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Review

# Developments in life cycle assessment applied to evaluate the environmental performance of construction and demolition wastes

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ABSTRACT

This paper provides a review of the literature that applies the life cycle assessment (LCA) methodology to the assessment of the environmental performance of the life cycle of construction and demolition waste (CDW) management systems. This article is focused on generating a general mapping of the literature and on identifying the best practices in compliance with LCA framework and proposing directions for future LCA studies in this field. The temporal evolution of the research in this field and the aim of the studies have grown in parallel with the legal framework related to waste and energy efficiency of buildings. Most studies have been published in Europe, followed by USA. Asia and Australia, being at an incipient application stage to the rest of the world. Topics related to "*LCA of buildings, including their EoL*" and "*LCA of general CDW management strategies*" are the most frequently analysed, followed by "*LCA of EoL of construction elements*" and "*LCA of natural material vs recycled material*". Regarding the strategies, recycling off-site and incineration, both combined with landfill for the rejected fractions, are the most commonly applied. Re-use or recycling on-site is the strategy least applied. The key aspect when LCA is applied to evaluate CDW management systems is the need to normalise which processes to include in the system boundary and the functional unit, the use of inventory data adapted to the context of the case study and the definition of a common set of appropriate impact assessment categories. Also, it is important to obtain results disaggregated by unit processes. This will allow the comparison between case studies.



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## 1. Introduction

Large quantities of construction and demolition wastes (CDW) are produced during the construction and demolition of buildings and civil engineering works. Yet, despite the limited space available for disposal to landfill, the depletion of resources such as wood, metal and aggregates, and the embodied energy of construction materials, significant quantities of these materials are landfilled, without any previous treatment (JRC, 2011). This is despite widely available and environmentally effective alternative methods of waste management, such as reuse and recycling. Therefore it can be seen that there are considerable opportunities for improving current CDW management practices from an environmental point of view.

This is reflected in the ambitious target that European legislation (Directive 2008/98/EC) has set to increase the recovery and recycling of CDW to 70% by 2020. The EC waste hierarchy has established a sequence of management preferences: prevention, preparing for re-use, recycling, other recovery, and finally disposal as the least desirable option. However, variations from this framework are possible for specific waste streams and under specific circumstances in order to ensure the best solution for the environment.

The Life Cycle Assessment (LCA) methodology (ISO 14040-44, 2006) is increasingly being used to identify strategies that will improve the environmental performance of waste management systems. Its application to evaluate the environmental behaviour of alternative scenarios for managing construction and demolition wastes (CDW) started in end-90s (Craighill and Powell, 1999) and has been recently increased mainly due to the support measurements set by the legal framework established by Directive 2008/98/EC and Directive 2010/31/EC.

Laurent et al. (2014a,b) reviewed studies that focused on the application of LCA to waste management in general, concluding that there was very few LCA studies addressing CDW and that there was important opportunities to expand this area of research. This review identified five studies that focused specifically on the application of LCA to evaluate the environmental performance of construction and/or demolition waste management systems (Blengini and Garbarino, 2010; Coelho and de Brito, 2012; Grant and James, 2005; Mercante et al., 2012; Ortiz et al., 2010b). However, a new body of literature in this field can be find if studies focused on analysing the whole life cycle of buildings or other civil engineering works, including its end-of-life (EoL), are included inside the boundary of the review.

In that context, the LCA methodology has been widely applied in the literature in order to analyse the environmental performance of buildings, the embodied energy and carbon consequence of buildings or their products and materials (Ortiz et al., 2009; Khasreen et al., 2009; Sharma et al., 2011; Buyle et al., 2013; Cabeza et al., 2014a). However, most of the literature included in these reviews focuses on the use stage of the building or on the materials and products used in its construction, and generally considers that the EoL of the building finishes with its demolition. This review goes beyond that stage and explores the management of CDW after the demolition process, including impacts or avoided impacts due to recycling, incinerating, landfill or other alternative treatment for CDW.

The overall aim of this paper is to provide a robust review of the literature focused on applying the LCA methodology to assess the environmental performance of CDW management systems, in order to identify a commonality across the studies and thus identify best practices for CDW management under a range of locations and circumstances. This will provide guidelines for future LCA research, as applied to CDW management systems, to enable comprehensive comparisons of results across different cases studies.

To achieve this overall aim, the following specific objectives have been defined: (1) to provide a comprehensive and detailed mapping of LCA studies (since early studies in the later 1990s to early 2015) specifically focused on assessing the management of CDW once it has been produced either during the construction, refurbishment or after the demolition of buildings or engineering works. In addition CDW generated at a regional or national level, altogether regardless of its origin; (2) to identify the temporal evolution, geographical location, origin and type of CDW, etc. for each study; (3) to classify studies according to their purpose and analyse the influence of the legal framework on them; and finally (4) how the LCA methodology has been applied in each case study, to identify best practices and provide a guidance for future studies in compliance with the standardised LCA framework.

Keeping these objectives in mind, the scope of this review is to include studies considering totally or partially, the environmental impacts created or avoided through the different life cycle stages that can be identified in any CDW management system: collection and segregation of CDW, transport to different treatment/disposal facilities, valorisation process (re-use, on-site/off-site recycling, incineration, etc.) or final disposal in landfill.

Other different reviews have been published but they focus on different aspects of CDW outside the boundary of this study. Yuan and Shen (2011) analysed publications related to CDW in order to identify the potential future trends in six topics (generation, reduction, reuse, recycling, management in general and human factors), Wu et al. (2014) and Masudi et al. (2012) review methods for quantifying CDW, Behera et al. (2014), Väntsi and Kärki (2014) and Evangelista and De Brito (2014) review the status of materials made out of recycled CDW, Clark et al. (2006) review the CDW regulation in US, or Yeheyis et al. (2013) review the current situation of CDW management in Canada. So, none of them apply the LCA methodology to assess the environmental performance of the life cycle of CDW management which this review aims to undertake.

## 2. Research methodology

### 2.1. Identification of studies

To achieve a comprehensive understanding of the current knowledge published in the field of environmental performance of CDW management from a life cycle perspective, the following procedure was followed:

- The identification of studies in scientific journals was undertaken by a systematic search in Scopus search engine as a starting point. The general string used were "construction and demolition waste", "construction waste" or "demolition waste" and more specific strings were added for more refined searches