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Influence of construction and demolition waste management on the environmental impact of buildings

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ABSTRACT

The purpose of this study is to quantify comparable environmental impacts within a Life Cycle Analysis (LCA) perspective, for buildings in which the first (Materials) and last (End of Life) life cycle stages are adjusted to several waste/material management options. Unlike most LCAs, the approach is "top-down" rather than "bottom-up", which usually involves large amounts of data and the use of specific software applications. This approach is considered appropriate for a limited but expedient LCA designed to compare the environmental impacts of different life cycle options.

Present results, based on real buildings measurements and demolition contractor activities, show that shallow, superficial, selective demolition may not result in reduced environmental impacts. Calculations actually show an increase (generally less than 5%) in most impact categories for the Materials and End of Life stages because of extra transportation needs. However, core material separation in demolition operations and its recycling and/or reuse does bring environmental benefits. A reduction of around 77% has been estimated in the climate change impact category, 57% in acidification potential and 81% in the summer smog impact (for the life cycle stages referred).

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1. Introduction

The work described here stems from a wider study which analyses selective and traditional demolition practices in technical and economic terms. It is also linked with construction and demolition waste (CDW) generation (Coelho and de Brito, 2010a) and distribution quantification in Portugal (Coelho and de Brito, 2010b).

The work as a whole is an analysis of the technical, economic and environmental viability of a large-scale fully-developed CDW recycling plant in Portugal. It is a tentative comparative analysis of the environmental impacts of different options in CDW management at the end-of-life stage of a building's life cycle. The purpose is to quickly quantify the environmental effects of applying deconstruction techniques and recycling options by incorporating these processes into the environmental impact of producing materials and transporting them to site ("closing" the cycle).

The environmental impact of a building's life cycle has been researched widely in recent years by various authors (Junnila, 2004b; Pinto, 2008; Balazs et al., 2001; Pascualino et al., 2008; Blengini, 2006, 2008; Xiaodong et al., 2010; Krogmann et al., 2009; Schuer et al., 2003). Building projects not intended for research purposes but which include LCA approaches in the design phase are very few, however (Hes, 1998, 2001a,b). One of the major barriers to this is the reluctance to move design time lines to accommodate the extra time needed for an LCA, even though this might offer clear financial and environmental benefits (Hes, 2001a).

Most of these studies have adopted a "bottom-up" approach using databases with embodied energy and emissions of several construction materials (González and Navarro, 2005; Peuportier, 2001; Junnila, 2004b). These environmental impact analyses of buildings rely heavily on drawings, specifications and/or data from the actual buildings.

This approach is generally adequate when information on building quantities (bill of quantities), final drawings and appropriate construction products environmental impact databases is available, bearing in mind the location of the buildings in relation to building materials suppliers and waste management operators. When these conditions are met, with high levels of transparency (clear definition of system boundaries, clear allocation methods, no mixing of data from different sources, etc.), along with coherent end-of-life and recycling considerations, present-day LCA software tools will provide reasonably accurate environmental impact results, reproducible to about ±10% (Peuportier & Putzeys, 2005). Neglecting some or all of these requirements will naturally make LCA unreliable, or at least questionable.

This is called the "process-based" LCA and it enables very specific analysis, although it requires detailed information, which makes it time consuming and costly. In fact, the longer the supply chain

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the more time and money the analysis will require, particularly if local product environmental profiles are not readily available (Schuer et al., 2003; Kofoworola and Gheewala, 2008). Other authors (Blengini et al., 2010), while praising the merits and advantages of the process-based LCA approach, acknowledge that it is often regarded as too complicated, too data and knowledge intensive, and rather time consuming.

Moreover, the sensitivity analysis of current alternatives or future building improvements (e.g.: interventions on existing buildings or better building design) and definition of scenarios is particularly important, given the still significant uncertainty which hinders LCA (Junnila, 2004a; Schuer et al., 2003). Not surprisingly, though, when it comes to quantifying the impacts generated at the end-of-life cycle stage and their consequence on global environmental impacts, there are divergences between process-based methods and this leads to different global impact estimations, especially in partial assessments (by life cycle phase – e.g.: production, transport, end-of-life stage) (Lasvaux et al., 2009). So when it comes to LCA on buildings it is important to define precisely what measures for end-of-life material management there are, and the implications of recycling and reuse for initial materials production.

Another method of estimating life cycle environmental impacts has also been used in the last few years, especially for assessing entire industry sectors, and even for national economies (Carnegie Mellon University Green Design Institute, 2008). Its underlying theory was originally published by Leontief (1970) and later enhanced by Hendrickson et al. (1998), and it is generally called economic input–output life cycle assessment (EIO-LCA). Unlike the process-LCA this method tends to be applied to large-scale systems like a whole industrial sector/segment, although it can and has been applied to specific buildings (Kofoworola and Gheewala, 2008), in a hybrid approach – an LCA-process with EIO-LCA. Although not applied in our study, it is referenced as a possible "top-down" approach which has been used on some occasions.

The process-LCA "bottom-up" approach makes sense when it is possible to perform the life cycle inventory and environmental impact analysis using design blueprints, site data and database access for estimating the impacts of all the activities involved in the construction, operation, maintenance and end-of-life option of a building. This was not the case in this study, in which the environmental analysis was supplementary, not the main purpose.

A simpler and quicker analysis was therefore necessary. The EIO-LCA was not an option, as its full application to a single building (even an "averaged" building, compiled from several case-studies) has no precedents and for this specific purpose has only been applied as a complement (Kofoworola and Gheewala, 2008). Furthermore there would be difficulties in describing processes, linking monetary values with physical units and having to deal with the impacts of "out of (local) economy" imports (Carnegie Mellon University Green Design Institute, 2008). For these reasons an alternative method was sought.

2. Literature review

Among the studies that focus on single buildings' LCA are Schuer et al. (2003), Kofoworola and Gheewala (2008), Dewulf et al. (2009) and Asif et al. (2007). In the last work only the materials' life cycle stage was analysed, and only from an embodied energy perspective, though others analyse several buildings, allowing comparison and consideration of their differences from an environmental impact point of view (Junnila, 2004a; Peuportier, 2001).

Other studies have emphasised the performance of low energy buildings, focusing on life cycle energy (Thormark, 2001) or using large arrays of indicators (Blengini et al., 2010). These studies are highly detailed and site specific, which is an advantage when the precise determination of environmental impacts is important. Generalization of these results is not advisable, however, although some general remarks are given (Blengini et al., 2010).

In (Thormark, 2001), in particular, transportation calculations have been over simplified and may not reflect regional transportation needs, while for recycling strategies it assumes that all materials taken from the building, when demolished in the future, are reinserted in the building construction products chain. This ignores the possibility of down-cycling, which is the fate of most of the recycled construction material mass.

Some focus has also been directed at the end-of-life stage in construction projects, such as in Blengini and Garbarino (2010), which analyses the process of recycling demolished construction materials quite deeply – especially concrete/ceramic aggregates and steel – but deliberately excludes other building life-cycle stages.

This study, although making use of a combined "top-down"/"bottom-up" approach, in choosing a meaningful suite of indicators, is clearly "bottom-up" as far as the LCA calculation process is concerned. It is also dedicated to the aggregate industry processes, involving natural or recycled aggregates, in order to reach some conclusions on what a sustainable supply mix (of aggregates for the construction industry) should be.

In this domain, studies like that of Weil et al. (2006) also specifically analyse the aggregate production industry, with particular reference to civil and structural engineering works. The authors apply an LCA to the concrete production industry in Germany, in which a certain amount of recycled aggregates, calculated from a mass-flow analysis, are integrated in the industrial process and compared to their present form.

This has been done in view of stricter environmental threshold values for materials which will be in contact with the soil. Although relevant and useful, it is mainly an up-stream analysis in relation to the building construction cycle that does not take into account, for instance, the end-of-life operations and their possible variations.

Embodied impacts have also been studied in some detail, from a life cycle perspective, by Chen et al. (2000). Their study focuses solely on embodied energy, and considers only one end-of-life scenario in which steel and aluminum are entirely recycled. This scenario, although linked to the fact that, in the study, steel and aluminum are the most energy intensive materials used in the buildings (two high rise housing blocks in Hong Kong), is unlikely to be recreated in practice, since a 100% replacement level is considered. Also, transportation energy requirements are determined in a very simplified manner, since distances, especially those out of the island, are calculated considering that all materials coming from a neighbor country come from its geometric centre.

A less traditional approach to life cycle embodied impacts, following the same line of research, was performed by Dewulf et al. (2009). Here the concept of Exergy was used to quantify the potential to perform work, embodied in construction materials applied in a single dwelling. The Cumulative Exergy Consumption impact parameter is employed to quantify and compare three scenarios in end-of-life materials management, including a reference scenario where all materials are disposed of and two other scenarios combining reuse, recycling and incineration (combined heat and power) techniques.

3. Methodology

This method resembles a process-based LCA, but one constructed from a "top-down" point of view. This approach was based on relevant published data, in particular (Junnila, 2004a; Blengini, 2006).

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