ESTIMATION METHOD OF PRODUCTION AND COMPOSITION OF CONSTRUCTION AND DEMOLITION DEBRIS

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ABSTRACT

In the present framework of sustainable construction, management of construction and demolition (C&D) debris is fundamental, and its correct development requires a previous estimation of the precise quantities and detailed composition of C&D debris. Once these data are known, current strategies based on reducing, reusing, recycling and revaluing ought to be applied. A procedure has been developed in order to obtain this information in any territory, starting from the data of a particular territory: new construction surface, rehabilitation surface and demolition surface (estimated from the existing data for the last years), and from the construction and demolition (C&D) debris produced at each building work type (obtained from recent construction works or architectural projects of old buildings). The developed method enables determination of a medium-term estimate of these data, and has been applied specifically to Galicia territory (in detail to each of its counties) and has been generalized to Spain disaggregating data by Autonomous Communities.

Keywords: Construction and Demolition (C&D) Debris, Management of C&D Debris, Quantification of C&D Debris, Composition of C&D Debris, Recycled Aggregate.

1. INTRODUCTION

Construction and Demolition (C&D) Debris are waste materials generated by the construction, renovation and demolition of buildings, public works and urban developments. According to the European Waste Catalogue, (EWC, 2000, 2001), excavated earth from previous activities is included in the C&D Debris classification, although most Management Plans and C&D Debris applications do not include soil excavation.

C&D Debris are inert materials and therefore not considered to be hazardous. However, owing to their sheer volume, in order to protect the Environment, the management of these wastes must be programmed. The first step towards the correct management of this type of debris is to determine their volume, given the fact that at the present time there are a number of studies that report very different values regarding the production of C&D Debris, ranging from 160 kg/inhab./year in Ireland in 1997 to 1200 kg/inhab./year in Madrid (Spain) in 2003 [1] [2] [3] [4]. Focusing our attention on Spain alone, there is a broad variation in data among regions. For example, according to the II PNRCD [5] in 2005, 145 kg/inhab./year were generated in Ceuta and 1664 kg/inhab./year in Castilla – La Mancha. These wide-ranging values may be attributed to a number of different causes: lack of reliable studies, differences
in economic power, city size, construction practices, differences related to the predominant population type (rural or urban), etc.

Both the information on the amounts of waste material produced, and the data reporting on C&D Debris composition are heterogeneous. It is important to note that the values reported are highly dependant upon the zone under study since the materials and construction techniques used can vary [1] [4] [6] [7] [8] [9] [10] [11] [12]

2. METHODOLOGY DEVELOPED

2.1. General Comments

The methodology used in this work is based on those procedures developed in the Franklin Report to U.S. Environmental Protection Agency Municipal and Industrial Solid Waste Division (USA) [13], applied by Cochran to Florida state [14]. Thus, the quantity of C&D Debris generated will be obtained adding both the building-related waste and the debris from public works activities. Different procedures are used to calculate each type of waste material since the circumstances of each waste are different.

The hypotheses used to calculate building-related C&D Debris are described in detail below:

- The number of construction, renovation and demolition works may be adjusted to a theoretical function (linear, parabolic, exponential, etc.) that depends on time. In other words, if the data from a specific time period is known, then it will be possible to predict it in the future.
- Construction activities are distributed throughout the whole region and the distribution is assumed to be the same every year.
- The surface area of the construction, renovation or demolition project can also be adjusted by a function of time. If the data used to make the estimates is insufficient, it will be assumed that the average area which is constructed, renovated or demolished surface in each county is constant over time.
- The quantity of debris generated per unit of surface area is assumed to be the same for each type of construction.

The hypotheses used to obtain the C&D Debris materials generated as a result of public works activities are listed as follows:

- Public works are not distributed over the entire region; instead they are concentrated in specific zones.
- Public works do not include many different types of projects which means that the number of different types of debris materials is lower that in building-related activities. Moreover, given the fact that each project takes a longer time to complete, the materials are put to better use and as a result, a reduced amount of debris is produced from each type of material. Hence, public works projects generate fewer different types of debris, smaller quantities of each and their classification is easier.
- Very few demolition activities are carried out in public works projects. Despite certain kinds of public works become obsolete demolition is not a common approach.
- In public works projects, renovation activities seldom generate demolition debris as they usually consist of the expansion or upgrading of existing works.
- The quantity of debris generated from public works projects is proportional to the budget of the project in question.
2.2. Procedure for the calculation of the amount of C&D Debris generated in building-related activities

This method can be used to calculate the C&D Debris generated for the horizon year (H.Y.) distributed over smaller geographic areas referred to here as Autonomous Communities (A.C.). The C&D Debris generated in this area during the H.Y. (Rbuild) will be determined as the sum of the debris generated from new construction activity (Rc), renovation activity (RR) and demolition (RD) in each A.C., according to equation (1).

\[ R_{\text{build}} = \sum_{\text{A.C.}} \left( R_c + R_R + R_D \right) \]  \hspace{1cm} (1)

In each A.C. the debris generated from new construction, renovation and demolition activities will be calculated by multiplying the total surface area of the activities related to new construction (SC), renovation (SR) and demolition (SD) carried out in each A.C. during the H.Y. by the quantity of debris generated per unit of surface area in new construction (CC), renovation (CR) and demolition (CD), projects respectively, according to equation (2).

\[ R_{\text{build}} = \sum_{\text{A.C.}} \left( R_c + R_R + R_D \right) = \sum_{\text{A.C.}} \left( C_c \cdot S_{\text{C}} + C_R \cdot S_R + C_D \cdot S_D \right) \] \hspace{1cm} (2)

The proposed procedure is:
1. Computation of the area of constructed surface in each A.C. for the H.Y.
2. Computation of the area of demolished surface in each A.C. for the H.Y.
3. Computation of the area of renovated surface in each A.C. for the H.Y.
4. Computation of the quantity of debris generated per unit area in construction activities.
5. Computation of the quantity of debris generated per unit area in demolition activities.
6. Computation of the quantity of debris generated per unit area in renovation activities.

3. THE PROCEDURE APPLIED TO SPAIN

3.1. Introducción

Spain is divided into 17 Autonomous Communities and 2 Autonomous Cities, their surface area and population in 2008 are included in Table 1.

<table>
<thead>
<tr>
<th>Autonomous Community</th>
<th>Area (km²)</th>
<th>Population 2008</th>
<th>Autonomous Community</th>
<th>Area (km²)</th>
<th>Population 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andalucía</td>
<td>87,598</td>
<td>8,202,220</td>
<td>Extremadura</td>
<td>41,635</td>
<td>1,097,744</td>
</tr>
<tr>
<td>Aragón</td>
<td>47,720</td>
<td>1,326,918</td>
<td>Galicia</td>
<td>29,574</td>
<td>2,784,169</td>
</tr>
<tr>
<td>Asturias (Principado de)</td>
<td>10,604</td>
<td>1,080,138</td>
<td>Madrid (Comunidad de)</td>
<td>8,028</td>
<td>6,271,638</td>
</tr>
<tr>
<td>Balears (Islas)</td>
<td>4,992</td>
<td>1,072,844</td>
<td>Murcia (Región de)</td>
<td>11,313</td>
<td>1,426,109</td>
</tr>
<tr>
<td>Canarias</td>
<td>7,447</td>
<td>2,075,968</td>
<td>Navarra (Comunidad Foral)</td>
<td>10,390</td>
<td>620,377</td>
</tr>
<tr>
<td>Cantabria</td>
<td>5,321</td>
<td>582,138</td>
<td>País Vasco</td>
<td>7,235</td>
<td>2,157,112</td>
</tr>
<tr>
<td>Castilla y León</td>
<td>94,225</td>
<td>2,557,330</td>
<td>Rioja (La)</td>
<td>5,045</td>
<td>317,501</td>
</tr>
<tr>
<td>Castilla - La Mancha</td>
<td>79,462</td>
<td>2,043,100</td>
<td>Ceuta (Autonomous City)</td>
<td>19</td>
<td>77,389</td>
</tr>
<tr>
<td>Cataluña</td>
<td>32,113</td>
<td>7,364,078</td>
<td>Melilla (Autonomous City)</td>
<td>13</td>
<td>71,448</td>
</tr>
<tr>
<td>Comunidad Valenciana</td>
<td>23,255</td>
<td>5,029,601</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Area and population in 2008 of the A.C.
3.2. Estimation of C&D Debris generated from building activity

The data were taken from the Instituto Nacional de Estadística de España (National Institute of Statistics of Spain) [15], which also include the data of the Ministerio de Fomento Español (Spanish Ministry of Development). Details of the data are presented hereby:

- For all A.C. except for País Vasco from 1990 to 2008 and 1998 to 2008, and for the Autonomous Cities (Ceuta and Melilla) from 2005 to 2008,
  - Newly constructed buildings: number of buildings and total surface area constructed each year.
  - Renovation projects: total number of buildings on which some kind of work involving repair, remodeling or expansion has been undertaken.
  - Demolition activities: total number of demolished buildings.

- For Spain, in addition to the above data, and from 2000 to 2008,
  - Number of buildings and surface area of expansion work.
  - Number of buildings and surface area of emptying reforms.
  - Number of buildings of reforms of foundations, roofs and façades (reforms without emptying).
  - Number of business premises.
  - Number of buildings and surface area of partial demolitions.
  - Number of buildings and surface area of total demolitions.

3.2.1. Estimation of the number of buildings and the surface area of new construction projects and estimation of the Lumber of buildings of renovation and demolition projects in each A.C. for 2013.

For each A.C. and for each of the four parameters, the estimates were made using three function types: linear, exponential and parabolic, as the number of existing data is sufficient (19 except for País vasco, which is 11). Analyzing the shape of the curves, the absolute and relative errors and the sum of the squares of the errors, the best linear function was adopted.

For the Autonomous Cities the available data comprise only 4 years, and consequently these regions are not considered in this work.

3.2.2. Computation of the average surface area to be demolished in Spain and the surface area to be demolished in each A.C. in 2013.

There are no data related to the surface area of the demolished buildings for each A.C., but as the average size of new buildings is different among the A.C, the surface area ratio was defined as the ratio between the average surface area of the buildings in each A.C., and the average surface area of all of the buildings in Spain.

The total surface area to be demolished in each A.C. in 2013 is calculated using the number of buildings demolished in 2013 in each A.C., the surface area ratios and the average surface area to be demolished in Spain.

3.2.3. Computation of the average surface area to be renovated (for each of the five groups) in Spain and the surface area to be renovated in each A.C. in 2013.

The renovation projects are very diverse, so in this study these were divided into 5 groups (although one work may belong to several groups): expansion work, emptying reforms, reforms without emptying (foundations, roofs and façades), reforms of business premises and partial demolitions.
Data on the number of works of each type is known only for the whole country (Spain), so a similar distribution is assumed in each A.C. in order to estimate the number of works pertaining to each group.

The areas involved in the expansion works, in the emptying reforms and in the partial demolition partial demolition are known only for the whole country, so the average surface area is calculated for each group. The particular case of reforms without emptying has not been considered, as no surface has been constructed or demolished.

Finally, the average area of the premises has been considered 170 m2, after a research done by the authors comprising more than 200 premises of Galicia.

3.2.4. Computation of the quantity of debris generated per unit of surface in construction, demolition and renovation activities.

It was confirmed that the quantity of debris generated per unit of surface in construction, demolition and renovation projects in Galicia is similar to Spain [16]. This result was compared to the values obtained in Cataluña [12] and in the Second National Plan [5], and found to be very similar.

The values used in this work are: 100 kg/m2 in the construction projects, expansion works and emptying reforms, 140 kg/m2 in the reforms of business premises and 1350 kg/m2 in the partial and total demolition works.

3.2.5. Computation of construction, renovation and demolition debris in each A.C. for 2013.

If the quantity of debris per surface area for each A.C. is multiplied by the estimated surface area for 2013 for both new construction, renovation (expansion work, emptying reforms, partial demolition and reforms of business premises) and demolition, the debris generated in each A.C. are obtained (see Table 2). Dividing those by the estimated population for 2013, the debris generated per inhabitant and year in each A.C. are got (see Table 2).

<table>
<thead>
<tr>
<th>Autonomous Community</th>
<th>C&amp;D Debris (thousand tons/year)</th>
<th>RCDs (kg/inhab/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andalucía</td>
<td>2,526</td>
<td>198</td>
</tr>
<tr>
<td>Aragón</td>
<td>2,192</td>
<td>140</td>
</tr>
<tr>
<td>Asturias (Principado de)</td>
<td>1,088</td>
<td>1350</td>
</tr>
<tr>
<td>Balears (Islas)</td>
<td>436</td>
<td>1350</td>
</tr>
<tr>
<td>Canarias</td>
<td>313</td>
<td>1350</td>
</tr>
<tr>
<td>Cantabria</td>
<td>275</td>
<td>1350</td>
</tr>
<tr>
<td>Castilla y León</td>
<td>836</td>
<td>1350</td>
</tr>
<tr>
<td>Castilla - La Mancha</td>
<td>2,094</td>
<td>1350</td>
</tr>
<tr>
<td>Cataluña</td>
<td>6,435</td>
<td>1350</td>
</tr>
<tr>
<td>Comunidad Valenciana</td>
<td>4,075</td>
<td>1350</td>
</tr>
<tr>
<td>Extremadura</td>
<td>466</td>
<td>1350</td>
</tr>
<tr>
<td>Galicia</td>
<td>1,686</td>
<td>1350</td>
</tr>
<tr>
<td>Madrid (Comunidad de)</td>
<td>2,117</td>
<td>1350</td>
</tr>
<tr>
<td>Murcia (Región de)</td>
<td>804</td>
<td>1350</td>
</tr>
<tr>
<td>Navarra (Comunidad Foral de)</td>
<td>588</td>
<td>1350</td>
</tr>
<tr>
<td>País Vasco</td>
<td>427</td>
<td>1350</td>
</tr>
<tr>
<td>Rioja (La)</td>
<td>815</td>
<td>1350</td>
</tr>
<tr>
<td>Spain</td>
<td>29,048</td>
<td>1350</td>
</tr>
</tbody>
</table>
3.3. Estimation of the Composition of Building-related C&D Debris

The composition of C&D Debris (figure 1) has been obtained using both the average composition of debris from construction (used for new construction projects, expansion works, emptying reforms and reforms of business premises), and the average composition of debris from demolition (used for partial and total demolition projects).

3.4. Estimation of the Generation of C&D Debris Resulting from Public Works

The second hypothesis highlights the fact that public works activities are fewer than building ones. It means that much less debris is generated in the former, since the resources are optimized. Moreover, since fewer types of waste materials are produced, and generally more space is available (more land is available in rural areas than in towns and cities), selective waste collection is generally undertaken. Even if the selective method is not used, the type of debris accumulated will generally be homogeneous.

Considering the data provided by the construction company NECSO, now called ACCIONA INFRAESTRUCTURAS, S.A. (having a turnover in 2007 of 2923 million euros, and ranking fourth among the leading construction companies in Spain in terms of sales volume), most of the waste generated in the construction of public works is made of metal, wood, or, in a much smaller proportion, paper and plastic.

Public works demolition is rare, due to unsafe structures or projects that interfere with the construction of new infrastructures. Similarly renovation activities in public works do not usually entail prior demolition.

The C&D Debris materials generated by construction work are considered to be directly proportional to the project’s budget, depending on the type of activity (highways, railways, dams etc.)

To help us carry out this study NECSO provided data on the C&D Debris generated and the budget of 18 construction projects including railways, ports, hydraulic works, highways and airports. It was concluded that the above public works generated roughly 1900 kg of metals and 400 kg of wood per million euros of budget.

According to data from SEOPAN (SEOPAN, 2004), public contracts issued by all the administrations in Galicia for works of civil engineering totaled 1,239.20 million euros in 2003. If this datum is multiplied by the above values, the quantity of metals and wood generated in public works activities amounts to 2% and 1%, respectively, of the waste generated in the construction of buildings.

For the stated reasons, it is concluded that public works generate far less debris than building-related activities in Galicia and therefore in Spain, and with except of a few specific cases, its estimation should be studied specifically, which is out of the scope of this paper.
4. CONCLUSIONS

The conclusions resulting from this study are stated below:

- If the current trend continues, in the year 2013 30.5 million tons of C&D Debris will be generated in Spain. Roughly 50% will be generated from new construction, 10% from renovation and 40% from demolition.
- According to this estimation, 600 kg/inhab/year will be generated in Spain in 2013, although the weight per inhabitant and year varies greatly from one A.C. to another.
- The composition of construction debris differs from that of demolition debris, and it depends on the type of construction and materials used in each country: high percentages of ceramic materials are exhibited in Spain compared to other countries (U.S.A., U.K.).
- 45% of the C&D debris generated in Spain consist of ceramics materials, 26% of concrete and mortar, and 24% of materials having a stable recycling cycle (metals, plastics, wood, paper and cardboard).

ADDITIONAL NOTE

All this research has been based on the currently available data (1990 to 2008), so the economic crisis that has affected Spain these last two years is considered, reversing the previous trend characterized by the steady and simultaneous growth of the construction sector and the overall economy. In any case, as recent data become available the accuracy of the estimation will be improved.
REFERENCIAS


