calculate the inventory results. In the next, the inventories are further analyzed using a certain impact assessment method and indicator results of the studied impact categories are derived. The last phase is to interpret the results based on the goal and scope definition, as well as to conduct advanced analyses to detect the emission hotspots. This study generally follows the four-phase structure of LCA.

2.1. Goal and scope definition

The goal of the present research is to investigate the carbon emissions of precast and cast-in-situ construction methods for high-rise residential buildings. A typical private building project in Hong Kong is studied. The project provides about 3500 units in the site area of 96,800 m^2. The buildings are 30–35 floors with 8 apartments per floor. The layout plan of a typical floor is shown in Fig. 1. The project adopts precast façade which accounts for 6% of total concrete volume. Of the 8 apartments, A and H are three-bedroom apartments with a symmetrical layout design. Three different precast façade elements are used in apartments A and H, namely Element 10, Element 11, and Element 12, while Element 12 is shared by the two apartments. The analyses in this research will focus on apartments A and H.

In terms of the inclusion of life cycle stages, there are two types of LCA: full LCA and partial LCA. Full LCA refers to those LCA studies that consider all the life cycle stages of a product, i.e. cradle-to-grave. On the other hand, partial LCA only considers one or a few stages, such as gate-to-gate, cradle-to-gate, cradle-to-site, etc. This study is a partial LCA to include ‘cradle-to-end of construction’ life cycle stages.

As shown in Fig. 2, the processes included in cast-in-situ (IS) and precast (PC) scenarios (refer to Section 2.2.2 for the description of scenarios) are different. For the IS scenarios, the study system covers the initial stage of raw material extraction from mines and the production of materials in factories. Cement, aggregate and admixture are then transported to concrete batching plant for mixing and ready-mix concrete is produced. Ready-mix concrete, reinforcing bar and timber formwork are transported to the construction site for in-situ casting. The PC scenarios embrace the processes related to precast façade manufacturing. The precast yard is located in Guangdong Province in mainland China. To produce precast concrete, mixing of concrete is conducted in the batching plant located within the precast yard. The concrete mix and reinforcing bar are then poured into steel mold. After curing and stripping the steel mold, aluminum window frame is installed and the precast façade is stored in the storage area in precast yard. The precast façade elements are transported to construction site in Hong Kong and then installed. Other concrete elements, e.g. column, beam, slab, etc., are cast-in-situ. The treatment of construction waste is also considered in this study.

2.2. Life cycle inventory

2.2.1. Collection of data

Data collection is a critical step in LCA modeling. While an ideal LCA should be based entirely on site-specific data, soliciting such data from stakeholders requires large amount of time and effort [21]. The popularity of LCA is largely due to its effectiveness by using well-established databases. The combination of site-specific