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Assessing the economic impact and ecological footprint of construction and demolition waste during the urbanization of rural land

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ABSTRACT

The present work analyses the management of construction and demolition waste (C&DW) in urbanization projects from a dual perspective: ecological and economic. A well-established model for waste quantification, previously developed by the authors, is employed and adapted for the assessment of urbanization work. The quantification model is based on the work breakdown system (WBS) of construction budgets. Five urbanization projects are evaluated; two are industrial and three residential. The quantities, budget, and ecological footprint (EF) are determined. The EF evaluation follows the same methodology as defined by the authors for construction projects but with several new incorporations, such as the quantification for the felling of trees and the machinery footprint. The result shows that 98% of the C&DW generated is due to earthworks and tree felling. An overwhelming 97% of the EF is due to fuel consumption by on-site machinery and construction materials. Finally, a new scenario is proposed in which the soil is 100% reused and the inert waste is crushed and used as concrete aggregate, which reduces the EF by more than 20% in all cases analysed. The results show that it is possible to quantify the integral impact within construction projects of the application of recycling and of reuse strategies by means of a WBS. Finally, from a construction project perspective, the traditional model for waste management and economic control can be completed with an environmental analysis using the EF indicator.

1. Introduction

In recent years, a global issue has arisen regarding the environmental impact of the construction industry, especially that of its construction and demolition waste, C&DW (Agamuthu, 2008). Among the many reasons identified for the limited effectiveness of C&DW management, feature the contrasting opinions held by the two major groups involved in the process. The first group includes the authorities and general public whose focus is on minimizing the amount of C&DW entering landfills. The other major group is comprised of promoters and subcontractors who are more concerned about the benefits and profits from conducting C&DW management, and less interested in whether the generated C&DW would burden the environment (Yuan and Shen, 2011).

There is major economic and environmental concern due to the fact that materials extracted from nature that are involved in delivering the target building elements, are thrown away as construction waste. Li et al. (2016), in accordance with the mass balance principle, calculates that the sum of the weight of the construction materials, packaging materials, and extracted materials is equal to that of the target building elements and construction waste.

Waste minimization is economically feasible and plays an important role in the improvement of environmental management. From this standpoint, economic instruments for minimizing construction waste can be employed to encourage waste-prevention efforts, to discourage the least desirable disposal practices, as well as to prevent the negative consequences of environmentally unfriendly treatment and disposal practices of construction waste materials (Begum et al., 2007). Construction method, project size, building type, material storage method, human error, and technical problems are the main factors that affect the waste generation of newly constructed buildings (Mokhtar et al., 2011).

In order both to minimize the amount of C&DW entering landfills and to reduce the cost of the construction project, a good waste management plan is needed. The first step is to predict the amount of waste generated during the construction processes. The volume

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determined can then be used to define the container sizes and types and the pick-up frequency, both necessary in order to reach the next step: material recycling and/or reuse. A good quantification procedure at project level also allows waste to be properly treated, by preventing mixtures and deterioration (del Río Merino et al., 2010; Li and Zhang, 2013).

Many models have been established over the last decade to determine the project waste quantities, such as SuperDrecksKescht fir Betriber (Oeko-Service Luxembourg, 2002), which proposes quantification of C&DW at the worksite, and is able to estimate types and volumes produced. The National Technical University of Athens (NTUA) has developed an indicative mathematical model for the estimation of the quantities of C&DW generated (Kourmpanis et al., 2008). SMARTWaste™ is another quantification method, applied in the United Kingdom, and is based on data obtained from previous experiences and calculates the waste volumes in 13 categories: ceramic, concrete, wooden pallet, etc. (BRE, 2008). Other C&DW quantification models, mathematical and software development, can be found in (Cheng and Ma, 2013; Wu et al., 2014).

The present authors, together with others, have also developed a quantification model to estimate the type and quantity of waste generated by a range of construction projects, such as new buildings, demolition, renovations, and alterations (Solís-Guzmán et al., 2009). The input parameters in the model are: work type, number of storeys, foundation type, and total built area. In recent years, the model has been tested at the Los Alcores Community (Seville, Spain) treatment plants. The classification code used is the same as that which Spanish quantity surveyors normally employ to obtain the bill of quantities, thereby making the model both easy to understand and to implement (Marrero and Ramirez-De-Arellano, 2010). In 2013 (Pérez-Carmona et al., 2013), the model was successfully implemented in Ecija Community, Spain. The model has also been adapted to road construction evaluation (Solís-Guzmán et al., 2014).

None of the previous models has considered the analysis of yet another major impact on building development: the resources needed to transform farmland into an urbanized estate ready for the construction of the building. Environmental awareness programs have broadened the scope to include 'green' concepts and principles through the introduction of a variety of green-rating tools and similar mechanisms for the evaluation of the expected environmental performance of a structure. However, these principles and mechanisms are, in general, related only to built structures, and fail to take into account the entire landscape and socio-cultural ecosystem within which they function (Deal, 2001).

A new model is proposed that considers all the waste-generating activities which occur during land transformation. These activities cover earthmoving and land conditioning, landscaping, the construction of new roads, walkways, and of parking areas, and the introduction of installations, which include sewage and rainwater disposal, gas supply, street lighting, telecommunication lines, and electrical power. The new proposed methodology for the waste quantification starts directly in the project budget classification. A new classification is not needed, and budgets are normally well controlled and defined in the construction sector then in the present methodology each work unit has its corresponding waste generation quantities. Then the methodology only depends on the quality of the definition of the construction work units leaving aside other considerations.

Five case studies, in Andalusia, Spain, are analysed and a waste management strategy is proposed in order to minimize both costs and the impact on the environment. The present work establishes a procedure in order to determine the quantities of waste and the waste management costs in urbanization works. For the cost evaluation, the Andalusian Construction Cost Database (ACCD, 2014) is used and new unitary costs are proposed that are created using its work breakdown system (WBS).

Once the waste quantities are determined, the environmental assessment is made. The impact of buildingís construction has been studied through ecological indicators, such as the Ecological Footprint (Bastianoni et al., 2007), Carbon Footprint (Solís-Guzmán et al., 2015) and Emergy Analysis (Marchi et al., 2015; Pulselli et al., 2014, 2007).

In those previous works, the environmental impact of construction materials was obtained through LCA from international databases. In the current work, the Ecological Footprint (EF) analysis uses Ecoinvent data through Simapro, since this database covers all the commonly employed materials in buildings construction, making it easier to analyse complete buildings (Martínez-Rocamora et al., 2016a). In order to obtain the CO_2 emissions embodied into construction materials, their Life Cycle Inventory (LCI) is analyzed after applying the IPCC 100a methodology. This methodology, which is used for the Carbon Footprint indicator, isolates CO_2 and other GHG emissions from the LCI, being thus easier to account for CO_2 emissions. More complex methodology such as ReCiPe or Ecoindicator 99 are not necessary in the EF calculations, making possible its high acceptance potential in the construction sector, mainly due to its simplicity and that it allows fast comparisons between constructive solutions in projects, i.e. rockwool vs. PE insulation in walls, or inclined vs. flat roofs (González-Vallejo et al., 2015b).

Specifically in the construction sector, cost control always takes place by means of the project budget and its bill of quantities (Marrero et al., 2014b). In the latter, the various tasks taking place on the construction site are broken down into three key elements: manpower, materials and machinery. Emission or embodied energy factors are then applied to those elements, which are subsequently converted into environmental impacts. The previous facilitates the incorporation of simple ecological indicators, such as EF, into the construction sector by means of the always presented cost control (González-Vallejo et al., 2015a; Martínez-Rocamora et al., 2016b; Solís-Guzmán et al., 2013).

The environmental assessment is made using the Ecological Footprint (EF) indicator. A previously established model by the authors among others for the evaluation of construction projects is adapted to the C&DW footprint (González-Vallejo et al., 2015a; Solís-Guzmán and Marrero, 2015; Solís-Guzmán et al., 2013). 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. The EF is defined as 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. On this basis, the proposed model assesses the waste management in urbanization projects by means of an overall vision: environmental and economic evaluation.

On one hand, there are several strong aspects concerning the EF methodology, such as its simplicity, ease in calculation, and the fact that it can be understood and adopted by the general public (Weidema et al., 2008); an indicator that is easy to communicate and reliable can influence consumers' decisions, legislation, and regulation (European Comission (EC), 2003; Galli et al., 2012), allowing the benchmarking of human demand for renewable resources and of carbon uptake capacity with the natural supply, and the determination of clear targets (Galli et al., 2012). The main differentiating aspects are the aggregation of factors of different sources and the importance of productivity changes.

EF provides an aggregated assessment of multiple anthropogenic pressures; methodologies that include several indicators can be preferable because they prevent the overlapping of impact categories (Finnveden et al., 2009). It is also true that the EF can be studied per category (different land classifications), which aids