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Demolition waste generation for development of a regional management chain model

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ABSTRACT

Even though construction and demolition waste (CDW) is the bulkiest waste stream, its estimation and composition in specific regions still faces major difficulties. Therefore new methods are required especially when it comes to make predictions limited to small areas, such as counties. This paper proposes one such method, which makes use of data collected from real demolition works and statistical information on the geographical area under study. Based on a correlation analysis between the demolition waste estimates and indicators such as population density, buildings ageing index, buildings density and land occupation type, relationships are established that can be used to determine demolition waste outputs in a given area. The derived models are presented and explained. This methodology is independent from the specific region with which it is exemplified (the Lisbon Metropolitan Area) and can therefore be applied to any region of the world, from the country to the county level. Generation of demolition waste data at the county level is the basis of the design of a systemic model for CDW management in a region. Future developments proposed include a mixed-integer linear programming formulation of such recycling network.

1. Introduction

The construction industry is one of the largest sectors of the world economy. A great number of construction, renovation and demolition activities concerning buildings, utilities, structures and roads take place around the world on a continuous basis. These activities result in huge volumes of construction and demolition waste (CDW) that have to be disposed of and managed, with serious financial and environmental implications.

Besides the significant amount of waste produced, the impending high financial impact stimulates the identification of sustainable construction and demolition technologies for the recovery of reusable flows and the creation of suitable recycling networks for CDW management. This motivates the need for an integrated optimization of the entire CDW network, viewed as a closed-loop supply chain that includes reverse flows for recovery, reuse and recycling of materials. CDW consists mostly of diverse nonhazardous, uncontaminated materials that may also contain residual hazardous materials that need to be separated and subsequently processed or disposed of, as enforced by national regulations. Some of the construction and demolition debris may have economic value as reusable or recovered materials, and can thus be profitably reintroduced in the construction supply chain.

Efforts to initiate closed-loop material flows in the construction industry have mainly focused on the recovery of waste material from underground engineering; successful recovery strategies in this sector have already been implemented in many countries. However, the handling of CDW and materials arising from the deconstruction, modification or renovation of buildings poses a problem. In the existing building stock, the long-term lag between initial design and construction of the building/infrastructure and the final deconstruction at the end of its lifetime cause high uncertainty about their materials' composition, i.e. deconstruction planning faces severe problems, especially when the building/infrastructure involved has not been designed and built with the intention of recovering its used components and materials (Schultmann and Sunke, 2007).

Abbreviations: CDW, construction and demolition waste; CAOP, Carta Administrativa Oficial Portuguesa (*Portuguese Official Administrative Chart*); GBA, gross building area; DW, demolition waste; EWL, European Waste List; INE, Instituto Nacional de Estatística (*Portuguese Statistics Institute*); LMA, Lisbon Metropolitan Area; MILP, mixed-integer linear programming; NRB, non-residential building; RB, residential building.

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Interest in sustainable management of waste and recycled materials in construction started in the early 1990s and has grown continuously ever since (Vandecasteele and van der Sloot, 2011). Although many studies on CDW management in the literature collect data, mainly through surveys and case studies, the scope of the approaches proposed for recovery, reuse and recycling in CDW management is limited. In fact, there are few papers aimed at optimizing the waste recovery operations for the deconstruction/demolition phase of a project, e.g. Peng et al. (1997), Spengler et al. (1997), Barros et al. (1998), Wang et al. (2004), Roussat et al. (2009) and Xanthopoulos et al. (2009). In a recent survey of the research trend in CDW management, Yuan and Shen (2011) acknowledge that, following the application of simple methods for data analysis presented in the literature, more complex methods start to emerge. In their view, research using different modeling techniques to capture the complexity and dynamics of the CDW chain should be highly encouraged since it can contribute to improve the effectiveness of CDW management. Hiete et al. (2011), who present a CDW chain model for a region of Germany, also emphasize that modeling of the entire CDW chain in the literature is scarce.

This work is part of a wider project to develop a systemic model for a regional network for CDW collection, transport, recovery and reuse, which in its first phase requires estimating CDW generation. Based on previous work (Coelho and de Brito 2011a,b,c), an innovative process of CDW estimation, with significant refinement, is presented for that purpose. The procedure is illustrated for the Lisbon Metropolitan Area (LMA), in Portugal, using statistical information down to the county level.

The paper is organized as follows: Section 2 reviews studies that quantify CDW generation, with particular emphasis on Portugal and Section 3 describes the methodology developed to estimate CDW generation from demolition works, exemplifying it for LMA. A correlation analysis between computed CDW indicators and other significant indicators for LMA municipalities (population density, buildings ageing index, buildings density and land occupation type) is performed in Section 4 and some models are derived to estimate CDW generation based on such indicators. A final discussion and future developments of this study are presented in Section 5.

2. Previous studies on CDW generation

Table 1 presents the CDW and total amount of waste produced in the EU countries in 2011. A total of 859.5 million tonnes of CDW were produced. If one looks at the proportion between CDW and total waste (also in Table 1), a discrepancy between UE countries is clearly visible, which shows the unreliability of official data on CDW generation.

Recent studies claim that waste from the construction industry constitutes approximately 35% of all industrial waste produced worldwide (Alencar et al., 2011). Altunku and Kasapseçkin (2011) estimate that 8% of the CDW come from new constructions, 44% from renewal activities, and 38% from demolition interventions.

Nonetheless, CDW generation per capita may have in fact very different values depending on the country. Saghafi and Teshnizi (2011) mention that CDW generation in Tehran, Iran is estimated to be 4.64 kg per capita per day, a higher value than those typical of developed countries, like the USA, where daily CDW generation per capita is around 0.77 kg.

Another issue is the recycling ratio. Báez et al. (2012) state that, in 2008, about 45 million tonnes of CDW were produced in Spain, of which only 13.6% were recycled. In Denmark, CDW is about 25–50% of the total volume of generated waste and recycling is an established practice. Back in 1986, about 12% of CDW were already reused and/or recycled, mostly due to the low capacity of landfills.

Table 1
CDW proportion in the total amount of waste generated in EU-27 (Eurostat, 2011).

Country	Total quantity of waste (Mton)	CDW amount (Mton)	CDW proportion (%)
EU-27	2615.2	859.5	32.9
Austria	56.3	31.4	55.8
Belgium	48.6	15.4	31.7
Bulgaria	286.1	1.8	0.6
Cyprus	1.8	0.4	22.2
Czech Republic	25.4	10.7	42.1
Denmark	15.2	5.7	37.5
Estonia	19.6	1.1	5.6
Germany	372.2	197.2	53.0
Greece	68.6	6.8	9.9
Finland	81.8	24.5	30.0
France	345.0	253.0	73.3
Hungary	20.1	5.2	25.9
Ireland	23.6	n.a.	n.a.
Italy	179.0	69.7	38.9
Latvia	1.5	0.0	0.8
Lithuania	6.8	0.4	5.9
Luxembourg	9.6	8.3	86.5
Malta	1.5	1.1	73.3
Netherlands	99.6	59.5	59.7
Poland	140.3	6.9	4.9
Portugal	36.5	8.1	22.2
Romania	189.3	0.3	0.2
Slovenia	5.0	1.4	28.0
Slovakia	11.5	1.3	11.3
Spain	149.3	44.9	30.1
Sweden	86.2	3.3	3.8
United Kingdom	334.1	101.0	30.2

n.a. - not available

According to the Danish environmental protection agency, the recycling ratio was 89% back then. In 1996 in the Netherlands, approximately 76% of CDW were reused and/or recycled and there were about 120 recycling facilities with a capacity of 16.26 million tonnes per year (Ruivo and Veiga, 2004). Currently, the Dutch recycling rate reaches 90% (Li et al., 2011).

In Portugal, there are few reliable statistics for CDW generation. One of the first studies to estimate CDW generation in Portugal was the one by Pereira (2002), in which the Symonds Group (1999) estimation of 325 kg/person/year was applied directly. Pereira (2002) came up with the estimate of 6,440,000 tonnes/year. This study lacked useful and representative information from data collection. In this study, a survey to companies was still carried out, to which only 4.4% of them responded. Carvalho (2001), using official data from INE, the Portuguese Statistics Institute and the National Institute of Waste, estimated two disparate values for CDW overall generation in Portugal: 7,690,749 and 63,614 tonnes/year. In Ruivo and Veiga's study (2004), estimations have been made for the year 2002, using two different methods. The first method used CDW production indicators from INE and the second one used surveys to municipal solid waste management systems in the country. Using the first method, the authors came up with 4.4 million tonnes per year and, with the second method, a value of 0.18 million tonnes per year. There is a clear discrepancy between these values. In the Coelho and de Brito (2011c) research, the methodology used to estimate CDW generation at national level was based on the Franklin Associates' (1998) study procedures, where real data were used. However, due to the lack of actual works available to be monitored for new construction, rehabilitation and demolition activities, Coelho and de Brito (2011c) measured actual buildings projects with varying ages. The results hint at an overall CDW generation of 1,966,874 tonnes/year (excluding excavation soils). The methodology used in the Mália et al. (2013) study was based, essentially, on the procedures of Cochran et al. (2007) and Franklin Associates (1998), which used data from previous studies found in the literature. In Mália et al.