P. MERCADER-MOYANO*, A. RAMÍREZ-DE-ARELLANO-AGUDO**

Quantification of C&D waste in the spanish dwellings

Abstract

The objective of this research is the application of a quantification model of C&D waste, elaborated by the autors in precedent researches, to quantify the C&D waste generated in the construction of 2-storey spanish dwellings. A practical example has been carried out on ten dwellings in Sevilla Spain, thereby allowing the identification and quantification of the C&D waste generated in their construction and its environmental condition. This reference model enables: other researchers to establish comparisons between the various improvements proposed for the minimization of the environmental impact produced in construction; new corrective measures can be proposed in future policy plans that regulate the production and management of C&D waste in construction.

Keywords: C&D waste management; material resources consumed; selective classification; quantification model of C&D waste; residential buildings; conventional constructive model; environmental impact

Introduction

Construction and demolition waste (C&D waste) management has become one of the principal environmental problems worldwide, first in economically advanced countries and now in emerging economies (Agamuthu 2008), and affects to a governmental level, not only all participating agents in the building processes, but also the users of these buildings.

Under current practices in architecture and construction, 40% of material resources and world-wide energy is consumed in construction (López-Mesa et al. 2009), with the building industry generating 35% of the total industrial waste worldwide (Hendriks & Pietersen 2000). In 2006, the industry sector and the construction sector accounted for 81% of all waste produced by economic activities (Statistical Office of the European Communities 2011).

In the European Union alone, 40% of the total consumption of natural resources is used in the manufacturing of construction materials, and the construction of buildings generates 40% of the waste (Mercader et al. 2010). Europe generated approximately 890 million tonnes of C&D waste in 2008 (Villoria-Sáez et al. 2011), while the level of recovery of materials was only 25% (European Environmental Agency 2002). It is therefore necessary to address the problem by means of the management process, both in terms of the C&D waste generated, and the origin of the waste, thereby affecting the selection and consumption of the construction materials most frequently used in the construction of the buildings that generate this waste.

The management models in place for C&D waste remain far from achieving the aims, as outlined in the Waste Framework Directive since current figures demonstrate that only 50% is recycled (Soniego et al. 2010). These aims are considered one of the pivotal European Directives (ED 2008/98/EC 2008), and consist of recycling 70% of C&D waste generated in the EU by the year 2020.

In an attempt to correct this situation, laws and plans for the sustainable management of C&D waste are being developed that promote the culture of recycling and reuse, at international, European and local levels: The waste management plan in the construction projects established by the government of Hong Kong in 2003 (Tam 2008); Resolution 307 of 5 July, 2002, of the Agency of environmental protection CONAMA, government of Brazil, where the initialization of local plans are required for the sustainable management of C&D waste (Brazilian Government – Environmental Protection Agency 2002); the strategy of C&D waste management generated in construction in Bulgaria, by means of the use of advanced methods of recycling used in the United States (Hadjieva-Zaharieva et al. 2003); the strategy of minimization of waste in the United Kingdom, where more than 50% of waste comes from construction (Ferguson et al., 1995); the law on prohibition of eliminating recyclable waste in dumps in France (Buyle-Bodin 1993).

These plans include the Royal Spanish Decree 105/2008 (RD 105/2008) (Spain MP 2008), which aims to establish the legal framework for the production and management of C&D waste, in order to promote its prevention, reuse, recycling and other forms of recovery, and ensures that waste destined for disposal receives suitable treatment and contributes towards the sustainable development of construction activity.

This concern extends to environmental professionals who develop and implement waste management models and involves: analysis of the various models that exist in the management of municipal waste in order to improve these models (Morrissey & Browne 2004); proposal of alternatives with the introduction of selective waste collection specified into national plans and ISO standards (Bovea et al. 2010); and the development of models for the quantification and management of C&D waste that predict the volume of waste generated within the planning and design phase of the project (Solís-Guzmán et al. 2009).

Hitherto, no official information on the generation and composition of C&D waste has been created which is applicable to all EU members. The Regulation Waste Statistic (Statistical Office of the European Communities 2011) provides

*Ph.D. P. Mercader-Moyano, Department of Building Construction I, H.T.S of Architecture. University of Seville, 41012 Seville, Spain
** Ph.D. A. Ramirez-de-Arrelano-Agudo, Department of Building Construction II, H.T.S of Engineering building. University of Seville, 41012 Seville, Spain

this information for only 2006 and 2008 and is limited to a few countries.
The principal aim of this article is the development of a methodology directed towards the quantification (in weight and in tonnes per m^2 of constructed area) of C&D waste, generated in the construction of Spanish dwellings, by the application of models developed in precedent researches. This methodology is based on the quantification of material resources consumed in the construction process and its practical application to the CCM defined. Furthermore, this model provides a tool that allows C&D waste to be managed in response to the requirements set out in the RD 105/2008 of 1st February, by providing information related to the choice of material resources for the development of architectural projects.

Methodology
The development of the model of quantification of C&D waste corresponds to an established hierarchical order, whereby the achievement of the objectives of smaller rank has temporary priority, which in turn leads to the quantification of the construction waste generated in the construction of the CCM defined.

Stage 0: Environmental Database. This stage satisfies the objectives of Level 0, through the selection of a sample of dwellings that represent the 2-storey of the Conventional Constructive Model (CCM), and the quantification of the Basic Material Components (BMCs) consumed in their construction, expressed in kilogram per square meter, kgm-2 of constructed area. The typological, morphological and constructive characteristics of the CCM, dwellings that represent the current trend in the Spanish construction of 2-storey dwellings industry are:
– Types of buildings designed to meet the required living conditions for a slightly continental Mediterranean climate with variable rainfall, very hot dry summers and mild winters, an annual average temperature of 18.6ºC, and average rainfall of 534 mm per year.
Morphological characteristics corresponding to residential dwellings with two floors with inner courtyard and constructed area between 120–150 m^2.
– Construction characteristics with reinforced concrete structure, one-way spanning concrete slab, enclosure formed by an outer brick layer with a cardboard-plaster interior cladding, flat roof, and outer aluminum windows and door frames (Mercader et al. 2011).
Ten implementation projects are selected in Seville, Spain, whose characteristics coincide with those defined in the CCM.
The material resources consumed in the construction of the CCM established in the sample set are quantified, in kgm-2 of constructed area, based on the knowledge of the basic components that constitute the constructive elements (Mercader-Moyano 2010). The detailed development of the resources is found in the list of Basic Material Components (BMCs) consumed, which constitutes the starting point for the development of the next stage of the methodology.

Stage 1: Waste Management. This stage responds to the aim set out in Level 1; the quantification of construction waste generated in the construction of a CCM as a result of the material resources consumed, by means of classifying and characterizing the most relevant waste. The unit of measure chosen for the waste is the tonne (t), and the results are expressed in tonne per square meter, tm-2 of constructed area.
The model used is adapted to the characteristics of the waste, using the practical application of the model described in Chapter 6 of the book *Giving a Construction Estimate* (Ramírez-de-Arellano-Agudo, 2010), called "Measurements by Weighted transfer". This model points to the origin of the waste as a source of information which is necessary and sufficient to tackle its measurement and subdivides it into: 1. Excavated soil; 2. Breakage in transportation and storage; 3. Packaging of materials and products; 4. Breakage and loss in production processes; and 5. Dismantled or demolished building components.
From the list of BMCs, the objective of this level can be achieved by means of the development of the following sub-steps:
– **Classification of construction waste.** Resources consumed in the construction of the CCM are classified in accordance with the waste management classification from the Building cost system in Andalusia, (Andalusian Construction Costs Database, 2009). Each of the Basic Material Components (BMCs), consumed in the construction of the CCM, is classified. The Basic Material Component (BMC) from which the waste originates can be clearly identified and this information can be incorporated into the next stage of the methodology.
– **Conversion of consumed resources into generated waste.** The waste generated by each BMC is identified by applying a coefficient of transformation called "CR*", capable of measuring the part of the constructive element which becomes waste, on the application of the methodology called Measurement by Weighted Transfers, that serves as a tool to help determine the amount of C&D waste based on the measurement of the constructive elements from which they originate, using following equation, Eq. (1), developed in (Mercader-Moyano et al 2013):

$$Qr = \varphi\,(Qm) = Qm\,(CR^*) \quad (1)$$

This equation accepts the hypothesis of proportionality between the amount of waste generated and the amount of product consumed, where:
Q_r = amount of waste,
Q_m = amount of material from which the waste originates.
CR* = the coefficient to measure the proportion of every BMC consumed in the construction of the CCM which is turned into waste. For those BMCs to which it was possible to assign a coefficient from the table specified in (Ramírez-de-Arellano-Agudo et al 2002), coefficients were determined specifically, thereby resulting in (Mercader-Moyano et al 2013): a complete list of BMCs consumed in the construction of the CCM and their respective CR*.
– **Quantification of the waste generated in weight m-2 of constructed area.** Various types of waste generated in the implementation of the CCM are quantified, and the results are expressed in tm-2 of constructed area. Finally, the various waste materials generated are classified and grouped.
Having transformed the quantities obtained of every BMC into tm-2 of constructed area, the

detailed breakdown of material resources consumed in the construction of the CCM is then required (Mercader-Moyano 2010).

Results and discussion

Following the proposed methodology, by the application of the model to the sample of ten implementation projects of dwellings, which are representative of the CCM in Seville, Spain, we obtain the following results shown in percentages in Fig. 1.

The quantification model proposed enables measurement of the proportion of each original BMC that has been turned into waste, and the type of waste generated. This waste has been classified according its relevancy: steel, aggregates, cardboard and paper, ceramics, concrete, wood, plastic, and others, whereby this last category represents those types of waste with values ≤ 0.00001 tm-2.

Here, the waste in the form of cardboard and paper, and of wood and plastic are derived from the packaging in which the materials arrive at the work site, and the rest are losses produced when construction materials are consumed during the construction process.

In view of the results obtained, it is evident that alternative solutions must be sought to problems caused by the use of certain materials in the process of construction: for example the use of prefabricated materials. Furthermore, the transport of construction materials from the factory to the work site must also be controlled, due to the great proportion of waste generated in their packaging. This issue could be one of the measures, to be addressed in future political plans of action, to complement the set of actions arising from the application of the RD 105/2008 published on 1st February, 2008 by the Spanish Government, which regulates the production and management of C&D waste from the design phase to completion of the construction.

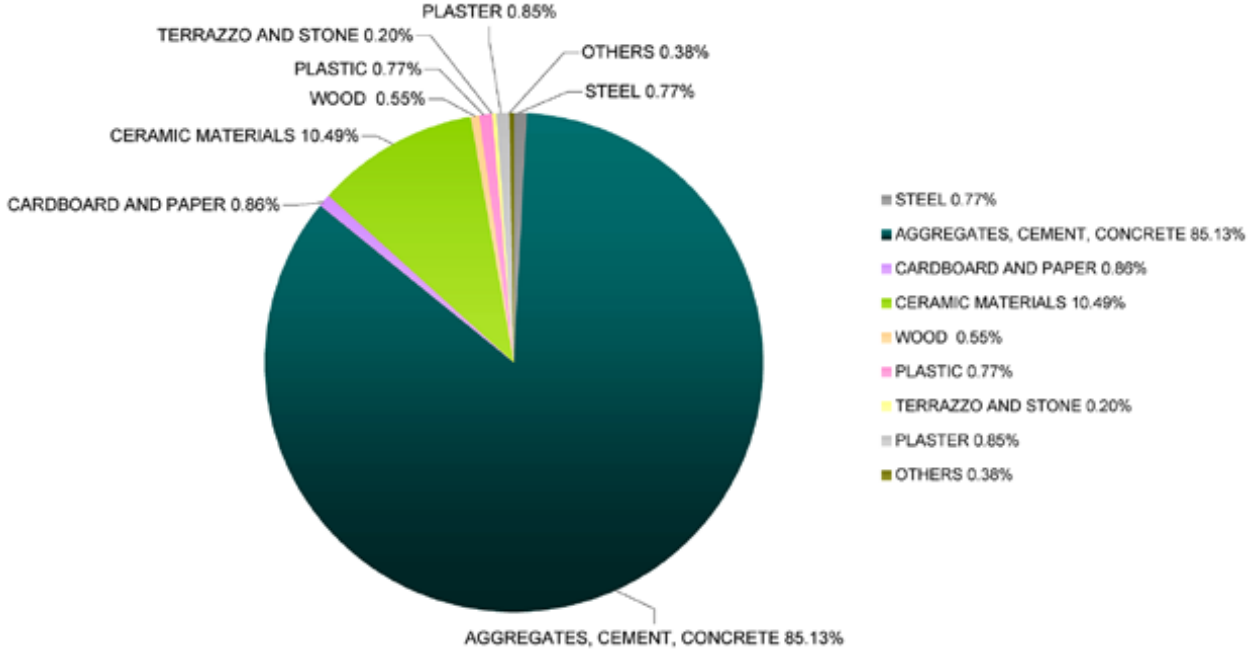
This work aims to develop a model of quantification based on the identification of the material resources commonly used in construction, the estimation of the proportions contained in the measurements in the implementation projects, the classification of the C&D waste generated, and its calculation through the analysis of the origin of the waste and its source. This work proposes an extension of the cited RD 105/2008 to include not only the stage of the manufacture of construction products, and the implementation of corrective measures in its transport to the work site, but also the application of penalties for the incorrect choice of building materials in the design phase of projects despite awareness, thanks to the application of models such as that presented here, of the large amount of waste that can be generated.

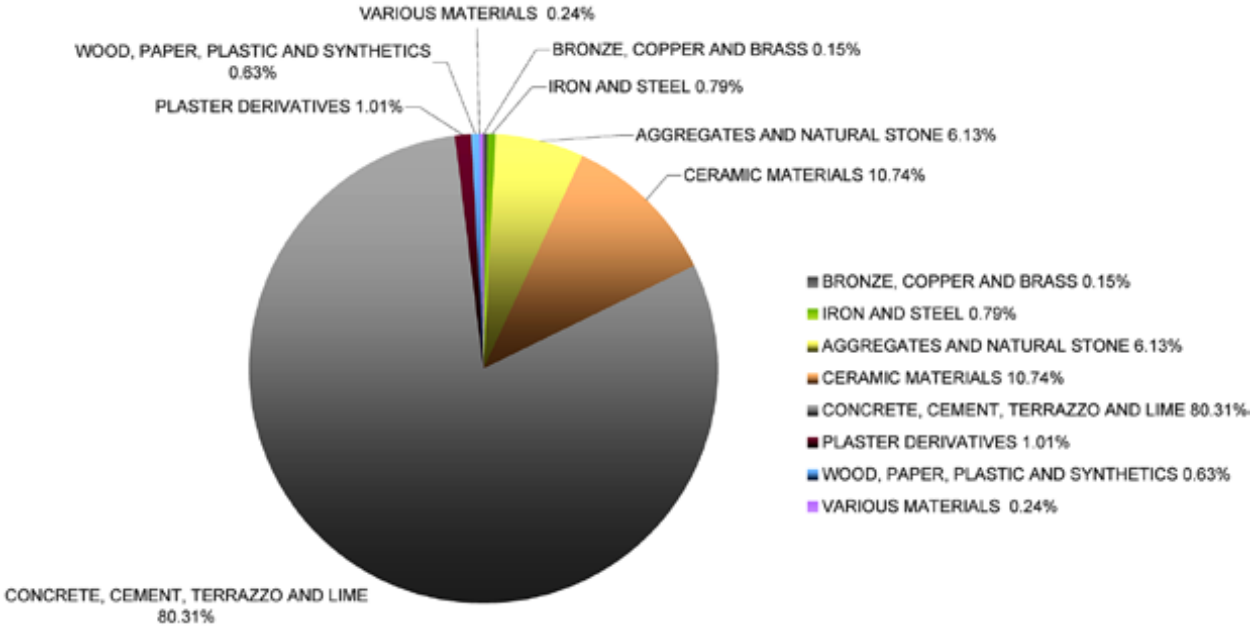
Conclusions

The following conclusions can be drawn from the application of the model proposed for the construction of the reference dwellingsgs:

1. Of the total waste generated, that which is derived from the loss of materials in the process of construction, (aggregates, cement and concrete) yields 85.13% of the total waste generated; followed by the waste derived from ceramic materials at 10.49%, and far exceed the tonnage of waste generated from packaging.
2. Graphically (Fig. 2) represents the percentage of total waste generated by those material resources that generate the greatest quantity of waste in the construction of the CCM.
3. The proposed quantification model of C&D waste has enabled: quantification of the tonnes of waste generated per m^2 of constructed area; the classification of waste according to its nature; and the identification of the consumed resources that generate the greatest waste, including the identification of origin of the waste generated. This, in turn, enables correct management of building work, through the ability to determine the appropriate container, to establish a selective separa-

il. 1. Waste generated in terms of type, in the construction of the CCM





il. 2. Material resources that generate the greatest quantity of waste in CCM

tion of waste, and the type and frequency of its withdrawal, and to determine its transport to specialist plants for further treatment and reuse in order to help prevent environmental degradation.

4. The model is applicable to any building type and country, and the results of this case study on a Spanish dwelling makes it a reference model against which to compare other research in the same field.

BIBLIOGRAPHY:

[1] Agamuthu P., *Challenges in sustainable Management of construction and demolition waste*,Waste Management and Research, 26(6), 2008, 491–492.

[2] Bovea M.D., Ibá ez-Forés V., Gallardo A., Colomer-Mendoza F.J., *Environment assessment of alternative municipal solid waste management strategies*, A Spanish case study. Waste Management 30 (11), 2010, 2383–2395.

[3] Brazilian Government – Environmental Protection Agency (CONAMA), 2002. Resolution No. 307. Environmental Protection Agency, Brasilia, Brazil. <http://www.mma.gov.br/port/conama> (accessed 2 september 2011).

[4] Buyle-Bodin F., *Organisation Project for the reclamation of industrial wastes in the French North and Pas de Calais region*, [in:] Proc. of Int. Rec. Congress ReC'93, Vol. III. Geneva, Switzerland, 1993.

[5] European Directive 2008/98/EC. Waste Framework Directive targeting construction and demolition waste and waste from households, 2008.

[6] European Environmental Agency (EEA), Review of Selected Waste Streams. Technical Report No. 69. European Environmental Agency, Copenhagen, Denmark 2002.

[7] Ferguson J., Kermode N., Nash C.L., Sketch W.A.J., Huxford R.P., *Managing and Minimizing Construction Waste: A Practical Guide*, Institution of Civil Engineers, London, United Kingdom 1995.

[8] Hadjieva-Zaharieva R., Dimitrova E., Buyle-Bodin F., *Building waste management in Bulgaria: challenges and opportunities*, Waste Management 23 (8), 2003,749–761.

[9] Hendriks C.F., Pietersen H.S., *Sustainable Raw Materials: Construction and Demolition Waste*, RILEM Publication, Cachan Cedex, France 2000.

[10] López-Mesa B., Pitarch A., Tomás A., Gallego T., *Comparison of environmental impacts of building structures with in-situ cast floors and with precast concrete floors*, Building and Environment 44 (9), 2009, 699–712. DOI: 10.1016/j.buildenv.2008.05.017

[11] Mercader M P., Marrero M., Solís J., Montes M .V, Ramírez A., *Cuantificación de los recursos materiales consumidos en la ejecución de la cimentación (Quantification of material resources consumed during concrete slab construction)*, Informes de la Construcción (Construction Reports) 62 (517), 2010, 125–132. DOI: 10.3989/ic.09.000

[12] Mercader-Moyano M P., Anexo XVI, Tomo II, *Tesis doctoral: Cuantificación de los recursos consumidos y emisiones de CO_2 producidos en las construcciones de Andalucía y sus implicaciones en el protocolo de Kioto (Quantification of the resources consumed and CO_2 emissions produced on construction sites of Andalusia and their implications for the Kyoto Protocol)*, Ph. D. thesis, Published by University of Seville, Seville, Spain 2010.

[13] <http://fondosdigitales.us.es/tesis/tesis/1256/cuantificacion-de-los-recursos-consumidosy-emisiones-de-co2-producidas-en-las-construcciones-de-andalucia-y-susimplicaciones-en-el-protocolo-de-kioto> (accessed 2 septiembre 2011).

[14] Mercader-Moyano M P., Ramírez de Arellano Agudo A., Olivares Santiago, M. *Calculation Methodology to Quantify and Classify Construction Waste,* The Open Construction and Building Technology Journal, 2011,5, (Suppl 2-M3), 2011, 131–140. DOI:10.2174/1874836801105010131.

[15] Mercader-Moyano P., Ramírez de Arellano Agudo A., *Selective classification and quantification model of C&D waste from material resources consumed in residential building construction*, Waste Management & Research 31 (5), 458–474. DOI: 10.1177/073424X13477719.

[16] Morrissey A.J., Browne J., *Waste management models and their application to sustainable waste management*, Waste Management 24 (3), 2004, 297–308.

[17] Ramírez-de-Arellano-Agudo A., *Presupuestación de Obras. 4 Edición, actualizada con la gestión de residuos (Giving a Construction Estimate. 4rd Edition, updated with waste management)*, Secretariado de publicaciones Universidad de Sevilla (Publicity Secretary of the University of Seville), Seville, Spain 2010.

[17] Ramírez-de-Arellano-Agudo A., Llatas-Oliver C., García-Torres I., Linares-Romero P., García-Caraballo E.I., Escobar-García M., Carnerero-Moya M., Hernández-Juárez R., *Retirada Selectiva de residuos: Modelo de Presupuestación (Selective Waste Disposal: Estimate Model)*, Fundación Aparejadores (foundation builders), Seville, Spain 2002.

[18] Solís-Guzmán J., Marrero M., Montes-Delgado M .V., Ramírez-de-Arellano A., *A Spanish model for quantification and management of construction waste*, Waste Management 29 (9), 2009, 2542–2548.

[19] Soniego P., Hestin M., Mimid S., *Management of construction and demolition waste in the EU*, European Stakeholders workshop. Bio intelligence service. Brussels, Belgium 2010.

[20] Spanish Government Department of Public Works and Housing of the Regional Government of Andalusia, (2010). Base de Costes de la Construcción de Andalucía, 2010 (Andalusian Construction Costs Database, 2010). Department of Public Works and Housing of the Regional Government of Andalusia, Seville, Spain.Database <http://www.juntadeandalucia.es/viviendayordenacionderritorio/www/estaticas/planificacion/publicaciones/banco_precios_construccion/bcca0709/BCCA_09_Rev1e.bc3> (accessed 6 Mayo 2011).

[21] Spanish Government – Ministry of the Presidency, (2008). Real Decreto 105/2008, de 1 de Febrero, por el que se Regula la Producción y Gestión de los Residuos de Construcción y Demolición (National Decree 105/2008, enacted on 1st February, 2008, which Regulates the Production and Management of C&D waste), Ministry of the Presidency, Madrid, Spain.

[22] Statistical Office of the European Communities (EUROSTAT), (2011). Statistical Database <http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search> (accessed 2 february 2011)

[23] Tam V.W.Y., *On the effectiveness in implementing a waste-management-plan method in construction*, Waste Management 28 (6), 2008, 1072–1080.

[24] Villoria-Sáez P., Del-Río-Merino M., Porras Amores C., San Antonio González A., *Construction and demolition waste generation and recycling rates in Europe*, Legal measures to improve their management. 4th International Congress on Energy and environment engineering and management, Mérida, Spain 2011, 119.