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Analysis of the implementation of effective waste management practices in construction projects and sites

Marta Gangolells ^{a*}, Miquel Casals ^a, Núria Forcada ^a, Marcel Macarulla ^a

^a Universitat Politècnica de Catalunya, Department of Construction Engineering, Group of Construction Research and Innovation (GRIC), C/ Colom, 11, Ed. TR5, 08222 Terrassa (Barcelona), Spain

* Corresponding author: Marta Gangolells. Tel: (+34) 93 7398947, Fax: (+34) 93 7398101. Email: marta.gangolells@upc.edu

ABSTRACT

In this paper, the implementation of effective waste management practices in construction projects and sites is analysed, using data from a survey answered by 74 Spanish construction companies based in Catalonia. Most commonly implemented practices were found to be on-site cleanliness and order, correct storage of raw materials, and prioritisation of the nearest authorized waste managers. The least widespread practices were the use of a mobile crusher on site, the creation of individualized drawings for each construction site, and the dissemination of the contents of the waste management plan to all workers, to help them to meet its requirements. Waste regulations for construction and demolition, and the corresponding construction waste management facilities, were designed before the recession in the Spanish construction sector. Current waste generation rates are still below predicted levels, and the infrastructure was designed for five times more waste generation. Even so, the percentage of reused and recycled waste currently amounts to 43%. Survey respondents highlighted various instruments and measures that would make the management of construction and demolition waste more sustainable. Most of the opportunities identified by construction firms are within the scope of government and related to a combined system of bonus and penalties and the establishment of environmental awareness and training programs for all the stakeholders. Within the scope of authorized waste managers, firms suggested improvements such as the standardization of fees, a reduction of the time until the issue of waste management certificates, a higher number of inspections, and a change in the current model of a few large construction waste management facilities. This research is useful to better understand the current status of construction and demolition waste management in construction projects and sites. Thus, the results of this research will guide policy makers and relevant stakeholders such as contractors, clients, architects and engineers to achieve the EU target of recovering 70% of construction and demolition waste in 2020. In this sense, reliable information can help governments and professional associations to set future C&D waste management regulations, training programs and dissemination tools, inspections, etc.

Keywords:

construction and demolition waste management, construction companies, construction sites, waste management practices, questionnaire, Spain

1. INTRODUCTION

Despite increasing efforts by the construction industry to reduce the environmental impact of its processes, construction sites are still a major source of pollution and have adverse impacts on the environment (Fuertes et al, 2013). According to Gangolells et al. (2009), Gangolells et al. (2011) and Gangolells et al. (2013), typical negative impacts of construction activities include atmospheric emissions, water emissions, soil alteration, resource consumption, local issues, transport issues, effects on biodiversity, incidents, accidents and potential emergency situations, and waste generation.

According to Eurostat (2013a), the amount of waste generated by the construction sector in the European Union (EU-27) amounted to 859 million tonnes in 2008, which is a little over one third (37.56%) of all waste produced by economic activities. While the 2008-2015 Spanish Waste Plan (Spain, 2009) recognizes that there are no reliable statistics on the production and management of construction and demolition (C&D) waste, it has been estimated that approximately 45 million tonnes of this kind of waste were produced in Spain in 2008 (European Topic Centre on Resource and Waste Management, 2009). Although some European countries have reuse and recycling rates as high as 80%, this rate is still quite low in many European countries (Eurostat, 2010a), such as Spain. According to the European Topic Centre on Resource and Waste Management (2009), only 14% of C&D waste was recycled in Spain in 2006. Figures from the Catalan Waste Agency (Catalan Waste Agency, 2012) indicate that nearly 11 million tonnes of waste were generated during the construction boom in Catalonia in 2006. As a consequence of the economic recession, by 2012 this figure had dropped to 2.5 million tonnes of C&D waste, with a reuse and recycling rate of 43% (Catalan Waste Agency, 2012).

In this context, and taking into account that Directive 2008/98/CE (Europe, 2008) states that waste recovery must be increased to a minimum of 70% by weight in Europe by 2020, it is important to deploy initiatives that contribute to an effective waste management scenario reaching high C&D waste recovery rates. Relevant research in this area has been conducted in Spain. Most of the studies focused on describing models for the design stage to estimate the volume of C&D waste that will be generated on a site (Mañà et al., 2000; Solís-Guzman et al., 2009; Martínez et al., 2010; Llatas, 2011; Marrero et al., 2011; de Guzmán et al., 2012; Villoria et al. 2012). In other initiatives, such as those led by Ortiz et al. (2010) and Mercante et al. (2012), the research was based on life cycle assessment. Rodríguez et al. (2007) analysed how environmental management systems contribute to the generation and management of C&D waste. Del Río et al. (2010) focused on the current legal framework for C&D waste management in the Madrid autonomous community, whereas Morán del Pozo et al. (2011) presented a holistic approach towards effective C&D waste management, describing the current legal framework and outlining future improvements. Solís-Guzman et al. (2013) determined the ecological footprint related to C&D waste. However, little attention has been paid to best practices of C&D waste management in the European Union (Villoria et al., 2013). Effective waste management practices are undoubtedly the best way to

achieve a more sustainable scenario characterized by C&D waste prevention and high recovery rates. In this sense it is worthwhile to highlight the contribution of Villoria et al. (2013) who identified the best practices for C&D waste management and the most appropriate building types in which to implement them.

The main objective of this paper is to use data from a survey to analyse the implementation of effective waste management practices in construction projects and sites during the design, planning and construction phases, and to assess how construction companies perceive the current Spanish legal framework. The paper also highlights limitations in the current waste management model and waste facilities, and points out some measures and instruments that would help to achieve more sustainable management of C&D waste. Following this introduction, Section 2 introduces the current legal framework for C&D waste management in Spain and Catalonia. Section 3 describes the methodology used in this research, and Section 4 discusses the results. Finally, conclusions and future work are detailed in Section 5.

2. LEGAL FRAMEWORK

Directive 91/156/EEC (Europe, 1991) was incorporated into the Spanish legal framework by means of Law 10/1998 (Spain, 1998). However, the devolvement of environmental responsibilities from the central government to regional governments and the absence of a common legal framework prior to 1998 led to increased differences between the autonomous communities. Catalonia was a pioneering region in the regulation of C&D waste through Decree 201/1994 (Catalonia, 1994), modified later by Decree 161/2001 (Catalonia, 2001). After the expansion of the construction sector, the Spanish government passed Royal Decree 105/2008 (Spain, 2008a) to regulate for the first time C&D waste production and management in Spain. Subsequently, most of the autonomous communities adapted the rulings of Royal Decree 105/2008 (Spain, 2008a) to the their context (Andalucía, 2012; Aragón, 2009; Basque Country, 2012; Cantabria, 2010; Catalonia, 2010; Extremadura, 2011; Galicia, 2009; Madrid, 2009; Navarra, 2011) and thus, current legal framework on C&D waste management does not show substantial differences amongst the Spanish regions. In Catalonia and according to Decree 89/2010 (Catalonia, 2010), the project developer (or waste producer) must include a C&D waste management study in the construction project and the contractor (waste owner) must draw up a C&D waste management plan for the construction site (Figure 1). Both documents must contain waste minimization measures; an estimation of the amount of C&D waste that is expected to be generated on-site, classified and coded according to the European Waste Catalogue (Spain, 2002); a description of foreseen reuse, recovery and/or disposal operations; and the corresponding estimated management cost. As waste classification is required if certain threshold values are exceeded, both documents must also include a description of on-site measures for waste handling and storage. Along the lines of Decree 201/1994 (Catalonia, 1994), the current legal framework also includes the need to make a deposit that can be refunded once construction works are finished and proper waste management demonstrated (Figure 1).

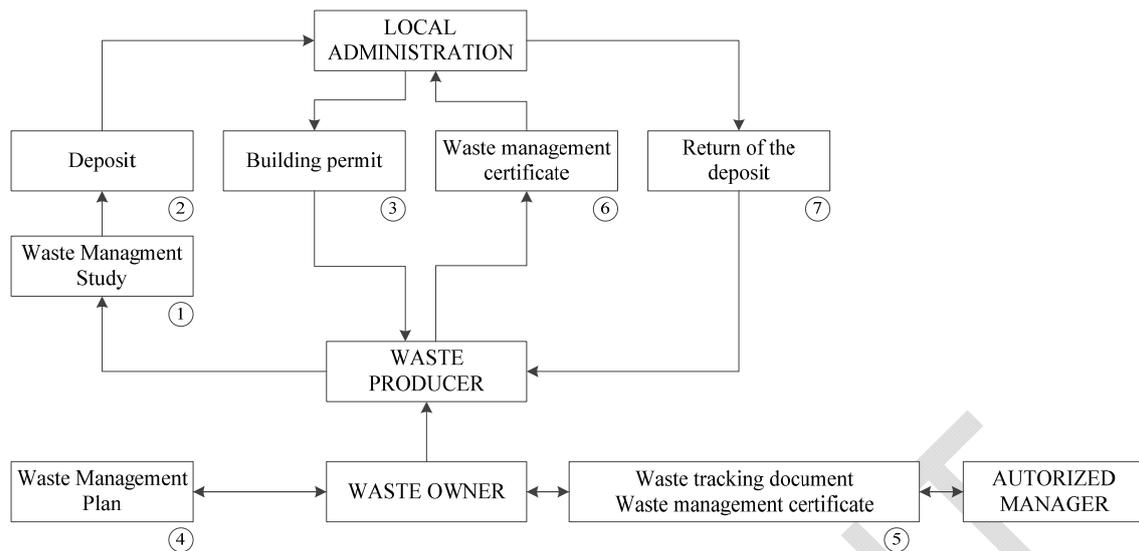


Figure 1. Construction and demolition waste management model, according to Decree 89/2010 (Catalonia, 2010)

Source: Adapted from the Catalan Waste Agency (2010).

3. METHODOLOGY

3.1 QUESTIONNAIRE

The questions in the survey were selected according to the main objectives of the study. They were based on results obtained in previous stages of research, mainly during a review of the literature and of the current legal framework, and on the experience gained in past European research projects. The survey finally included 49 questions in four different sections (see Appendix A). Section A included questions related to the company and the respondent. Section B gathered all the questions related to C&D waste management during the design, planning and construction phases. Finally, Section C focused on the legal framework.

Thirty-nine questions were formulated according to the Likert scale, where number 1 represents least agreement and number 5 represents most agreement. Seven questions were designed to have an open answer, while three questions were closed-ended, but also allowed respondents to write their own response (see Appendix A). A pilot test was carried out to assess the suitability and comprehensibility of the questionnaire. Eleven construction companies were contacted by phone and once they had given their consent, the questionnaire was emailed to them. The respondents were asked to complete the questionnaire and to review its design and structure. All the comments that were received were positive and thus no changes were made. The response rate for the pilot survey was 100%.

3.2 SAMPLE CHARACTERISTICS

The survey was issued to operative Catalan construction companies with salaried employees in May 2003. According to the Spanish Statistics Institute (2013), Catalonia

had 28,414 construction companies with salaried employees in 2013. Choosing a margin of error of 5% and confidence interval of 95%, the required sample size was 379. Construction companies were contacted by email to ensure that no interviewer bias was introduced. The email contained a letter introducing the project, an invitation to participate in it and a link to the online survey form. More than 800 electronic addresses were obtained from the databases of the two largest professional associations of construction companies covering all the provinces in Catalonia (Table 1). However, due to inconsistencies and duplications within these databases, the final sample size was 658 construction companies (Table 1). Despite reminders sent 7 and 15 days after the first email, only 63 valid questionnaires were returned. Taking into account that the responses obtained during the pilot survey were added to the final sample, the total number of questionnaires was 74, which represents a response rate of 11.20% (Table 1).

Databases	Number of companies	Number of contacted companies	Number of respondent companies
Professional association of construction companies in Barcelona and the surrounding area (<i>Gremio de Constructores de Obras de Barcelona y Comarcas</i>)	590	658	74 (11.20%)
Private foundation for the regulation of the construction sector in Catalonia (<i>Fundación Privada para la Ordenación del Sector de la Construcción en Cataluña</i>)	203		
Construction companies contacted during the pilot survey	11		

Table 1. Number of construction companies invited to participate in the study and number of respondents.

Information about the respondents and their companies was obtained in Section A of the survey (Appendix A). Table 2 details the role of the respondents in the company. The main activity of the surveyed companies was generally related to construction works (Table 3). Most of the companies were working on 2-5 construction sites at the time they were surveyed (Table 4). Almost half of the respondents reported they had between 10 and 49 workers (Table 5). Internal workers (with fixed or indefinite term contracts) were found to be predominant in the surveyed companies (Table 6). In general, the targeted companies reported that their workers were mostly Spanish (Table 7).

Role of the respondent in the company	Responses	
Manager / director / owner	35	47.30%
Environmental manager	11	14.86%
Administrator	10	13.51%
Site manager	4	5.41%
Quality, safety and environmental manager	4	5.41%
Safety manager	1	1.35%
Human resources manager	1	1.35%
Other	8	10.81%

Table 2. Role of the respondent in the company.

Company's main activity in the construction sector	Responses	
Construction activities	27	36.49%
Demolition activities	3	4.05%
Construction and demolition activities	22	29.73%
Refurbishment activities	3	4.05%
Installation	5	6.76%
Others (i.e. earthworks, pavements, architecture, engineering, etc.)	14	18.92%

Table 3. Company's main activity in the construction sector.

Number of ongoing construction sites	Responses	
1 ongoing construction site	8	10.81%
2 to 5 ongoing construction sites	52	70.27%
6 to 10 ongoing construction sites	5	6.76%
More than 10 ongoing construction sites	9	12.16%

Table 4. Number of ongoing construction sites.

Total number of workers	Responses	
Less than 10 workers	28	37.84%
10-49 workers	36	48.65%
50-249 workers	7	9.46%
More than 250 workers	3	4.05%

Table 5. Total number of workers.

Contractual status of the companies' workers	Responses	
Less than 20% of internal workers	0	0.00%
21-40% of internal workers	8	10.81%
41-60% of internal workers	9	12.16%
61-80% of internal workers	18	24.32%
More than 80% of internal workers	39	52.70%

Table 6. Contractual status of the companies' workers.

Workers' nationality	Responses	
Less than 20% of national workers	3	4.05%
21-40% of national workers	0	0.00%
41-60% of national workers	4	5.41%
61-80% of national workers	10	13.51%
More than 80% of national workers	57	77.03%

Table 7. Workers' nationality.

The results indicate that construction firms consider that on-site waste prevention is a priority ($\bar{x}=4.09$; $\sigma=0.93$). However, 56.76% of the surveyed companies reported they had no environmental management system, although 20.27% of them claimed that they were working on future implementation. The remaining 41.89% reported having an environmental management system based on either EMAS (8.11%) or ISO 14001 (33.78%). Finally, 1.35% of the respondents stated that they did not have any information on environmental management systems.

3.3 STATISTICAL ANALYSIS

A statistical analysis was carried out using the Statistical Package for the Social Sciences (SPSS) for Windows (Version 19.00).

4. RESULTS AND DISCUSSION

Uncontrolled dumping of C&D waste has practically disappeared (Catalonia, 2010), as a result of the development and application of specific regulations since 1994 (Spain, 2009). In addition, the proportion of C&D waste that is reused or recycled has significantly increased in recent years (Table 8), and is now close to the objectives stated in the Construction Waste Management Program (PROGROC) (Catalonia, 2010). Therefore, considerable improvements have been brought about by the new regulations on C&D waste management (Spain, 2008a; Catalonia, 2010) that promote on-site waste sorting, and by the Spanish Structural Concrete Code (EHE-08) (Spain, 2008b), which allows the use of recycled aggregates in structural and non-structural concrete.

	Year 2006	Year 2012 (PROGROC)	Year 2012 (real)
Waste generation [tons of waste]	10,961,141	12,000,000	2,540,320
Fraction destined to reuse and recycling [%]	17.14%	50.00%	43.05%
Waste management facilities [ut.]	62	123	120
Reuse and recycling facilities [ut.]	13 (reuse and recycling facilities) + 8 (transfer stations)	65	44 (recycling facilities) + 9 (waste sorting plants) + 12 (transfer stations)
Dumping sites [ut.]	41	58	55

Table 8. Construction and demolition waste generation, percentage of reuse and recycling and existing waste management facilities in Catalonia in 2006 and 2012, and estimated values and objectives set by the Construction Waste Management Program - PROGROC for 2012

Source: own elaboration with data from the Catalan Waste Agency (2010, 2012).

The results obtained in the questionnaire (Table 9) indicate that the factors that motivate construction companies to implement effective waste prevention and management actions are: (1) improve health and safety conditions at work ($\bar{x}=4.20$; $\sigma=0.87$), (2) follow current legislation and avoid fines ($\bar{x}=4.15$; $\sigma=0.85$), (3) increase the company's commitment to sustainability ($\bar{x}=4.12$; $\sigma=0.93$), (4) improve its public image ($\bar{x}=4.09$; $\sigma=0.93$), (5) increase the company's competitiveness ($\bar{x}=3.89$; $\sigma=1.06$), and finally (6) reduce costs ($\bar{x}=3.68$; $\sigma=1.10$).

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
7.1 Meet current legislation.	1 (1.35%)	1 (1.35%)	13 (17.57%)	30 (40.54%)	29 (39.19%)
7.2 Improve the company's public image.	1 (1.35%)	3 (4.05%)	14 (18.92%)	26 (35.14%)	30 (40.54%)
7.3 Increase our commitment to environmental sustainability.	2 (2.70%)	0 (0.00%)	16 (21.62%)	25 (33.78%)	31 (41.89%)
7.4 Reduce costs.	3 (4.05%)	8 (10.81%)	19 (25.68%)	24 (32.43%)	20 (27.03%)
7.5 Improve health and safety work conditions.	2 (2.70%)	1 (1.35%)	7 (9.46%)	34 (45.95%)	30 (40.54%)
7.6 Increase the company's competitiveness.	2 (2.70%)	6 (8.11%)	16 (21.62%)	24 (32.43%)	26 (35.14%)

Table 9. Factors motivating construction companies to implement effective waste prevention and management actions.

The next sections analyse the implementation of effective waste management practices in construction projects and sites during the design, planning, and construction phases, as well as how construction companies perceive the current legal framework.

4.1 SECTION B. COMMON WASTE MANAGEMENT PRACTICES IN CONSTRUCTION PROJECTS AND SITES

Wang et al. (2014), Lu and Yuan (2011), Ekanayake and Ofori (2004) and Osmani et al. (2008) state that some aspects of project design indirectly contribute to on-site waste generation. According to the results of the questionnaire (Table 10), it is common during the design phase to consider the future reuse and/or recycling of construction elements and materials ($\bar{x}=3.88$; $\sigma=0.97$), and to introduce elements and materials from earlier buildings ($\bar{x}=3.70$; $\sigma=1.06$). The collected data indicate that project stakeholders (client, architect, engineer, on-site workers, etc.) usually coordinate waste minimization actions during the design phase ($\bar{x}=3.72$; $\sigma=1.01$). Similarly, but to a lesser extent, the standardization of construction materials and elements and dimensional coordination are usually taken into account during the design phase ($\bar{x}=3.65$; $\sigma=0.88$).

Survey results on the planning phase (Table 10) indicate that construction companies prioritize the authorized waste managers that are closest to the construction site ($\bar{x}=4.14$; $\sigma=1.11$). In general, a waste management plan coordinator is designated during the planning phase. This person is responsible for ensuring that the plan is followed on-site ($\bar{x}=3.85$; $\sigma=1.14$). The results also show that the quantities and types of expected construction waste in each construction stage are usually estimated during the planning phase ($\bar{x}=3.73$; $\sigma=0.98$). Similarly, the surveyed companies reported that construction sites usually have enough space and resources to implement a waste management plan ($\bar{x}=3.68$; $\sigma=0.95$). They also state that internal waste movements are tracked and new opportunities for waste minimization are periodically considered ($\bar{x}=3.53$; $\sigma=1.09$). In

most cases, project stakeholders are involved in coordinating the waste management plan ($\bar{x}=3.42$; $\sigma=1.09$). To a lesser degree, budgets generally include detailed cost data on the adopted waste management strategies, including labour costs, auxiliary elements, transport, fees, etc. ($\bar{x}=3.39$; $\sigma=1.21$) and workers are familiar with the waste management plan and contribute to meeting its requirements ($\bar{x}=3.35$; $\sigma=1.01$). Finally, the respondents stated that an individualized drawing illustrating the size and location of stockpiles, waste storage areas and traffic pathways is usually attached to the waste management plan ($\bar{x}=3.24$; $\sigma=1.15$).

The survey results (Table 10) indicate that on-site cleanliness is frequently encouraged during the construction phase ($\bar{x}=4.26$; $\sigma=0.84$). The storage of materials in protected areas to prevent them from damage ($\bar{x}=4.14$; $\sigma=0.79$) and the separate storage of hazardous waste in suitable containers ($\bar{x}=4.11$; $\sigma=1.10$) were found to be the most widespread on-site practices. An accurate forecast of the quantity of materials needed to carry out the job is usually made, and long periods of on-site storage are avoided ($\bar{x}=3.91$; $\sigma=0.84$). As far as possible, selective dismantling or disassembly is prioritized over massive demolition ($\bar{x}=3.80$; $\sigma=0.99$). According to the collected data, the waste management plan is applied and complied with in most cases ($\bar{x}=3.80$; $\sigma=0.92$), on-site workers are properly trained in on-site waste management ($\bar{x}=3.74$; $\sigma=0.92$), and waste is sorted at the time that it is generated ($\bar{x}=3.74$; $\sigma=1.07$). Finally, subcontractors do not often make a written commitment to meet the on-site waste management policy ($\bar{x}=3.51$; $\sigma=1.22$). Similarly, it is not very common to have a mobile crusher on-site to recycle and reuse inert waste ($\bar{x}=2.34$; $\sigma=1.43$).

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Design phase					
8.1 Coordination has been established among the stakeholders of the project (client, developer, architect, engineer, on-site workers) during the project's design phase to minimize construction and demolition waste.	3 (4.05%)	6 (8.11%)	15 (20.27%)	35 (47.30%)	15 (20.27%)
8.2 Standardization and dimensional coordination of construction materials and elements were considered during the project's design phase.	1 (1.35%)	7 (9.46%)	19 (25.68%)	37 (50.00%)	10 (13.50%)
8.3 Reusable elements from earlier buildings were introduced in the project during the design phase, provided that this was technically and economically feasible.	4 (5.41%)	5 (6.76%)	17 (22.97%)	31 (41.89%)	17 (22.97%)

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
8.4 Future dismantling and reuse or recycling of the construction elements and materials were considered during the project's design phase.	3 (4.05%)	2 (2.70%)	16 (21.62%)	33 (44.59%)	20 (27.03%)
Planning phase					
9.1 All the stakeholders (client, promoter, architect, engineer, on-site workers, etc.) are involved in the coordination of the waste management plan.	5 (6.76%)	9 (12.16%)	21 (28.38%)	28 (37.84%)	11 (14.86%)
9.2 A coordinator of the waste management plan is designated and is responsible for ensuring that the plan is followed on site.	3 (4.05%)	9 (12.16%)	9 (12.16%)	28 (37.84%)	25 (33.78%)
9.3 All personnel working on-site know the waste management plan and contribute to meeting the requirements stated in it.	2 (2.70%)	14 (18.92%)	23 (31.08%)	26 (35.14%)	9 (12.16%)
9.4 Types and quantities of construction and demolition waste are estimated for each phase of the work.	0 (0.00%)	10 (13.50%)	18 (24.32%)	28 (37.84%)	18 (24.32%)
9.5 An individualized drawing illustrates the size and location of stockpiles, waste storage areas and traffic pathways.	7 (9.46%)	13 (17.57%)	17 (22.97%)	29 (39.19%)	8 (10.81%)
9.6 Each construction site has the free space and the resources required to ensure compliance with the waste management plan.	1 (1.35%)	9 (12.16%)	16 (21.62%)	35 (47.30%)	13 (17.57%)
9.7 Movement of generated waste is tracked from the moment it is generated right up to its final destination, and new opportunities for waste minimization are periodically considered.	4 (5.41%)	9 (12.16%)	19 (25.68%)	28 (37.84%)	14 (18.92%)
9.8 The nearest authorized managers are prioritized.	3 (4.05%)	5 (6.76%)	8 (10.81%)	21 (28.38%)	37 (50.00%)
9.9 The budget includes detailed cost data on the waste management strategies (labour, auxiliary elements, transportation, taxes, etc.).	7 (9.46%)	10 (13.50%)	18 (24.32%)	25 (33.78%)	14 (18.92%)

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Construction phase					
10.1 The waste management plan is applied and compliance is ensured.	2 (2.70%)	4 (5.41%)	16 (21.62%)	37 (50.00%)	15 (20.27%)
10.2 Construction staff are properly trained in on-site waste management.	1 (1.35%)	7 (9.46%)	16 (21.62%)	36 (48.65%)	14 (18.92%)
10.3 Selective dismantling or disassembly is prioritized over massive demolition.	3 (4.05%)	3 (4.05%)	18 (24.32%)	32 (43.24%)	18 (24.32%)
10.4 The construction site is kept clean and well organized.	1 (1.35%)	2 (2.70%)	7 (9.46%)	31 (41.89%)	33 (44.59%)
10.5 Materials are properly stored in a protected area to prevent premature damage.	1 (1.35%)	1 (1.35%)	10 (13.50%)	37 (50.00%)	25 (33.78%)
10.6 On-site waste sorting is done at the time waste is generated.	4 (5.41%)	6 (8.11%)	12 (16.22%)	35 (47.30%)	17 (22.97%)
10.7 Hazardous waste is properly separated and conveniently stored off the ground in suitable containers that are clearly labelled and kept under cover.	3 (4.05%)	4 (5.41%)	11 (14.86%)	20 (27.03%)	36 (48.65%)
10.8 Accurate forecasts of the quantity of materials needed to carry out the job are made and long periods of on-site storage are avoided.	1 (1.35%)	3 (4.05%)	15 (20.27%)	38 (51.35%)	17 (22.97%)
10.9 Mobile crushers are available on-site to recycle and reuse inert wastes.	31 (41.89%)	13 (17.57%)	14 (18.92%)	6 (8.11%)	10 (13.50%)
10.10 Subcontractors commit in writing that they are responsible for meeting the on-site waste management policy.	5 (6.76%)	13 (17.57%)	13 (17.57%)	25 (33.78%)	18 (24.32%)

Table 10. Common waste management practices in construction projects and sites during the design, planning and construction phase.

4.2 SECTION C. LEGAL FRAMEWORK FOR C&D WASTE MANAGEMENT

Section C of the questionnaire (Appendix A) allowed the identification of some limitations and opportunities for improvement in the current legal framework for C&D waste management. Although most of the surveyed construction companies agreed that the current legal framework is appropriate ($\bar{x}=3.19$; $\sigma=1.02$) and, to a lesser degree, effective ($\bar{x}=2.93$; $\sigma=0.93$), more or less half of the respondents reported that it is not easy to apply ($\bar{x}=2.51$; $\sigma=0.93$) (Table 11). Most respondents also stated that, in their opinion, the current legal framework does not provide financial benefits for their business ($\bar{x}=2.26$; $\sigma=0.96$) and is not tailored to companies of all sizes ($\bar{x}=2.14$; $\sigma=1.03$) (Table 11).

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
11.1 It is easy to apply.	11 (14.86%)	25 (33.78%)	28 (37.84%)	9 (12.16%)	1 (1.35%)
11.2 It is appropriate.	5 (6.76%)	13 (17.57%)	24 (32.43%)	27 (36.49%)	5 (6.76%)
11.3 It is financially profitable.	18 (24.32%)	26 (35.14%)	25 (33.78%)	3 (4.05%)	2 (2.70%)
11.4 It is aimed at companies of all sizes.	26 (35.14%)	19 (25.68%)	24 (32.43%)	3 (4.05%)	2 (2.70%)
11.5 It is effective.	7 (9.46%)	11 (14.86%)	39 (52.70%)	14 (18.92%)	3 (4.05%)

Table 11. Assessment of the current legal framework for construction and demolition waste management.

Construction firms highlighted a huge number of barriers (question 11 of the survey), most of them related to the economic cost of complying with the current legal framework. They stated that waste management increases costs and reduces productivity. The respondents argued that the development of an individualized waste management plan for each construction site and on-site waste sorting, especially in demolition works, involve a significant extra cost. The surveyed companies also reported that the overall budget often does not include enough items for effective on-site construction waste management. Lots of complaints focused on the high disposal and treatment fees. Respondents argued that this may cause illegal dumping. According to the gathered information, the fees change significantly depending on the autonomous community, causing unfair competition when companies export their waste to other regions. However, by law, waste must be managed in the autonomous community where it is generated. All these aspects acquire even more importance within the current economic recession and particularly in small and medium-sized companies. However, companies with greater environmental awareness (having an environmental management system) report that the current fees are still too low to discourage the waste disposal option.

Respondents also emphasized some barriers related to operational aspects of C&D waste management. They stated that the lack of space in some construction sites (small

new-start construction projects, minor construction works and refurbishment works) hinders on-site waste sorting. In this sense and taking into account some successful experiences as the one reported by Weisheng and Hongping (2012), off-site sorting of C&D waste could be explored. Surveyed companies also highlighted that the wide range of materials and elements included in construction projects, together with their nature (mainly in terms of materials' adhesion) significantly hamper on-site C&D waste sorting. Some responses also highlighted a need to speed up administrative procedures related to waste management. Firms reported that local administrations take several weeks to refund the deposit once construction works have been completed and the corresponding waste management certificates have been submitted.

Respondents also highlighted some barriers related to subcontracting works in the construction sector. They mainly reported difficulties in tracking, controlling and managing the waste generated on-site by subcontractors and the environmental awareness of small subcontractor's workers.

Although awareness is ranked as one of the most significant success factors for conducting effective C&D waste management (Lu and Yuan, 2010; Osmani et al., 2008; Begum et al., 2009), a lack of training and environmental awareness was also attributed to all project stakeholders (i.e. executive managers, technicians, site managers and workers). According to the respondents, the environmental awareness of managers was rather low and basically oriented towards avoiding fines and penalties. The survey results also emphasise that technicians do not know the potential of reused or recycled materials, while on-site workers are neither motivated nor trained for on-site waste sorting. The low environmental awareness of potential clients is also an important factor to take into account, as effective on-site waste management is not appreciated by future clients (or promoters).

Respondents also highlighted some shortfalls in the activities of authorized managers, such as not issuing waste management certificates, mixing waste that has already been sorted on-site, and illegal dumping. According to some respondents, authorized managers may classify C&D waste in different ways and thus construction companies must sort waste following the rules established by the authorized manager.

Finally, construction firms identified some opportunities for improvement in the current legal framework for C&D waste management when answering question 12 of the survey (see Appendix A). The respondents considered that the current legal framework should be modified to include effective measures for verifying and guaranteeing its correct application. In addition and according to the surveyed construction companies, the established procedures should be easier, cheaper and more dynamic. Respondents also claimed that more technical support should be provided to small companies, because they are not aware of some important aspects related to C&D waste management (identification of the closest waste management facilities, information on how to achieve waste sorting at minimum cost, etc.). Therefore, further efforts should be made to disseminate information on existing tools, particularly the waste management facilities database (Catalan Waste Agency, 2013), which can be used to find facilities by name, location and/or management option. Construction firms also requested the creation of a reliable, user-friendly tool to better estimate the amount of waste generated during different phases of the construction process. According to the respondents, this would improve the estimation of items related to on-site waste

management in the budget. In addition, the owner (represented by the project management team) could ask for documents justifying the management of all the generated waste. The survey data indicate that more dissemination of tools is required, despite the link on the Catalan Waste Agency's website to a computer application for simulating the quantity and type of waste generated in construction sites (ITeC, 2013). In this sense, results obtained by Wu et al. (2014) about C&D waste quantification methodologies could be useful. Construction companies also advocate durable constructions (eliminating the use of prefabricated units) and the promotion of more sustainable techniques and systems in new-start construction projects such as prefabricated elements along the lines of Lachimpadi et al. (2012). They also support the use of reused and recycled materials, materials with high possibilities of future reuse or recycling, and refurbishment works over massive demolition works. Some respondents emphasized that public works should provide an example for the private sector to follow, and highlighted the need for more research resources to achieve profitable waste management. Many suggestions focused on establishing programs and actions to raise the environmental awareness of all the stakeholders (managers, technicians and contractors' and subcontractors' workers, project management team, promoters, architects, engineers, manufacturers, authorized waste managers, government technicians, etc.). An increase in clients' environmental awareness and that of society in general was also highlighted by the survey respondents as a measure to be taken into account. Construction companies also stated that invoicing the costs related to C&D waste management separately is a good instrument set by the Royal Decree 105/2008 (Spain, 2008), because in this way the client realises how much money had been spent on correct environmental management. According to the respondents, the waste management plan should be individualized for each construction project and agreed on with all the parties involved, especially in the case of demolition works. Within the scope of operational aspects, respondents considered that hazardous waste collection should be made easier using adapted containers with a higher capacity. In their opinion, an increase in disposal fees, discounts in treatment fees depending on the quality of the waste, fines for incorrect procedures such as illegal disposal or mixed waste, and the standardization of disposal and treatment fees in the autonomous communities are imperative measures. They considered that it would be useful to provide new licenses for authorized waste managers, to open up a market that seems to be monopolized by a few companies. They also stated that it was important to reduce the amount of time that companies have to wait for waste management certificates to be issued by the authorized managers. According to the respondents, waste management certificates and the waste reception process could be simultaneous. In this context, construction firms demand strict inspections of waste transport and management companies along the lines of De Melo et al., (2011). Respondents also suggested that the authorization of recycling plants closer to C&D waste production areas would reduce the costs of waste transport. However, a deeper analysis of the situation indicates that waste management facilities in Catalonia could now be oversized. The amount of generated C&D waste was 77% lower in 2012 than in 2006, due to the deceleration of the construction sector (Table 8). During the same period, the number of waste management facilities has increased significantly (93%), particularly waste sorting plants and recycling facilities (152%) (Table 8). In order to revise the current waste management and infrastructure model and envisage future challenges, the maximum capacity of existing C&D waste reuse and recycling facilities in Catalonia should be analysed and compared to real data on C&D waste generation. However, data on the treatment capacity of existing facilities are not currently available.

Low waste disposal costs have been often considered responsible for discouraging waste prevention and reuse and recycling in construction projects and sites. According to the Spanish waste plan for the 2008-2015 period (Spain, 2009), rates should be increased according to the amount of waste sent to disposal, its contents of non-inert and reusable or recyclable materials, and whether it has previously been classified or treated.

5. CONCLUSIONS

In this paper, we analysed the implementation of effective construction waste management practices adopted by construction companies and other sector stakeholders during the design, planning and execution phases in construction projects and sites using data from a survey answered by 74 Spanish construction companies. The results, collected by means of closed questions, revealed that the most commonly implemented practices included on-site cleanliness and order, correct storage of raw materials, and prioritisation of the nearest authorized waste managers. The least widespread practices were the use of a mobile crusher on site, the creation of individualized drawings for each construction site, and the dissemination of the contents of the waste management plan to all workers, to help them to meet its requirements. We also analysed construction firms' perceptions of the current legal framework three years after Decree 89/2010 (Catalonia, 2010) entered into force and in a different economic context to that in which the legislation was developed. The results, collected through a closed question, show that, according to construction firms, the current legal framework is not sufficiently adapted to companies of all sizes. It represents an extra cost, and is difficult to apply. Besides highlighting the exemplifying role of public works, most of the opportunities identified by construction firms in an open question are within the scope of government. Firms support a combined system of bonus and penalties, including an increase in disposal fees which would lead to obtaining net benefits from conduction C&D waste management according to Yuan et al. (2011), discounts in treatment fees depending on the quality of the waste, fines for incorrect procedures such as illegal dumping or mixed waste, bonuses for using more sustainable materials, techniques and construction methods, and advantages for having individualized site drawings, among other measures. Many of the improvements suggested by construction firms were found to be related with the establishment of environmental awareness and training programs for all the stakeholders. Within the scope of authorized waste managers, the surveyed firms suggested improvements such as the standardization of disposal and treatment fees, a reduction of the time until the issue of waste management certificates, a higher number of inspections of waste transport and management companies, and a change in the current model of a few large construction waste management facilities. However, future research in this area should focus on analysing the adequacy of the reuse and recycling capacity of the construction waste management facilities that are currently located in Catalonia. In order to obtain a more accurate picture of C&D waste management, future steps should seek to increase the sample size and its diversity in order to be able to study the influence of the respondent's role or the size of the company on the obtained results.

APPENDIX A. Construction and demolition waste management survey

Section A. Information about the company and respondent

1. Role of the respondent in the company:					
2. Company's main activity in the construction sector:					
<input type="checkbox"/> Construction					
<input type="checkbox"/> Demolition					
<input type="checkbox"/> Construction and demolition					
<input type="checkbox"/> Refurbishment					
<input type="checkbox"/> Installation					
<input type="checkbox"/> Other, please state:					
3. Number of ongoing construction sites:					
<input type="checkbox"/> 1 ongoing construction site					
<input type="checkbox"/> 2 to 5 ongoing construction sites					
<input type="checkbox"/> 6 to 10 ongoing construction sites					
<input type="checkbox"/> More than 10 ongoing construction sites					
4. Total number of workers:					
4.1.a. Number of internal workers (workers with fixed or indefinite term contracts, discontinuous indefinite contracts, etc.):			4.1.b. Number of national workers:		
4.2.a. Number of external workers (self-employed workers, subcontractors' workers, etc.):			4.2.b. Number of foreign workers:		
5. Qualify the influence of the following factors on the company's current business strategy:					
	Not at all important	Not very important	Quite important	Very important	Extremely important
5.1 Increase productivity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.2 Reduce labour costs, production costs, etc.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.3 Prevent on-site waste generation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.4 Improve health and safety management	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.5 Improve the company's public image	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. Is there any kind of environmental management system available in your company?					
<input type="checkbox"/> We have no environmental management system.					
<input type="checkbox"/> There is no environmental management system at the moment, but we are working on one.					
<input type="checkbox"/> Yes, we have an environmental management system, and it is based on EMAS.					
<input type="checkbox"/> Yes, we have an environmental management system, and it is based on ISO 14001.					
<input type="checkbox"/> Other, please state:					

7. Which of the following items motivate your company to establish actions to prevent, reduce and properly manage construction and demolition waste?					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
7.1 Meet current legislation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.2 Improve the company's public image.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.3 Increase our commitment to environmental sustainability.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.4 Reduce costs.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.5 Improve health and safety work conditions.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.6 Increase the company's competitiveness.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Section B. Common waste management practices in construction projects and sites

8. Bearing in mind the construction projects you undertook during the last three years and in relation to the design phase:					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
8.1 Coordination has been established among the stakeholders of the project (client, developer, architect, engineer, on-site workers) during the project's design phase to minimize construction and demolition waste.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8.2 Standardization and dimensional coordination of construction materials and elements were considered during the project's design phase.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8.3 Reusable elements from earlier buildings were introduced in the project during the design phase, provided that this was technically and economically feasible.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8.4 Future dismantling and reuse or recycling of the construction elements and materials were considered during the project's design phase.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

9. Bearing in mind the construction projects you undertook during the last three years and in relation to the planning phase:					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
9.1 All the stakeholders (client, promoter, architect, engineer, on-site workers, etc.) are involved in the coordination of the waste management plan.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9.2 A coordinator of the waste management plan is designated and is responsible for ensuring that the plan is followed on site.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9.3 All personnel working on-site know the waste management plan and contribute to meeting the requirements stated in it.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9.4 Types and quantities of construction and demolition waste are estimated for each phase of the work.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9.5 An individualized drawing illustrates the size and location of stockpiles, waste storage areas and traffic pathways.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9.6 Each construction site has the free space and the resources required to ensure compliance with the waste management plan.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9.7 Movement of generated waste is tracked from the moment it is generated right up to its final destination, and new opportunities for waste minimization are periodically considered.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

9.8 The nearest authorized managers are prioritized.	<input type="checkbox"/>				
9.9 The budget includes detailed cost data on the waste management strategies (labour, auxiliary elements, transportation, taxes, etc.).	<input type="checkbox"/>				

10. Bearing in mind the construction projects you undertook during the last three years and in relation to the construction phase:					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
10.1 The waste management plan is applied and compliance is ensured.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.2 Construction staff are properly trained in on-site waste management.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.3 Selective dismantling or disassembly is prioritized over massive demolition.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.4 The construction site is kept clean and well organized.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.5 Materials are properly stored in a protected area to prevent premature damage.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.6 On-site waste sorting is done at the time waste is generated.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.7 Hazardous waste is properly separated and conveniently stored off the ground in suitable containers that are clearly labelled and kept under cover.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.8 Accurate forecasts of the quantity of materials needed to carry out the job are made and long periods of on-site storage are avoided.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.9 Mobile crushers are available on-site to recycle and reuse inert wastes.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10.10 Subcontractors commit in writing that they are responsible for meeting the on-site waste management policy.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Section C. Legal framework for construction and demolition waste management

11. The legal framework for construction and demolition waste management:					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
11.1 It is easy to apply.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11.2 It is appropriate.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11.3 It is financially profitable.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11.4 It is aimed at companies of all sizes.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11.5 It is effective.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. In your opinion, what are construction companies' main barriers to reducing on-site waste generation and improving its management?

- 1...
- 2...
- 3...
-

12. In your opinion, what improvements should be implemented to reduce on-site waste generation and improve its management?

- 1...
- 2...
- 3...
-

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