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Sustainability based on LCM of residential dwellings: A case study in Catalonia, Spain

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ABSTRACT

Life cycle management (LCM) can be applied to the whole construction process, thus making it possible to improve sustainability indicators and also minimize the environmental loads of the full building life cycle. To illustrate this, a case study has been carried out based on the application of the LCM approach to a typical Spanish Mediterranean house located in Barcelona with a total area of 160 m^2 and a projected 50-year life span, which has been modeled according to the Spanish building technical code (CTE). The aim of this research is to use sustainability indicators in the pre-construction and operation (use and maintenance) phases and also to promote and support the adoption of the LCM within the construction industry. This paper concludes that regarding the significant environmental issue of climate change, there was a total emission of 2.34E03 kg CO_2-Eq/m^2 per 50 years, of which about 90.5% was during the operation phase (use 88.9% and maintenance 1.7%) and the pre-construction phase account for a total of 9.5%. In terms of this dwelling's environmental loads, the operation phase is the most critical because of the high environmental loads from energy consumption for heating, ventilation and air conditioning (HVAC), lighting, electrical appliances and cooking.

Additionally, the findings of this study state that the appropriate combination of building materials, improvement in behaviors and patterns of cultural consumption, and the application of government codes would enhance decision-making in the construction industry. Therefore, there is no doubt that applying LCM to the full building life cycle is very important for reducing environmental loads and thereby improving sustainability indicators. Finally, this research will help develop guidelines based on LCM for the construction industry to assist stakeholders in improving customer patterns during the dwelling life cycle.

1. Introduction

In every country the construction industry is currently concerned with improving sustainability indicators [1]. On the one hand, both socially and economically, this sector is highly industrially active and can cause fluctuations in macroeconomic indicators like the gross domestic product (GDP) due to the sector's high rates of investment and contribution to growth in employment. Globally, in 2001 this sector represented 10% of global GDP with an annual output of USD 3000 billion, of which 30% was in Europe, 22% in the United States, 21% in Japan, 4% in the rest of the developed word and 23% in developing countries. It also employed an estimated 111 million workers [2]. In Spain, the construction industry watchdog (SEOPAN) said that in 2005 the construction industry took a lead growth rate of 6%, which accounted for 17.8% of GDP, and contributed almost 11% to the gross value added (GVA). SEOPAN also stated that in 2006 the regions with the highest percentage of housing starts nationwide were Andalusia (19.7%), Catalonia (14.5%) and the region of Valencia (13.8%) [3]. In Catalonia, the Catalan Department for the Environment and Housing stated that the number of houses built had increased from 81.786 units in 2002 to 131.517 in 2006 [4]. On the other hand, this sector is responsible for adverse environmental impacts, high-energy consumption, solid waste generation, greenhouse gas emissions, external and internal pollution, environmental damage and resource depletion [5].

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Table 1
Comparison of LCA studies for residential dwellings

Reference					
Specification	Blanchard and Reppe [8]	Asif et al. [9]	Adalberth et al. [10]	Peuportier [11]	Koroneos and Kottas [12]
Location	USA	Scotland	Sweden	France	Greece
Year	1998	2005	2000	2000	2005
Type of residential dwelling	Semidetached	Semidetached	Multi-family	Single-family house	Single-family house
Usable floor area	$\approx 228\,m^2$	$\approx 140\,m^2$	$700\,m^2$	$112\,m^2$	$225\,m^2$
Principal building materials	Concrete, gravel and wood	Concrete, timber, ceramics	Concrete, macadam	Concrete blocks	Brick
Wall composition	Double 2×4 studs, with a 8.9 cm spacing between the inner wall and outer wall studs. The wall cavity is filled with cellulose insulation	–	Masonry veneer, gypsum plasterboard, mineral wool, polyethylene foil, gypsum plasterboard on the inside of the wall	Concrete blocks and 8 cm internal insulation (polystyrene)	The external wall consists of double brick with interior insulation
Availability of sustainability indicators on energy production	None	None	None	None	Yes
HVAC analysis	Yes	None	None	None	None
Databases employed	DEAM and Óekoinvenatare für Verpackungen	–	Danish	Oekoinventare	–
Energy simulation software	Energy 10	–	Enorm	EQUER	HOT 2000
LCIA approach	Based on EPA600/R-92/245	–	Based on SBI's LCA tool	CML	Ecoindicator 95
Life cycle costing	Yes	None	None	None	None
Application of technical construction codes	Yes	None	None	Yes	Yes
Behaviours patterns during the operation phase	Yes	None	None	None	Yes

To deal with environmental considerations and increasing concern regarding today's resource depletion life cycle management (LCM) can be applied to the whole construction process, thus making it possible to improve sustainability indicators and also reduce the environmental loads of the full building life cycle. Therefore, the application of LCM can be fundamental in pursuing sustainability and improvements in building and construction and implies the use of the environmental management tool of LCA [6].

Life cycle assessment (LCA) within the construction industry is an important methodology for evaluating buildings from the extraction of raw materials, construction, operation and maintenance through to final disposal or demolition (cradle to grave) and also LCA has been gaining attention in the last decade as a means of evaluating building materials explicitly dedicate to residential dwellings [7]. For instance, some studies have already been published on complete LCAs of residential dwellings. One of the first publications evaluated the environmental impacts and energy use of a residential home in Michigan [8]. Asif et al. [9] also applied an LCA to a dwelling in Scotland. Adalberth et al. [10] has used an LCA to evaluate four multi-family buildings located in Sweden. Peuportier [11] compared three types of house with different specifications located in France. Koroneos and Kottas [12] evaluated the annual energy consumption of an existing house in Greece. While these studies describe various environmental considerations and energy use for residential dwellings in the USA and some European countries, there is no evidence from comparable studies in Spain (see Table 1). The LCA investigations presented here are not similar. There are differences in the LCA analyses and in the engineering and physical characteristics. For example, it is observed that some studies did not report the methodology used to evaluate the life cycle impact assessment (LCIA). Additionally, there are dissimilarities in the surface of heated volume, usable floor area, amount of building materials and energy use during occupation. Also, apart from Koroneos and Kottas, most studies did not show results of the environmental impacts of energy production. Therefore, in this study, it has been applied LCM approach to a typical Spanish Mediterranean house located in Barcelona with a total area of $160\,m^2$, split into two storeys and with a projected 50-year lifespan in order to assist the construction industry and also to evaluate environmental burdens at regional level during the full building life cycle. This case study uses current research to develop guidelines based on LCM and apply sustainability indicators within the construction industry. The aim of this research is to use sustainability indicators in the pre-construction and operation (use and maintenance) phases and also to support decision-making within the building sector. Finally, the present research can be used by stakeholders such as engineers, architects, building constructors, environmentalists and LCA advisors as an important point of reference for LCM and energy considerations.

2. LCA as a tool to support LCM

LCA is a methodology used to evaluate environmental loads throughout all stages of the building life cycle, from origin (raw materials) to end of life (disposal waste) [13]. LCA follows the international standard series of ISO 14040. Although there are plenty of valuable sources documenting the technical and practical details, LCA methodology is based on four essentials steps: goal and scope, inventory, impact assessment and interpretation [14]. First, defining the goal and scope involves defining the purpose, audiences and system boundaries. Second, analyzing the inventory includes collecting data regarding all relevant inputs and outputs of energy and mass flow as well as emissions to air, water and land for each part of the process. This phase includes calculating the material and energy input and output of a building system. Third, the impact assessment evaluates potential