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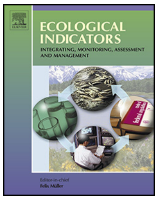

The ecological footprint of dwelling construction in Spain

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ABSTRACT

The construction industry is well known for its high impact on the environment; an even higher impact has taken place in recent years due to the real-estate bubble which has resulted in a surplus in the construction of dwellings in many countries. In Spain, about 500,000 dwellings were constructed during 2006–2010, which represent a 2% increase in four years. In the present work, a methodology is defined as the first step towards the creation of an effective assessment of the Ecological Footprint of this type of construction. The procedure is based on the project budget and its bill of quantities, organized by means of a systematic construction-work breakdown structure which divides the work into three major categories: materials, manpower, and machinery. Each stream generates partial footprints (i.e. energy, food, mobility, construction materials, and waste).

Ninety-two dwelling construction projects, which represent the most commonly built dwellings in Spain per statistical data from the authorities, are evaluated and their ecological footprints are determined. The indicator is sensitive to various building typologies, which range from detached houses to multi-family buildings. Detached houses generate an ecological footprint per square metre constructed of 1.5 times higher than that of 4-floor multi-family buildings and the indicator remains practically constant for taller buildings. This emphasises that not only is the traditional Spanish construction of a compact city with multi-storey buildings environmentally better from the mobility standpoint, but also from the building construction standpoint.

1. Introduction

During the past decade, Spain has experienced a huge construction bubble which has caused the biggest economic crisis since democracy was introduced (COAAT Barcelona, 2010). Not only does this high construction rate exert an impact in the economy, but it also causes an impact on the Spanish environment, which has yet to be evaluated. This construction is analyzed in Table 1 from official statistical data generated by the Ministry of Development in Spain (2011). The economic impact of this construction is well known, and resulted in an economic crisis that started in 2008 and continues to the present day. However, little has been done in order to measure its environmental impact. It is necessary to assess this through indicators, so that the weight of the environmental impacts can be qualified and quantified. The tools that analyze these impacts generally follow the methodology of life-cycle analysis (LCA) (Zabalza Bribián et al., 2011; Malmqvist and Glaumann, 2009). However, other approaches exist, such as the emergy analysis (Meillaud et al., 2005), and the material flow analysis (Sinivuori and Saari, 2006). Currently there is a tendency to use simpler methodologies as they can be more easily understood by society, among which feature the carbon footprint (Weidema et al., 2008; Solís-Guzmán et al., 2014) and the ecological footprint (EF) (Wackernagel and Rees, 1996). The latter can be adapted to the unique characteristics of the construction sector, and has been chosen for its comprehensibility, transparency, and adaptability (Cagiao et al., 2011).

The EF indicator was introduced by Wackernagel and Rees (1996), who measured the EF of humanity and compared it with the carrying capacity of the planet. According to its definition, the EF is the amount of land that would be required to provide the resources (grain, feed, firewood, fish, and urban land) and absorb the emissions (CO_2) of humanity (Wackernagel and Rees, 1996; WWF, 2008). By comparing the EF to the amount of land available, Wackernagel concluded that human consumption of resources currently stands 50% above the global carrying capacity in developed countries (WWF, 2010). The indicator has been used since its inception to determine impacts on greatly differing scales: to predict the impacts generated by humankind on Planet Earth, for the periodic calculation of the footprint of humankind on Planet Earth, and for

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Table 1
Buildings constructed in Spain from 2006 to 2010.

Year	New buildings						Old buildings	
	Residential				Non-residential	Total	Rehab.	Demolished
	Individual dwellings	Collective residence		Total				
		Permanent	Temporary					
2006	208,016	306	309	208,631	21,413	**230,044**	35,856	2848
2007	165,833	197	292	166,322	20,825	**187,147**	33,359	26,141
2008	79,467	126	159	79,752	13,926	**93,678**	34,807	14,573
2009	39,349	102	113	39,564	12,180	**51,744**	33,267	7984
2010	34,317	183	610	35,110	9671	**44,781**	31,910	8084
Total	526,982	914	1483	529,379	78,015	**607,394**	169,199	59,630

periodically calculating the EF of different countries, cities, productive sectors, and industries (Solís-Guzmán et al., 2013).

In this paper, Spanish dwelling construction is studied in 92 different projects by applying the procedure developed by Spanish researchers (Domenech Quesada, 2007; Cagiao et al., 2011) on corporate EF calculation and on the process of building construction (Solís-Guzmán, 2011; Solís-Guzmán et al., 2013).

This research, therefore, aims to bring all previous knowledge related to the EF indicator into the residential building sector in order to analyze the construction phase of dwellings, and to determine the advantages and disadvantages that this indicator may yield in the analysis of environmental impact on the building sector. Among the studies which apply the EF indicator in the construction sector is Bastianoni et al. (2007) who calculate the EF of two Italian buildings by taking into account the embodied energy of construction materials and that of the construction processes: the latter measuring only 5% of the former. The results generate three types of EF: CO_2 absorption land, forest land (for production of wooden materials) and the built land occupied directly. Solís-Guzmán et al. (2013) develop a similar model with some innovative hypotheses in that they include the workers food and mobility and the water consumption on the construction site; these factors are not normally included in the EF methodology. Teng and Wu (2014) analyzed the building life cycle (project design, construction, usage and demolition) in terms of EF (energy, resources, CO_2 and solid waste) and applied the methodology to an exposition centre in Wuhan, China.

The EF indicator has also been applied in the evaluation of high-rise districts in Tehran (Samadpour and Faryadi, 2008), real-estate development in Nanjing, China (Li et al., 2008), farmhouse construction (Zhao and Mao, 2013), hotel construction (Li and Cheng, 2010) and centenary house rehabilitation (Bin and Parker, 2012). Furthermore, an Ecological and Carbon Footprint evaluation tool has been defined for buildings (Olgyay, 2008).

The following procedure for the assessment of the EF in the construction of residential buildings is based on the project bill of quantities and on the systematic classification of construction work (Marrero and Ramirez-de-Arellano, 2010): materials, manpower, and machinery. An approach to the calculation of the EF, valid for any residential building construction, is described in detail therein.

For the selection of projects, the following steps were taken:

1. Search for current projects which represent the most common typologies.
2. Create a resource quantification database by means of a construction breakdown system (CBS), which defines materials, machinery, and manpower.
3. Once all project data is processed, the EF is calculated, based mainly on the authors' previously established methodology (Solís-Guzmán et al., 2013) and on new approaches to the quantification of resources, to the energy consumption of machinery, and to water consumption during the construction work.

The modifications to Solís-Guzmán et al. (2013) model are:

1. A separate analysis of construction and demolition waste from urban solid waste.
2. Determination of materials EF from a newly created resource quantification database.
3. Definition of machinery EF directly from the gasoline or diesel consumption.
4. Definition of the water EF from the actual consumption in 90 different construction projects.
5. A calculation strategy which allows, with a straight forward methodology, to adapt a CBS to the EF indicator.

2. Methodology

The present analysis of the EF focuses on the implementation and construction phase of residential buildings: research into the other two phases of the life cycle of buildings, those of use and demolition, does not constitute part of the present analysis. A second assumption is also considered: the only activity that exerts an impact on the study area is that which corresponds to the construction of the residential buildings considered above. The project budget becomes the main source of information for the quantification of the resources consumed during the building construction. The construction industry normally organizes works clearly in the project budget since cost control is always a major issue.

The budgets of 92 different dwelling projects, which met the construction characteristics evaluated in the following paragraph, are analyzed and classified; their budgets are reorganized in a CBS which enables comparison. This system, for the organization of the work and its quantities, has been successfully applied to control the generation of construction waste (Solís-Guzmán et al., 2009) and project cost (Marrero et al., 2014).

The typical construction characteristics can be obtained from the Ministry of Development in Spain (2011) and are multi-family buildings with 2 or more dwellings, 4 or more floors above ground level and 1 below ground level; each dwelling has a 72 m^2 floor space, two bathrooms, a garage and is privately owned. The building structure is of reinforced concrete with unidirectional beams, ceramic roof, ceramic façade, aluminium carpentry, wooden doors, false ceilings and exterior blinds.

In Table 2, the measurement of the projects is presented in terms of the average quantities per square metre constructed. These are grouped per number of floors above ground level. The sample sizes