

Life Cycle Assessment of the Environmental Impacts of Virgin Concrete Replacement by CO₂ Concrete in a Residential Building



M. Ma, Y. Zhou, V. W. Y. Tam, and K. N. Le

1 Introduction

Concrete is one of the most consumed materials in construction, with 25 billion tons produced globally per year [1]. However, it is considered as the most non-sustainable material. The acquisition of virgin aggregate consumes a considerable amount of energy and emits a large amount of greenhouse gasses [2]. Recycled aggregate from construction and demolition (C&D) waste could be a viable substitution in concrete production, both avoiding landfills and conserving natural resources [3]. Recycled aggregate could replace part or all virgin aggregate in concrete and the product is referred to as “recycled concrete” [1]. Although recycled concrete containing recycled aggregate is considered as comparable to virgin concrete, it is not widely accepted by the industry, because of uncertainty about material performance [4]. Recycled concrete has lower mechanical properties and higher shrinkage and creep than virgin aggregate with the same mix design [1]. In order to improve the properties of recycled concrete, CO₂ gas is injected into the recycled aggregate and the CO₂-treated aggregate is mixed into concrete as normal. This new concrete is known as “CO₂ concrete” and rivals the virgin concrete in its mechanical and durability qualities.

Environmental performance of the concrete has attracted increasing attention from academics [5]. Marinkovic et al. [1] summarized two research focuses on sustainable solutions for concrete production: (1) using recycled aggregate to partly or entirely replace virgin aggregate, and (2) replacing cement with cementitious materials [1]. Life cycle assessment is a commonly used tool to evaluate the environmental impact of a product [5]. Specifically, Xing et al. [6] compared the environmental benefits of

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virgin concrete, recycled concrete and CO₂ concrete, and found that CO₂ concrete was the best-performing product for greenhouse gas reduction, because the CO₂ was retained in the recycled aggregate during the carbonation process [6]. Residential buildings use a wide range of resources in their construction, including a great amount of concrete [7]. The environmental performance of a residential building using CO₂ concrete as a partial replacement for virgin concrete remains unknown, so our aim was to conduct a lifecycle assessment to evaluate the environmental impact of CO₂ concrete as a replacement in a residential building. Specifically, virgin concrete replaced by 0, 30, 50, 75 and 100%.

2 Methods

To fulfil the aim of this study, a building information modeling (BIM) and life cycle assessment integration program was used to conduct the life cycle assessment of a building in five scenarios where 0, 25, 50, 75 and 100%, respectively, of the virgin concrete was replaced by CO₂ concrete. The life cycle assessment was conducted according to the ISO 14040 framework, which provides a standard process of four phases, namely, goal and scope definition, life cycle inventory analysis, life cycle assessment analysis and life cycle interpretation phases. In this study, the process started with creating a BIM of a residential building as the goal and scope definition phase. The lifespan of the building was assumed to be 50 years. The analysis accounted for the full cradle-to-grave life cycle of the building studied across all stages, including material manufacturing, transportation, building construction, maintenance and replacement, and eventual end of life. In the life cycle inventory analysis phase, the bill of quantities for each building component was extracted from the BIM, and the life cycle inventory data of each component was retrieved from the GaBi 2018 databases, the Australian life cycle inventory database, and a literature review. The quantities of building components and their corresponding environmental impact coefficient were recorded in a spreadsheet. The life cycle environmental impact of the building in five scenarios was assessed by multiplying the quantities of building components by the corresponding environmental impact coefficient. In the life cycle interpretation phase, the building's environmental impact was expressed as global warming potential (reported in kg CO₂eq) based on the Traci 2.1 method [8].

3 Results and Discussion

The life cycle assessment results of the building in the five scenarios are presented in Table 1.

The results showed that replacing virgin concrete with CO₂ concrete in a building could greatly reduce its carbon emissions. By increasing the proportion of CO₂

Table 1 Life cycle environmental impact of a building in five scenarios

| | Scenario 1: 0% CO ₂ concrete | Scenario 2: 30% CO ₂ concrete + 70% virgin concrete | Scenario 3: 50% CO ₂ concrete + 50% virgin concrete | Scenario 44: 75% CO ₂ concrete + 25% virgin concrete | Scenario 5: 100% CO ₂ concrete |
|---|---|--|--|---|---|
| Global warming (t CO ₂ eq/m ²) (declined ratio compared with scenario 1) | 275.830 (0) | 271.33 (1.6%) | 268.36 (2.7%) | 264.632 (4.1%) | 260.848 (5.4%) |

concrete in a building, its carbon emission decreases over its life cycle. As much as 5.4% of the CO₂eq/m² can be reduced when 100% of the virgin concrete is replaced by CO₂ concrete.

This study evaluated the life cycle environmental performance of a residential building using CO₂ concrete as a replacement for virgin concrete. The results suggested that the application of CO₂ concrete in the building sector will bring great benefits in terms of environmental performance. However, the mechanical and durability qualities of CO₂ concrete have been considered in this study. In future work, more emphasis should be put on the mechanical and durability qualities of CO₂ concrete for application in the building sector.

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