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Research article

Cradle-to-grave life-cycle assessment within the built environment: Comparison between the refurbishment and the complete reconstruction of an office building in Belgium

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ABSTRACT

In the current context of the necessary sustainability transition of the built environment, it is widely recognized that buildings are a major contributor to the energy consumption of fossil fuels and the emission of CO_2. Most of the debates, policies and research are however dedicated to the sole construction of new very efficient (up to zero-energy) building, neglecting the potential of actions on the existing building stock. In this context, we argue that LCA tools are of a huge interest to objectivise the need to refurbish old buildings, in order to increase their energy efficiency and extend their life span, and to compare this strategy to the demolition/reconstruction of buildings. To achieve this aim, this paper aims at updating an existing tool that enables to carry out the life cycle assessment of buildings, by taking into account demolition and construction phases. Then, the tool is applied to one case study of the low-energy refurbishment of a public office building in Brussels, to compare the impacts of the complete demolition followed by a complete reconstruction (rebuild project) to the retrofitting of the existing building (retrofit project). Our main findings confirm the huge impact of the use phase, highlight the impact (energy and CO_2 emissions) of the construction and demolition phases and show that the in-depth renovation of this building leads to lower environmental indicators compared to its full reconstruction. The tool and results provided in this paper support the development of policies in favour of the retrofitting of the existing building stock and highlight the importance of including the whole life cycle of the building in the analysis.

1. Introduction

Energy uses in the building sector represent around 40% of the total energy used in Europe (European Commission, 2015), representing the most important sector, before transportation and industry. Reducing energy consumptions in the building sector is hence a major challenge to mitigate climate change. It has been recognized as an important policy target and progressively integrated into regulation frameworks, at the European, national and regional levels. Today, most efforts are concentrating on the construction of zero-energy buildings and on the reduction of the energy uses during the use phase of existing buildings through a better insulation. The Directive on the Energy Performance of Buildings (2002) that was implemented in 2002 aimed at enhancing energy efficiency in the building sector by establishing minimum standards on the energy performance of new buildings, and existing buildings larger than 1000 m^2 that are subject to major renovation. In 2010, this Directive was revised (EPBD, 2010) so that all new buildings built by 2020 (2018 for public buildings) should be nearly zero-energy buildings. Although guaranteeing the construction of energy efficient buildings and the energy efficient retrofitting of large buildings, this directive does not address the major challenges related to the retrofitting of the existing building stock. In the scientific literature also, much more attention is put on operational energy efficiency, than on the assessment of embodied energy and carbon (Pomponi and Moncaster, 2016). The challenge of embodied energy/carbon is however particularly important in

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numerous European countries, where the renewal rate of the existing building stock is quite low (Ma et al., 2012; Nemry et al., 2010; Office of Climate Change, 2007; Reiter and Marique, 2012; Roberts, 2008). To illustrate this low rate of renewal, in the UK for example, 87% of existing homes are expected to be standing in 2050 (Boardman, 2007). Because of the age and low energy performances of the existing building stock, it is today essential to objectify the interests of refurbishment works in a view to extend the energy efficiency and the life span of buildings, but also in comparison with the demolition of old buildings and their complete reconstruction, taking into account the use phase of the building as well as construction and demolition operations, that are often overlook in current LCA research.

In this context, the paper starts with a synthetic state of the art about demolition and refurbishment works in general and the interest of LCA tools to investigate this research question in particular. Afterwards, the updating of the LCA tool developed by Rossi et al. (2012a,b) to take into account the impacts of demolition phases (before reconstruction and at the end of life of the building) and construction phases is presented. The updated tool is used to study the refurbishment of the case study building (*retrofit* project), built in 1934, located in Brussels (Belgium) and to compare the results to its complete demolition and reconstruction (*rebuild* project). The main findings and perspective for further research are finally summarized in the last section of this paper.

2. State of art: demolition versus refurbishment

The issue of whether to demolish or refurbish old and/or poorly insulated buildings has been debated for over a century (Power, 2008) but the evidence on whether demolition/reconstruction or refurbishment of existing buildings would be the most environmentally sound is unclear. Power (2008) argues that upgrading the UK building stock to high environmental standards can be achieved at a lower cost than demolishing it, and with as significant carbon reduction. Also mentioned by Power (2008), the German Federal Housing, Urban and Transport Ministry has announced an ambitious energy reduction programme that will upgrade all pre-1984 homes in Germany by 2020 (an estimated 30 million units). This programme is based on the outcomes of several CO_2 reduction programmes since 1996, showing the feasibility of retrofitting. An 80% cut in energy use was achieved, making the performance of the renovated homes at least as good as Germany's current new building standards. Branders et al. (2010) explain that the decision to demolish or to retrofit an existing building depends upon numerous factors such as the initial state of the building, the targeted energy performances or the aesthetic and patrimonial quality of the building. Very few studies (e.g. Dubois and Allacker, 2015) conclude that significant reductions in CO_2 emissions can only be obtained through demolition/reconstruction of buildings. Boardman (2007) suggest to increase the current rate of demolition (stock turnover) of inefficient houses, in the UK context.

To objectivise the interest of refurbishment versus demolition/reconstruction of existing buildings, from an environmental point of view, the use of LCA tools seems of huge interest. The general LCA methodology is well defined in the ISO norms (ISO, 2006a and 2006b). Despite some current limitations of LCA, namely summarized by Pomponi and Moncaster (2016) on the basis of a systematic literature review, LCA tools are recognized as one of the best tools for environmental assessment of products and processes (Crawford, 2007) and are thus widely used in various domains related to the sustainability of built environments (e.g. biogas power plants (Erikson et al., 2016; Iordan et al., 2016), wastewater treatment (Lim and Park, 2009; Opher and Friedler, 2016; Pretel et al., 2016), residential water-using appliances (Lee and Tansel, 2012), waste management (e.g. Bovea and Powell, 2006), wood utilization (Höglmeier et al., 2015), pavement infrastructures (Inyim et al., 2016), urban transportation (Kliucininkas et al., 2012), materials (Hong et al., 2012; Kohler, 1995; Turk et al., 2015, Vieira et al., 2016)). LCA has also been identified as a promising framework for the environmental assessment of territories (Loiseau et al., 2012) or urban blocks (Stephan and Athanassiadis, 2017). LCA tools, specifically dedicated to buildings, have also progressively emerged as practical tools to assess and compare the environmental impacts of different scenarios, in the current debates about energy efficiency of our built environment. These LCA tools have today mainly been used to evaluate energy consumptions and/or greenhouse gas emissions in buildings, during the use phase or along the whole life-cycle of the building (e.g. Ji et al., 2014; Asif et al., 2007; Kofoworola and Gweewala, 2008). A great number of studies have been achieved on the development of LCA tools and on their application to buildings. And several review papers have recently been published to summarize the evolution, interests, limitations and results of buildings LCA (e.g. Bribian et al., 2009; Buyle et al., 2012; Cabeza et al., 2014; De Boeck et al., 2015; Dixit et al., 2010; Karimpour et al., 2014; Sartori and Hestness, 2007; SETAC, 2003). But, as stated by Pomponi and Moncaster (2016), even if incomplete assessment is better than no assessment (Hertwich et al., 2000), extra care is required when using and comparing results from published LCAs, which might be both partial and short sighted, due to the current limitation of these tools.

Amongst their numerous advantages, these LCA approaches can account for a large number of parameters that are known to act on the energy consumptions of a system and can be used to examine the influence of several energy efficiency strategies. However, as highlighted by Gaspar and Santos (2015), LCA of buildings mainly concentrate on the analysis of new and very efficient buildings, most of the time neglecting the existing building stock. Moreover, most studies dealing with the refurbishment of buildings only compare the environmental gains in comparison with the initial building, and not with a new equivalent construction (Ferreira et al., 2015). Using LCA to compare refurbishment scenario to demolition/reconstruction scenario has currently not yet been achieved and the assessment of demolition, construction and end-of-life phases (including the recycling phase) in buildings LCA has yet been assessed.

In his analysis of a residential building in Turin (Italy), Blengini (2009) considered the pre-use phase (production and transportation of materials), the use phase and the end-of-life phase (recycling and elimination of waste) and concluded, in this case, that the use phase is the most harmful one. This result is also highlighted in other papers related to existing buildings (Ferreira et al., 2015; Rossi et al., 2012a,b; Sartori and Hestness, 2007). Recent studies related to new buildings have however highlighted that when high energy consumption standards (such as the passive standard, the (nearly) zero-energy standard or even the positive standard) are reached, this general trend is reversed. In this case, the other environmental impacts (related to the construction phase for example) become significant (Andrade, 2010). It also worth mentioning that the assessment of the embodied energy in buildings can vary substantially, especially due to a quite high variability in the cradle-to-gate materials data (although those differences usually remain tolerable (Blengini, 2009)), the local energy mix (Rossi et al., 2012a,b) or the chosen service life time (Sartori and Hestness, 2007; Wallhagen et al., 2011).

Ortiz et al. (2015) studied an apartment building located in Barcelona (Spain). They assessed the impacts of the construction phase (fabrication and transportation of materials, energy use for