INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

# CONSTRUCTION AND DEMOLITION WASTE INDICATORS

**Miguel Ângelo Borges Mália**

Extended Abstract

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## 1. Introduction

The construction sector plays an important role in the European Union (EU), representing 28% and 7% of employment, in industry and in the entire economy of EU15 respectively (Enterprise & Industry, 2009). The influence of this activity is also reflected on the environment, since this sector consumes more raw materials and energy than any other economic activity and produces the vast majority of waste produced throughout the EU.

Construction industry consumes about 50% of all materials extracted from the Planet (Fortunato and Roque, 2009). This industry is also the third-largest $CO_2$ emitting industrial sector worldwide and representing 10% of the total anthropogenic $CO_2$ emissions in the EU (Habert *et al.*, 2009). Regarding waste generation within the EU, more than 450 million tonnes per year of construction and demolition waste are generated, the largest waste stream in quantitative terms, apart from mining and farm waste (Ortiz *et al.*, 2010). In Portugal, about 7.5 million tonnes of waste are produced every year (Agência Portuguesa do Ambiente, 2010), representing 20% of the total volume of waste generated (Coelho, 2010).

The level of waste at construction sites is considerable. Studies show that the waste rate in the Brazilian construction industry is 20 to 30% of the weight of total materials on site (Pinto and Agopayan, 1994). On the other hand, work in the Netherlands found that an average 9% (by weight) of the purchased construction materials ends up as site waste in the Netherlands (Bossink and Brouwers, 1996). New purchases to replace discarded materials and dealing with generated waste cause heavy financial losses to the contractor and increase the environmental impact of the activity. However, waste is not generated only in new construction activities since it is also produced during the renovation of buildings and, the vast majority, through demolition (**Table 1**).

**Table 1 – Percentage of waste generated per activity**
**(Source: Bossink and Brouwers, 1996; Waste Centre Denmark, 2010; Statistics Norway, 2006; John, 2000)**

<table>
<tr><th rowspan="2">Type of Activity</th><th colspan="4">% of waste per activity</th></tr>
<tr><th>Western Europe</th><th>Denmark</th><th>Norway</th><th>USA</th></tr>
<tr><td>Construction</td><td>20</td><td>5 - 10</td><td>20</td><td>8</td></tr>
<tr><td>Renovation</td><td rowspan="2">80</td><td>20 - 25</td><td>44</td><td>44</td></tr>
<tr><td>Demolition</td><td>70 - 75</td><td>36</td><td>48</td></tr>
</table>

Construction and demolition waste (CDW) has a mixed composition, consisting of fractions of different sizes, containing components such as: concrete and mortar; ceramics; wood; metals; various plastics; glass; paper and cardboard; paints and glues; bituminous materials; and soils. **Figure 1** shows the composition of CDW generated in the coastal region, in the north of Portugal. As a result of the perceived inert nature of this waste stream, studies pertaining to the characterization and management of CDW are limited. However, attention concerning this waste stream has increased as questions related to possible environmental impacts and recycling potential of CDW components have been raised (Cochran *et al.*, 2007).

In many countries, rising levels of waste generation, due to the rapid growth of towns and cities, and a significant number of illegal dumps have strained landfill capacities and have led to environmental concerns. In Portugal, most of these wastes are currently disposed of in landfills (Pereira, 2002). However, construction waste has a very high recovery potential as 80% of this waste can be recycled, although only a small proportion is actually recovered in the European Union as a whole. Currently, 75% of waste is being landfilled, although 80% recycling rates have been achieved in countries such as Denmark, the Netherlands and Belgium (Ortiz *et al.*, 2010). In this context, in order to preserve the environment and guarantee a sustainable growth, a great number of environmental regulations and initiatives have been developed. Most of these laws seek to minimize and control CDW production.

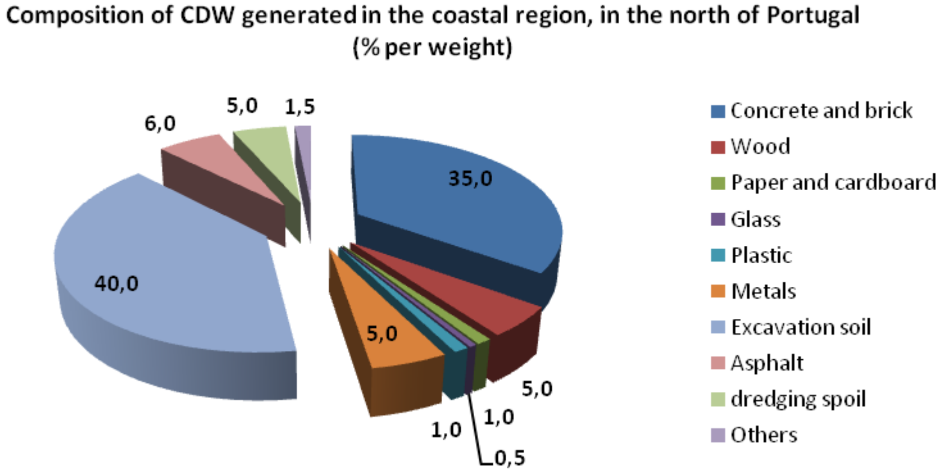


**Figure 1 – Composition of CDW generated in the coastal region, in the north of Portugal (Source: Pereira *et al.*, 2004)**

In the first part of this abstract, a detailed description of CDW regulatory framework in EU and Portugal is provided, in order to identify the main shortcomings of the new national decree to regulate the production and management of CDW, Decree-Law No. 46/2008. Later, this study aims at determining indicators to estimate the amount of CDW generated at the construction site, to provide a tool needed for evaluating the true size of waste produced on-site.

## 2. CDW regulatory framework in EU and in Portugal

In the European Union, there is no specific legislation for CDW. Nevertheless, this waste stream is regulated by Directive 2008/98/EC, which establishes the legislative framework for handling waste in the Community. In this regulation, there are two important references concerning CDW:

- in subparagraph (c) of Article 2, it is stated that "uncontaminated soil and other naturally occurring material excavated in the course of construction activities where it is certain that the material will be used for the purposes of construction in its natural state on the site from which it was excavated" shall be excluded from the scope of this Directive;

- in subparagraph (b) of Article 11, it is stated that "by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste (...) shall be increased to a minimum of 70 % by weight".

In the first item, a solution was found for excavation soils, which represent the largest fraction of CDW. In the second item, ambitious targets are drawn for CDW recycling in the EU, which needs to be improved, as shown.

Some EU countries took action way before Directive 2008/98/EC, creating various regulations and initiatives to encourage proper management of CDW. For instance, in the Netherlands, there have been a variety of initiatives since 1993 which led to a CDW recycling rate of 90% in 1999 (Ministry of Housing, Spatial Planning and the Environment, 2001). The main factors to achieve this high recycling rate were: separation at source of various types of CDW; a healthy market for recycled products; and the introduction of a prohibition on the landfill of recyclable CDW. Since 2000, most landfill sites have obtained an exemption from the ban on CDW landfilling, due to insufficient capacity for recovery or incineration of these waste streams (Ministry of Housing, Spatial Planning and the Environment, 2001). However, landfilling this fraction is unattractive, because of the high landfill tax (€ 122 per tonne).

Another example of best practice in CDW management is Denmark, where CDW recycling is a common practice. The target of achieving, in 2004, a recycling rate of 90% was reached in 1997 and remained at this level since then (Waste Centre Denmark, 2010). Until the 1980s, Denmark still relied heavily on landfills. The shift from landfills was precipitated by concerns over groundwater pollution, particularly because all of Denmark's drinking water comes from groundwater (Department for Environment, Food and Rural Affairs, 2003). In 1985, the Danish Environmental Protection Agency began to regulate the reuse of asphalt. In 1990, it allowed the re-use, without prior approval, of clean source-separated stone materials, unglazed tile materials and concrete in building and construction works (Montecinos and Holda, 2006). Later, local councils were charged with the duty of drawing up regulations on CDW in order to increase their recycling. The regulations must cover provisions that source separation be made, when total CDW arising from a building or construction project exceeds one tonne (Waste Centre Denmark, 2010). The waste tax for CDW landfill disposal, one of the highest in the EU, has also proved to be an effective tool to increase CDW recycling.

However, there are still many EU countries where the management of CDW is at an early stage, requiring a long way to achieve the success of countries with higher levels of development. It is the case of Portugal and Spain, whose governments passed a national decree to regulate the production and management of CDW only in 2008.

In Spain, this new regulation forces the project developer to include a CDW management study in the construction project and compels the contractor to design a CDW management plan for the construction site. Both the study and plan are required in order to obtain a construction permit and include two important aspects to control waste quantities and treatment cost (Solís-Guzmán *et al.*, 2009). The National Decree 105/2008 also enforces CDW separation on-site and forbids the disposal of waste without prior treatment, to discourage the disposal of recyclable CDW. Spain has undergone a decade of intense construction activity during which about 60% of the CDW ended up in illegal dumps without any previous treatment or control (Solís-Guzmán *et al.*, 2009). However, the country is now facing a new and challenging situation. The Spanish government has set a comprehensive legislative framework in order to achieve a CDW recycling rate of 40% (Ortiz *et al.*, 2010).

In Portugal, even though the first published law on waste management goes back to 1985, Decree-Law No. 488/85, only in 2008 was a specific law concerning CDW management published. In **Table 2**, an overview of the main legislation frame concerning wastes (all kinds) is presented, in chronological order.

Among other changes introduced by the Decree-Law No. 46/2008, the Portuguese Environmental Agency points out (Agência Portuguesa do Ambiente, 2010):

- Definition of the responsibility chain, in CDW production and management;

**Table 2 – Main legislative documents, which may concern CDW, released in Portugal, in recent years (Source: Coelho and Brito, 2007)**

| Legislation reference | General description |
|---|---|
| Decree nº 15/96, 23rd of January, 1996 | Approves waste management operations |
| Decree nº 335/97, 16th of May, 1997 | Establishes rules for waste transportation |
| Decree nº 818/97, 5th of September, 1997 | Approves the European list of wastes |
| Decree-Law nº 239/97, 9th of September, 1997 | Establishes general rules for waste management |
| Decree nº 961/98, 10th of November, 1998 | Legislates authorization processes in managing industrial, urban and other kinds of waste |
| Decree nº792/98, 22nd of September, 1998 | Approves the non-hazardous industrial waste map |
| Decree-Law nº 321/99, 11th of August, 1999 | Regulates the installation and management of nonhazardous industrial landfills |
| Decree-Law nº 516/99, 2nd of August, 1999 | Approves the Strategic Plan for non-hazardous industrial waste |
| Decree-Law n.º 152/2002, 23rd of May, 2002 | Regulates the installation, use, closure and post closure procedures for landfills |
| Decree nº209/2004, 3rd of March, 2004 | European waste catalogue |
| Decree-Law nº 178/2006, 5th of September, 2006 | Establishes general rules for waste management. Replaces Decree-Law nº 239/97 |
| Decree-Law nº 46/2008, 12th of March, 2006 | Establishes general rules for CDW management |

- Definition of procedures and practices to be adopted in the design and execution of the projects that emphasize the principles of waste hierarchy (reduce, reuse and recycle);

- Possibility of reuse of non-contaminated soils and rocks;

- Enforcement of CDW separation before landfill disposal;

- Definition of minimum technical requirements for sorting and fragmentation facilities;

- Licensing exemption for certain management operations, where the licensing procedure was a major obstacle to waste management in line with the principles of waste hierarchy;

- Utilization of CDW on-site subject to compliance with Portuguese and European technical standards;

- Conditioning the beginning and conclusion of works to the evidence of proper CDW management; a CDW management plan is required and most include an important aspect: waste quantities.

Although the relevance of such standards is undeniable, if high level recycling is to be done in the Portuguese construction industry, more needs to be done. For instance, this decree lacks the tools to estimate the amount of CDW generated at the construction site, in order for the CDW management plan to be properly done (Chaves, 2009). According to Lage *et al.* (2010), the first step towards the correct management of this type of debris is to determine its quantity. In order to fill this gap, this study produced indicators to estimate the amount of CDW generated on-site, as shown in the next section.

## 3. Waste quantification procedure

Although some attempts have been made to quantify CDW in Portugal, scatter is too big to allow any conclusive figures. Consulted studies present values as different as 63164 ton/year (Carvalho, 2001), 6440000 ton/year (Pereira, 2002), 4403779 ton/year (Ruivo e Veiga, 2004) and 1996874 ton/year (Coelho, 2010), the latter for CDW without soil content. European estimations have awarded

Portugal about 3200000 ton/year, calculated from a CDW capitation of 325 kg/person/year, with a 9.9 million population (Symonds Group Ltd. *et al.*, 1999). Other estimates have resulted on 63164 ton/year and 1690740 ton/year (Instituto dos Resíduos, 2003), reported as having been deposited in legalized sites.

Up to this moment, investigations carried out to quantify the amount of CDW are mainly based on *per capita* estimates and contact survey of waste management institutions, this led to values that reflect with low accuracy the current situation of CDW in Portugal. However, there are many ways to make an estimate of CDW generated, both globally and at the construction site.

For example, Mañà i Reixach *et al.* (2000) present a method to obtain the volume of construction and demolition debris per surface area unit for building works with different construction systems. In the volume of construction waste per unit area three different phases of construction are considered: structure (distinguishing the type of formwork used, wooden or metallic), walls and finishing (distinguishing ceramic waste from plasterboard debris). **Table 3** presents the indicators that allow the estimation of CDW in these construction phases. Demolition waste is calculated depending on the building type: residential buildings with masonry walls, residential buildings with concrete structure and industrial buildings with masonry walls.

**Table 3 – Volume of CDW generated in three different phases of construction, in $m^3/m^2$ (Source: Mañà i Reixach *et al.*, 2000)**

| Phases of construction | Volume of CDW |
|---|---|
| Structure (wooden formwork) | 0.01500 |
| Structure (metallic formwork) | 0.00825 |
| Walls | 0.05500 |
| Finishing | 0.05000 |
| Total | 0.12000 |

Solís-Guzmán *et al.* (2009) present another quantification method to estimate the volume of waste that is expected to be generated at the building site. This quantification model has been developed by studying 100 dwelling projects, especially their bill of quantities, and defining a CDW classification, which is the same as that normally employed by Spanish quantity surveyors to obtain the bill of quantities. These projects have been defined by five main characteristics: project (new construction or demolition); number of floors (from 1 to 10 floors, 1 or 2 basement levels and stores or offices at ground level); foundation (pile, reinforced concrete slab, reinforced concrete trench or pads); structure (reinforced concrete or brick walls); ceiling (pitched or horizontal).

Methodology used in the present work to estimate the generation of CDW at the construction site was based on the study procedures of Cochran *et al.* (2007), where data from previous waste composition studies reported in the literature was used. **Table 4** shows a sample of waste production rates (weight per unit area) collected from the literature; only composition studies reporting the area associated with the activity are included. CDW generation is estimated for the same six specific sectors as in Cochran et al. (2007) and Franklin Associates (1998): residential construction; non-residential construction; residential demolition; non-residential demolition; residential renovation; and non-residential renovation. CDW generated in public works (such as that from roads, bridges, decks, docks, stadiums, and other structures) was not included in this estimate because there is hardly any study that quantifies the waste generated in this activity. Several publications (Weisleder and Nasseri, 2006; Kofoworola and Gheewala, 2009) note the absence of such data, emphasizing that a high percentage of this waste corresponds to soil, which is almost never included in CDW studies.

In this paper, only the waste streams classified under chapter 17 (construction and demolition wastes) of the European Waste Catalogue (EWC) were accounted for, because these streams contribute more to the overall percentage (by weight) of waste generated on-site. Although it is classified under chapter 17 and represents a significant portion of CDW, excavated soil was not accounted for in this study for lack of available information, as mentioned. **Table 5** lists the waste streams accounted for by the six-digit code of the EWC. There are several codes for contaminated wastes in chapter 17 but in this study they were all included in code 17 09 03 as there was not enough information to differentiate the hazardous wastes generated on-site.

In the vast majority of studies, only an estimate of the mixture of concrete, bricks, tiles and ceramics was determined. This makes it difficult to produce indicators for each waste stream under subchapter 17 01 (concrete, bricks, tiles and ceramics). To overcome this difficulty, this study produced indicators for these waste streams and also for their sum. The same analogy was made for the mixture of construction and demolition wastes, leading to the development of an indicator that estimates the total amount of CDW generated on-site. These global indicators provide an essential tool to support the inspection of building sites where a poor CDW separation was performed.

Available information on waste generation is limited and therefore it was not possible to produce indicators that differentiate the main building characteristics (such as type of foundation, structure and ceiling). This information is also quite heterogeneous, which led to the need to produce a range of values for CDW generation instead of trying to generate a single value. According to Lage *et al.* (2010), these wide-ranging values may be attributed to a number of different causes such as the lack of reliable studies, differences in economic power, size of cities, construction practices and differences related to the predominant population type (rural or urban). Knowing that the data collected is highly dependent on the zone under study, a degree of confidence was assigned to the indicators (**Table 6**), to estimate their reliability.

In order to simplify the use of the proposed indicators, they were evaluated in $kg/m^2$. Only the gross area of the building or area of intervention, for renovation works, is required to obtain the CDW generation at the building site. **Table 7** shows the CDW indicators generated in this study. The feasibility of the indicators was tested in the next section through case studies' analysis.

## 3. Case studies

In this section, quantities of CDW generated in projects of construction, demolition and renovation were examined. The number of projects studied per category is outlined in **Table 8**. Practically all of the buildings under consideration were found to have been built with a reinforced concrete structure.

As in previous Portuguese studies, it was very difficult to obtain CDW information from construction and demolition contractors. In this work, about 30 institutions were contacted but only 4 (Mota-Engil Group, Ambisider, Demotri and Municipal County of Montemor-o-Novo) provided quantitative information. For this reason, only a small amount of the proposed indicators was tested.

**Table 4 (first part) – Job-site construction, demolition and renovation waste compositions determined from previous studies**

| Study | Country | CDW generation per EWC code ($kg/m^2$) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | 17 01 01 | 17 01 02 | 17 01 03 | 17 01 07 | 17 01[1] | 17 02 01 | 17 02 02 | 17 02 03 | 17 03 02 | 17 04 07 | 17 06 04 | 17 08 02 | 17 09 03 | 17 09 04 |
| **Residential construction activity** | | | | | | | | | | | | | | | | |
| Bergsdal *et al.* (2007) | Norway | 29.36 | | | | 6.50 | 6.50 | 5.68 | 0.24 | | | 0.11 | 1.20 | 3.04 | 0.07 | 9.60 |
| | | 30.77 | | | | 19.11 | 19.11 | 2.75 | 0.12 | | | 0.48 | 0.21 | 1.38 | 0.07 | 6.19 |
| Myhre (2000) | | | | | | 6.5 - 15.7 | 6.5 - 15.7 | 1.1 - 2.8 | 0 - 0.3 | | 0.7 | 0.2 - 1.2 | 0.1 - 1.2 | 0.8 - 3.5 | 0.02 | 8.8 - 9.6 |
| Solís-Guzmán *et al.* (2009) | Spain | 89.37 | | | | | | | | | | | | | | |
| Mañà i Reixach *et al.* (2000) | | 114.26 | 3.29 | | | 96.92 | 100.21 | 2.52 | | 0.14 | | 3.38 | | 5.93 | | 0.87 |
| | | 114.47 | 4.47 | | | 96.92 | 101.39 | 0.99 | | 0.15 | | 3.93 | | 5.93 | | 0.87 |
| Ortiz *et al.* (2010) | | 205.89 | 109.00 | 54.30 | 3.19 | | 166.49 | 3.08 | | 3.92 | | 10.46 | 0.04 | 14.70 | | |
| Lage *et al.* (2010) | | 80.00 | 2.48 | | | 38.08 | 40.56 | 5.44 | | 7.04 | | 14.08 | | 5.76 | | 0.72 |
| SMARTWaste (2010) | United Kingdom | 168.05 | 32.90 | 29.24 | 1.86 | 38.65 | 102.65 | 12.46 | | 2.94 | 2.62 | 2.80 | 3.32 | 7.64 | 0.21 | 20.99 |
| Cochran *et al.* (2007) | USA | 21.35 | 0.26 | 0.51 | | | 0.77 | 12.00 | | 0.15 | 0.39 | 0.30 | | 5.20 | | 1.40 |
| | | 43.70 | 22.90 | | | | 22.90 | 6.40 | | 0.49 | 1.50 | 0.90 | | 4.90 | | 0.93 |
| Salinas (2002) | | 20.00 | | 0.60 | | | 0.60 | 8.80 | | | | 0.60 | | 5.00 | | 3.60 |
| | | 39.00 | | 0.78 | | | 0.78 | 17.94 | | | | 2.34 | | 9.75 | | 5.85 |
| **Non-residential construction activity** | | | | | | | | | | | | | | | | |
| Bergsdal *et al.* (2007) | Norway | 30.77 | | | | 19.11 | 19.11 | 2.75 | 0.12 | | | 0.48 | 0.21 | 1.38 | 0.07 | 6.19 |
| | | 31.50 | | | | 17.52 | 17.52 | 4.05 | | | | 0.79 | 0.10 | 0.80 | 0.07 | 7.91 |
| Myhre (2000) | | | | | | 6.5 - 15.7 | 6.5 - 15.7 | 2.8 - 1.1 | 0 - 0.3 | | 0.7 | 0.2 - 1.2 | 0.1 - 1.2 | 0.8 - 3.5 | 0.02 | 8.8 - 9.6 |
| SMARTWaste (2010) | United Kingdom | 181.49 | 40.12 | 15.63 | 0.42 | 45.29 | 101.46 | 17.97 | | 1.65 | 3.38 | 7.21 | 3.36 | 5.02 | 2.79 | 22.05 |
| | | 200.04 | 35.64 | 21.53 | 2.31 | 41.53 | 101.01 | 12.76 | | 2.22 | 2.82 | 13.15 | 1.49 | 4.49 | 0.68 | 55.19 |
| | | 292.94 | 4.26 | 2.81 | 1.65 | 219.71 | 228.43 | 4.47 | | 1.27 | 16.33 | 2.80 | 1.05 | 5.84 | 0.01 | 26.49 |
| | | 205.98 | 38.33 | 16.92 | 0.69 | 57.09 | 113.03 | 12.57 | | 1.85 | 5.49 | 4.69 | 2.74 | 4.19 | 0.69 | 51.57 |
| | | 160.45 | 25.06 | 17.27 | 0.64 | 22.15 | 65.12 | 12.01 | | 1.87 | 6.56 | 6.33 | 2.35 | 10.11 | 0.66 | 43.60 |
| | | 133.50 | 18.32 | 19.74 | 0.15 | 53.82 | 92.03 | 4.34 | | 0.62 | 4.57 | 5.30 | 0.79 | 2.08 | 1.46 | 17.22 |
| | | 134.45 | 36.26 | 26.12 | 1.10 | 8.09 | 71.57 | 13.45 | | 1.46 | 2.34 | 4.59 | 2.31 | 6.33 | 0.74 | 21.74 |
| | | 285.17 | 11.47 | 28.19 | 1.17 | 132.43 | 173.26 | 23.53 | | 2.93 | 5.49 | 3.97 | 3.34 | 6.05 | 1.96 | 50.53 |
| Mañà i Reixach *et al.* (2000) | Spain | 114.26 | 3.29 | | | 74.96 | 78.25 | 3.23 | | 0.25 | | 3.38 | | 2.60 | | 0.87 |
| | | 114.47 | 4.47 | | | 74.96 | 79.43 | 1.70 | | 0.26 | | 3.93 | | 2.60 | | 0.87 |
| Ortiz *et al.* (2010) | | 205.89 | 109.00 | 54.30 | 3.19 | | 166.49 | 3.08 | | 3.92 | | 10.46 | 0.04 | 14.70 | | |
| Lage *et al.* (2010) | | 80.00 | 2.48 | | | 38.08 | 40.56 | 5.44 | | 7.04 | | 14.08 | | 5.76 | | 0.72 |
| Cochran *et al.* (2007) | USA | 11.50 | | | | | | 7.00 | | | | | | 0.50 | | 3.00 |
| | | 47.60 | 33.00 | | | | 33.00 | 3.30 | | | | 1.40 | | 5.20 | | 4.70 |
| **Residential demolition activity** | | | | | | | | | | | | | | | | |
| Bergsdal *et al.* (2007) | Norway | 575 | | | | 394.30 | 394.30 | 105.84 | 2.59 | 0.92 | | 4.45 | 1.69 | 3.37 | 0.40 | 59.02 |
| | | 1103 | | | | 1012.46 | 1012.46 | 48.55 | 0.44 | 0.32 | | 7.70 | | 0.01 | 0.42 | 31.21 |
| Myhre (2000) | | | | | | 387 – 1164 | 387 – 1164 | 23.6 - 98.5 | 0.3 - 3.3 | 0.3 - 6.5 | 1.00 | 3.3 – 29 | 0.1 - 2.2 | 0 - 4.1 | 0.57 | 22.8 - 35.3 |
| Metro Vancouver (2008) | Canada | 547 | 136.75 | | | | 136.75 | 240.68 | | | | 16.41 | | 10.94 | | 142.22 |
| | | 626 | 156.50 | | | | 156.50 | 275.44 | | | | 18.78 | | 12.52 | | 162.76 |
| Mañà i Reixach *et al.* (2000) | Spain | 608 | 90.77 | 425.27 | | | 516.04 | 11.80 | 1.00 | 0.01 | | 0.81 | | | | 6.64 |
| | | 805 | 769.04 | 317.70 | | | 1086.74 | 0.84 | 2.50 | 0.01 | | 3.24 | | | | 12.71 |
| Solís-Guzmán *et al.* (2009) | | 1053 | | | | | | | | | | | | | | |

**Table 4 (second part) – Job-site construction, demolition and renovation waste compositions determined from previous studies**

| Study | Country | CDW generation per EWC code (kg/m$^2$) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | 17 01 01 | 17 01 02 | 17 01 03 | 17 01 07 | 17 01[1] | 17 02 01 | 17 02 02 | 17 02 03 | 17 03 02 | 17 04 07 | 17 06 04 | 17 08 02 | 17 09 03 | 17 09 04 |
| **Residential demolition activity** | | | | | | | | | | | | | | | | |
| CYPE Ingenieros (2010) | Spain | 664 | 215.80 | 298.10 | 27.10 | | 541.00 | 32.40 | 0.60 | 0.40 | | 3.40 | | 81.30 | | 4.90 |
| | | 1061 | 767.85 | 193.27 | 17.57 | | 978.69 | 2.40 | 1.50 | 0.80 | | 13.60 | | 52.71 | | 10.40 |
| | | 619 | 293.00 | 176.00 | 16.00 | | 485.00 | 25.00 | 0.70 | 0.40 | | 55.00 | | 48.00 | | 5.00 |
| Lage *et al.* (2010) | | 1350 | 662.85 | | | 571.05 | 1233.90 | 58.05 | 1.35 | | 1.35 | 28.35 | | 10.8 | | 10.8 |
| Coelho (2010) | Portugal | 345 | | 191.01 | 8.29 | 21.08 | 220.38 | 50.01 | 0.98 | | | 4.23 | | 68.85 | | |
| | | 302 | | 117.88 | 17.40 | 27.15 | 162.43 | 53.49 | 0.50 | | | 1.23 | | 84.59 | | |
| | | 1371 | 491.73 | 486.17 | 4.41 | 307.97 | 1290.28 | 5.79 | 0.68 | | 0.22 | 9.81 | | 64.28 | | |
| | | 1277 | 807.86 | 169.56 | 10.56 | 258.14 | 1246.12 | 11.88 | 1.09 | 3.89 | 0.54 | 13.46 | | | | |
| | | 251 | | | | 170.77 | 170.77 | 26.49 | 1.68 | | | 7.37 | | | 4.08 | |
| **Non-residential demolition activity** | | | | | | | | | | | | | | | | |
| Bergsdal *et al.* (2007) | Norway | 1103.25 | | | | 1012.46 | 1012.46 | 48.55 | 0.44 | 0.32 | | 7.70 | | 0.01 | 0.42 | 31.21 |
| | | 601.95 | | | | 519.34 | 519.34 | 17.09 | 0.20 | 2.57 | | 45.31 | 0.09 | 0.31 | 0.23 | 14.67 |
| Myhre (2000) | | | | | | 387 – 1164 | 387 – 1164 | 23.6 - 98.5 | 0.3 - 3.3 | 0.3 - 6.5 | 1.00 | 3.3 – 29 | 0.1 – 2.2 | 0 – 4.1 | 0.57 | 22.8 – 35.3 |
| Franklin Associates (1998) | USA | 742.15 | 489.82 | 7.42 | | | 497.24 | 118.74 | | | 14.84 | 37.11 | | | | |
| Cochran *et al.* (2007) | | 845.00 | 690.00 | | | | 690.00 | 1.50 | | | | 44.00 | | | | 110.00 |
| Mañà i Reixach *et al.* (2000) | Spain | 1635.97 | 373.32 | 437.73 | | | 811.05 | 11.46 | | 0.05 | | 1.53 | | | | 0.83 |
| CYPE Ingenieros (2010) | | 664.00 | 215.80 | 298.10 | 27.10 | | 541.00 | 32.40 | 0.60 | 0.40 | | 3.40 | | 81.30 | | 4.90 |
| | | 1061.10 | 767.85 | 193.27 | 17.57 | | 978.69 | 2.40 | 1.50 | 0.80 | | 13.60 | | 52.71 | | 10.40 |
| | | 619.10 | 293.00 | 176.00 | 16.00 | | | 25.00 | 0.70 | 0.40 | | 55.00 | | 48.00 | | 5.00 |
| Lage *et al.* (2010) | | 1350.00 | 662.85 | | | 571.05 | 1233.90 | 58.05 | 1.35 | | 1.35 | 28.35 | | 10.80 | | 10.80 |
| Coelho (2010) | Portugal | 35.00 | 25.30 | | | | 25.30 | 0.75 | 1.32 | | | 7.26 | 0.12 | 0.35 | | |
| | | 258.00 | | | | 27.73 | 27.73 | 121.76 | 4.43 | | | 29.91 | | | | |
| | | 1637.00 | 1328.83 | 43.89 | 7.32 | 179.18 | 1559.22 | 19.94 | | 1.48 | 21.33 | 34.76 | | | | |
| | | 2410.00 | 1976.00 | | 4.27 | 357.21 | 2337.48 | 4.05 | 9.32 | 6.07 | | 52.83 | | | | |
| **Residential renovation activity** | | | | | | | | | | | | | | | | |
| Bergsdal *et al.* (2007) | Norway | 89.47 | | | | 40.40 | 40.40 | 37.94 | 0.29 | | | 0.38 | 0.62 | 5.90 | 0.03 | 2.70 |
| | | 60.13 | | | | 30.45 | 30.45 | 8.06 | 0.29 | | | 4.06 | 0.14 | 2.44 | 0.03 | 13.48 |
| Myhre (2000) | | | | | | 18.8 – 40.4 | 18.8 – 40.4 | 2.3 – 42.6 | 0.40 | | | 0.2 - 4 | 0.1 - 0.6 | 2.3 – 5.9 | 0.05 | 2.2 - 10.8 |
| Coelho (2010) | Portugal | 92.00 | | 63.33 | 12.56 | 9.79 | 85.68 | 5.02 | 0.84 | | | | | 0.16 | | |
| | | 396.69 | 21.39 | 319.46 | 3.05 | 19.34 | 363.24 | 6.69 | 0.65 | | | 2.61 | | 23.49 | | |
| | | 177.00 | | 106.08 | | 68.46 | 174.54 | 2.01 | 0.23 | | | | | | | |
| **Non-residential renovation activity** | | | | | | | | | | | | | | | | |
| Bergsdal *et al.* (2007) | Norway | 60.13 | | | | 30.45 | 30.45 | 8.06 | 0.29 | | | 4.06 | 0.14 | 2.44 | 0.03 | 13.48 |
| | | 33.18 | | | | 18.77 | 18.77 | 2.30 | 0.29 | | | 6.05 | 0.10 | 2.30 | 0.03 | 2.70 |
| Myhre (2000) | | | | | | 18.8 – 40.4 | 18.8 – 40.4 | 2.3 – 42.6 | 0.40 | | | 0.2 - 4 | 0.1 - 0.6 | 2.3 – 5.9 | 0.05 | 2.2 - 10.8 |
| Coelho (2010) | Portugal | 190.00 | | 11.24 | | 175.58 | 186.82 | 0.42 | 0.87 | 1.90 | | 0.18 | | | | |
| | | 104.00 | 4.30 | 50.51 | 16.90 | | 71.71 | 9.52 | | | | | | 22.85 | | |
| | | 326.13 | 191.21 | 62.02 | 0.16 | 64.20 | 317.59 | 0.37 | | | | 1.40 | | 6.90 | | |
| | | 167.04 | | 46.12 | 0.24 | 113.88 | 160.24 | 2.44 | 0.89 | | | 0.02 | | 3.07 | | |

[1] Resulting from the sum of waste streams under subchapter 17 01

**Table 5 – Waste streams accounted for**

| Waste stream | EWC code |
|---|---|
| Concrete | 17 01 01 |
| Bricks | 17 01 02 |
| Tiles and ceramics | 17 01 03 |
| Mixture of concrete, bricks, tiles and ceramics | 17 01 07 |
| Wood | 17 02 01 |
| Glass | 17 02 02 |
| Plastic | 17 02 03 |
| Bituminous mixtures | 17 03 02 |
| Mixed metals | 17 04 07 |
| Insulation materials | 17 06 04 |
| Gypsum-based construction materials | 17 08 02 |
| Mixed construction and demolition wastes containing dangerous substances | 17 09 03 |
| Mixed construction and demolition wastes | 17 09 04 |

**Table 6 – Degree of confidence assigned to the CDW indicators**

| Degree of confidence | Meaning |
|---|---|
| Solid | Many values were accounted for, leading to consistent estimates. Values are very conclusive. |
| Passable | Many values were accounted for, leading to inconsistent estimates. Values are inconclusive. |
| Weak | Few values were accounted for. It is possible, however, to draw some conclusions. |
| Poor | Very few values were accounted for. It is not possible to draw conclusions. |

**Table 7 – CDW indicators produced in this study**

| CDW indicators produced in this study concerning buildings with concrete structure (kg/m$^2$) | | | | | | |
|---|---|---|---|---|---|---|
| EWC Code | Construction | | Demolition | | Renovation | |
| | Residential | Non residential | Residential | Non residential | Residential | Non residential |
| 17 01 01 | 17.8 - 32.9 | 18.3 - 40.1 | 492 - 840 | 401 - 768 | 4.4 - 45.9[2] | 15.4 - 191.2[2] |
| 17 01 02 | 19.2 - 58.6 | 15.6 - 54.3 | 170 - 486 | 176 - 438 | 8.0 - 319.5[2] | 11.2 - 62.0[2] |
| 17 01 03 | 1.7 - 3.2 | 0.4 - 3.2 | 10.6 - 17.6 | 16 - 27 | 8.0 - 212.5[2] | 2.6 - 107.2[2] |
| 17 01[1] | 40 - 102 | 32 - 113 | 811 - 1290 | 497 - 1234 | 20 - 363 | 19 - 318 |
| 17 02 01 | 2.5 - 6.4 | 1.3 - 5.4[2] | 12 - 58 | 1- 20[2] | 2.0 - 37.9 | 2.3 - 42.6 |
| 17 02 02 | 0.0 - 0.3 | 0.0 - 0.3[2] | 0.4 - 2.6 | 0.2 - 4.4 | 0.2 - 1.4 | 0.3 - 0.9 |
| 17 02 03 | 0.1 - 0.8 | 0.2 - 1.9[2] | 0.4 - 7.4 | 0.4 - 6.1 | 0.6 - 1.3 | 1.9 - 2.6 |
| 17 03 02 | 0.4 - 2.6 | 0.7 - 6.6 | 0.2 - 1.9 | 1.0 - 1.4 | 12 | 8 - 12 |
| 17 04 07 | 0.9 - 3.9 | 0.9 - 7.2[2] | 9.8 - 28.4 | 28.4 - 53.0 | 0.4 - 6.8 | 0.2 - 16.4 |
| 17 06 04 | 0.1 - 1.2 | 0.1 - 1.5 | 0.1 - 2.2 | 0.1 - 4.4[2] | 0.1 - 0.6 | 0.1 - 0.6 |
| 17 08 02 | 3.7 - 7.6 | 2.6 - 6.3 | 10.8 - 64.3 | 10.8 - 75.7 | 2.4 - 23.5 | 2.3 - 22.9 |
| 17 09 03 | 0.02 - 0.33 | 0.01 - 0.74 | 0.4 - 0.6 | 0.2 - 0.6 | 0.03 - 0.05 | 0.03 - 0.05 |
| Total | 44 - 115 | 48 - 135 | 805 - 1371 | 742 - 1637 | 28 - 397 | 20 - 326 |

[1] Resulting from the sum of waste streams under subchapter 17 01

[2] This indicator was the object of a small correction in the next section of this abstract

**Table 8 – Number of projects studied per category**

| Project category | Number of projects |
|---|---|
| Residential construction | 0 |
| Non-residential construction | 10 |
| Residential demolition | 2 |
| Non-residential demolition | 4 |
| Residential renovation | 71[1] |
| Non-residential renovation | 18[1] |

[1] Only inert waste was considered

An approval rating was determined for each indicator tested (**Table 9**). This rating represents the percentage of values that are within the estimated range for each indicator. In general, proposed indicators seem to provide a reasonably robust way of measuring and reporting waste volumes generated in the construction site. However, validation of some of these indicators was negatively affected by poor CDW separation at the construction site and was distorted in some cases by the small scale of the sample. CDW separation is one of the greatest problems of the construction sector, because it is difficult to perform, due to the space required at the construction site, the amounts of waste produced, and the necessary workforce (Chaves, 2009).

**Table 9 – Approval rating of the proposed indicators**

| Approval rate of the proposed indicators | | | | | | |
|---|---|---|---|---|---|---|
| EWC code | Construction | | Demolition | | Renovation | |
| | Residential | Non residential | Residential | Non residential | Residential | Non residential |
| 17 01 01 | - | 20.0% | - | - | - | - |
| 17 01 02 | - | - | - | - | 0.0% | - |
| 17 01 03 | - | - | - | - | 5.9% | 25.0% |
| 17 01 | - | 40.0% | - | 100.0% | 91.0% | 62.5% |
| 17 02 01 | - | 88.9% | - | 0.0% | - | - |
| 17 02 02 | - | 100.0% | - | 100.0% | - | - |
| 17 02 03 | - | 66.7% | - | 75.0% | - | - |
| 17 03 02 | - | 25.0% | - | - | - | - |
| 17 04 07 | - | 66.7% | - | 25.0% | - | - |
| 17 06 04 | - | 88.9% | - | 66.7% | - | - |
| 17 08 02 | - | 0.0% | - | - | - | - |
| 17 09 03 | - | - | - | - | - | - |
| Total | - | 60.0% | - | 75.0% | - | - |

## 5. Conclusions

In the near future, it will be possible to analyze the effects on the Portuguese construction industry of the new legislative framework established. Although its success depend mainly on the commitment of all the participants (administrations, contractors and builders), some changes will need to be made to Decree-Law No. 46/2008, in order to push for improvements related to recycling of waste.

There is a need to supplement this decree with indicators to monitor waste produced at the construction site, in order for the CDW management plan to be properly completed (Chaves, 2009). In Portugal, there is a lack of reliable composition studies about waste generated by construction and demolition activities, and none of these truly focuses on the generation of waste on-site.

In this study indicators were produced that provide the Portuguese construction industry with an innovative benchmark against which to measure its waste generation on-site. These indicators can be used to determine the container size and type and the pick-up frequency in order to reach the next step, reusing the material. Such calculation allows waste to be properly treated and mixing and deterioration to be prevented (Sólis-Guzmán *et al.*, 2009).

Currently, the response of institutions operating in Portugal is very weak, when requested to provide information about waste. Due to this situation, it was possible to test only some of the proposed indicators. It is necessary to reverse this situation, particularly through the development of partnerships between businesses and universities. Making knowledge available through effectively linking academia with business will deliver innovative practice, enable businesses to benefit from specialist skills and provide a catalyst for sustainable economic growth throughout the region.

The feasibility of the proposed indicators was tested in this work through case studies' analysis. It was found that they provide a reasonably robust way of measuring and reporting waste volume generated at the construction site. However, these indicators need to be continuously evaluated in order to improve its accuracy.

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