Send Orders for Reprints to reprints@benthamscience.ae

BENTHAM OPEN

CrossMark

The Open Construction and Building Technology Journal

Content list available at: www.benthamopen.com/TOBCTJ/

DOI: 10.2174/1874836801711010334

REVIEW ARTICLE

Valorization of Building Retrofitting Waste as Alternative Materials in Gypsums

Mercedes Del Río Merino, Jaime Santa Cruz Astorqui, Paola Villoria Sáez*, Carmen Viñas Arrebola, Antonio Rodríguez Sánchez and César Porras Amores

Universidad Politécnica de Madrid, Escuela Técnica Superior de Edificación, TEMA Research Group, Spain

Received: June 06, 2017 Revised: July 10, 2017 Accepted: July 19, 2017

Abstract:

Introduction:

The lack of treatment of construction demolition waste (CDW) is a problem that must be solved immediately. It is estimated that the unused CDW generates an increase in the use of new materials close to 20% of the total materials consumed worldwide. Because of that, the use of CDW in building materials is an interesting alternative to guarantee their application. In the last years, many research works are being carried out in order to analyze the viability of using CDW as a substitute for the traditional raw materials that cause high environmental impact.

However, much remains to be done, because these works generally characterize materials but not specific applications that allow the agents of construction to provide assurance required by the projects.

Aim:

The research group TEMA from the School of Building Construction (UPM) is working on this topic with the University of Seville, University of Burgos and the University of Zaragoza, developing a research project called "Waste to resources (W2R)". The main goal of the project is to develop new materials, elements and construction systems, manufactured with CDW generated in building retrofitting works, to be used in improving the energy efficiency of buildings.

Results:

In this article, some of the results of the W2R project are presented, namely the identification, quantification and characterization of the types of waste generated in renovation works to improve the energy efficiency of buildings and their possible applications as fillers in plasters to improve the performance of the original materials with a significant reduction in raw material, and thus reduce the environmental impact.

Conclusions:

Concrete and ceramics are the most commonly generated waste categories in building rehabilitation works to improve the energy efficiency of the buildings. These waste categories are generated during the preparation of the surface prior to the execution of the works. Also, mixed waste from insulation materials can be highlighted due to its volume.

Keywords: Resources, Recycling, Building waste, Energy efficiency, Gypsums, Construction Demolition Waste (CDW).

1. INTRODUCTION

Residential buildings and offices account for 40% of the total energy consumption in the European Union. In Spain, this percentage is lower (27.7%) because the weather conditions are generally milder than central and northern Europe.

* Address correspondence to this author at the Escuela Técnica Superior de Edificación, Universidad Politécnica de Madrid, Spain; E-mail: paola.villoria@upm.es

However, the incidence on the global energy consumption is still to be taken into account to reduce the environmental impact of the buildings [1].

This situation, together with a growing interest in sustainable development and efficient energy consumption in the different sectors, particularly in construction, has led to the design of legal measures derived from the Directive 2002/91/EU on energy efficiency of buildings [2 - 4]. In particular, in Spain the Royal Decree of Energy Certification (RD 235/2013) requires for existing buildings --which are sold or leased-- to have an energy efficiency certificate. This requirement is undoubtedly driving the market towards systems and materials that improve the energy efficiency [2]. However, this situation is still emerging.

Therefore, this new legal scenario will cause a rocket increase of buildings' renovation and/or retrofitting works in Spain and consequently an increase of CDW. The proper management of this waste constitutes one of the main pillars of the framework of EU Strategy 2020, which aims to turn Europe in an efficient society regarding the use of resources, based on circular economy criteria following the "3R" principle (recovery, reuse and recycle) [3].

In view of the above and taking into account the serious crisis affecting the construction section, the industry is changing from new constructions to rehabilitation works, particularly rehabilitation works to improve the energy efficiency of buildings. In this regard, in the National Congress of Environment experts concluded that it is necessary to rehabilitate some 400,000 homes a year in order to achieve the target by 2050 [4].

Moreover, today the sectors of construction, energy and industry generate about 50% of the waste produced in Europe and in particular CDW accounts for 33% of the total waste generated in the EU [5]. For this reason, the European Union considers CDW flow as a priority for action. In fact, over the past decade, the intense activity in the field of construction in Europe generated about 827 million tons of CDW in one year and only 50% of it was recycled [6]. This has led Governments and Policy makers to implement a series of measures, such as those listed in Royal Decree 105/2008, which requires segregation when CDW exceeds certain amounts [7].

In this new scenario it is necessary to act on the generated CDW in construction works to improve the energy efficiency and that is why the research group in Buildings Technology and Environment (TEMA) of the Technical University of Madrid (UPM) is working with the universities of Seville, Zaragoza and Burgos on a project called: Waste to Resources (W2R). The main objective is to develope new materials, components and construction systems, fabricated with CDW generated in building rehabilitation works to improve the energy efficiency and thus close the life cycle of the buildings, creating zero waste and reducing the ecological footprint of the construction sector.

In recent years the number of scientific studies related to CDW has increased greatly [8, 9]. For the works estimating CDW quantitation ratios in a building construction site, it can be concluded that usually they obtain information from specific case studies or annual data released by the government. Since 2010, different models for quantification of CDW were established in Spain, based on the project budgets, quantifying various waste categories for new constructions, demolitions or rehabilitations [10 - 11].

Therefore, although there are numerous studies that analyze and quantify the waste generated in the building works, almost all of these works are carried out on new residential buildings and few references were found on studies quantifying CDW in rehabilitation, as they do not consider the specific aspects of the rehabilitation works to improve energy efficiency.

Moreover, it is estimated that not recycling or reusing the CDW leads to an increase in the use of raw materials about 20% of the total used [12]. Therefore including CDW in materials for construction represents an interesting alternative. In recent years, many research works have been carried out in order to analyze the feasibility of using CDW as a substitute for traditional raw materials [13 - 16]. In this article some of the results of the Waste2Resources project are presented, namely the identification and quantification of the types of waste generated in renovation works to improve the energy efficiency of buildings and their possible applications as fillers in binding materials that improve the thermal performance of the traditional materials.

2. METHODS

To solve the overall objective the following specific objectives were developed.

2.1. Analysis of the Usual Measures to Improve the Energy Efficiency in the Vertical Envelope of Buildings

The vertical envelope was chosen because it represents a high percentage of the contact surface, thus acting on the vertical envelope has a major effect on saving energy Fig. (**1**). To this end, a literature review was performed to search the main problems to be solved in the vertical envelope of the buildings to improve their energy efficiency as well as the most common solutions that are usually carried out in Spain [17, 18].

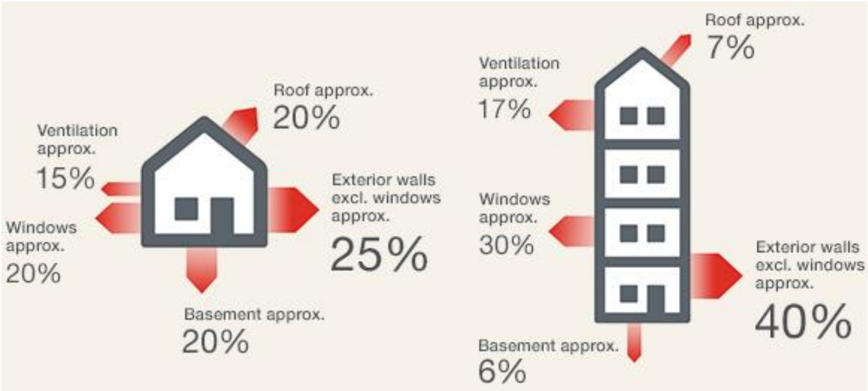


Fig. (1). Heat loss in buildings [19].

2.2. Identification and Quantification of the Waste Generated in Building EE Rehabilitation Works

At this stage of the methodology, the identification and quantification of CDW expected to be be generated in the most common works to imptove EE (identified in 2.1.) was carried out, using Arquimedes database [20], which provides the weight and volume of each CDW category generated in each work. These environmental parameters are determined for the entire action to improve energy efficiency, allowing to obtain the quantities of waste generated in each action per recovered m^2.

2.3. Characterization of New Building Materials Containing Waste and Possible Applications.

In view of the results obtained in the previous section, the most generated CDW in works of EE are ceramic waste and insulation. Therefore, the feasibility to obtain compounds of gypsum with those waste categories are analyzed through laboratory tests with the minimum requirements and results were compared with traditional gypsums and minimum values set by current regulations.

3. RESULTS

3.1. Analysis of the Current Rehabilitation Works to Improve Buildings' Energy Efficiency in Spain. The Vertical Envelope

The study to improve the building energy through actions in the envelope starts by determining the most common reparations and deficiencies of the construction systems of the envelope and that affect the energy efficiency of the building. The deficiencies are related to the requirable performance: thermal and acoustic insulation, waterproofing, durability and functionality. Some shortcomings are not due to deterioration or poorly design, but to the low level of demand for the rules that applied at the time of construction of the building (*e.g.* lack of insulation). It is important to note that deficiencies due to deterioration often affect partially to the envelope, while those due to regulations often affect all of it.

However, among the deficiencies found, only the lack or insufficient thermal insulation is related to the energy efficiency of the envelope, so special attention should be paid to the techniques that are focused to remedy it. The remaining shortcomings described only affect the health/functionality of the building and its appearance. Such failure relates in turn to the climate in which the building is located and the level of standards of the applicable rules, but generally is usually caused by the absence (or failure) of thermal insulation, which results in a low thermal resistance of the the enclosure. Insufficient thermal strength of the façade of a building is usually due to the absence of specific thermal insulation, the deterioration of the original insulation or insufficient thickness. Another important factor is that insulation can be interrupted by the edges and/or pillars, causing the resulting thermal bridges. In any case, the legal requirements of thermal insulation have increased considerably in Spain as a result of the successive energy crises [2, 21].

In general, an insufficient insulation of a façade directly implies higher energy consumption for heating and/or cooling. In addition of excessive energy consumption, there are other direct consequences due to the lack of insulation according to its location (Table **1**).

Table 1. Pathology by the lack of insulation in the vertical envelope.

Lack of Insulation Located	Pathology
On the opaque part of the façade	Interstitial condensation due to the dew point temperature being reached inside the outer sheet of the enclosure. It usually happens in combination with the absence of adequate ventilation in the air chamber (if any). Surface condensation on the inside of the building, in damp spaces (kitchens, bathrooms, *etc*). This effect occurs in combination with inadequate ventilation. As a positive effect, the lack of insulation causes the incorporation of the total mass of the enclosure to the inner mass (providing a greater thermal inertia).
Where the façade is in contact with the structure (pillars and slabs)	Surface condensation on the inside of the enclosure, in the areas of thermal bridges produced by direct contact of the structure with the façade and the interior environment. This effect usually occurs in combination with the absence of adequate vapor barriers and/or the absence of ventilated air chambers. Cracks produced on the outer sheet and/or inner partition of the façade, caused by the daily cycles of expansion-contraction of the structure.
Openings – Windows and doors (usually due to the use of single glass or blind boxes which are too permeable to air)	An excessive loss of energy in heating and/or cooling, both due to the high thermal transmittance and to excessive flow of air -from the outside- entering through faulty seals and joints poorly solved. Water condensation on the inside of the enclosure. Moisture on the inside of the enclosure, at the bottom of the opening produced by the condensation in the joinery.

The different intervention techniques on the vertical envelope of the building, leading to improved energy efficiency, depend to some extent on the area of action: exterior façade (including its openings), party-walls and retaining walls in basements. In this article only techniques that can be performed on the exterior façade and party-walls are discussed.

3.1.1. Techniques Applicable in Interventions to Improve the Thermal Insulation of the Building

In turn, depending on the type of action provided in the rehabilitation project, techniques can be divided in two: ones carried out from the outside of the building and others from the inside.

3.1.1.1. Techniques Applicable in Interventions from the Outside of the Façade

In general, they are techniques that apply a layer of continuous insulation on the outer face of the existing façade, covering the entire building. There are basically three options, depending on whether there is air chamber left between the insulation and the type of exterior finishing used:

-External Thermal Insulation Composite System (ETICS): This system allows applying an insulating layer on the outer side of the existing façade and later a thin finishing layer usually of cement mortar.

-Cladding system on insulation layer: Insulation material adhered to the outside of the existing façade and the finishing material consists of a cladding -of natural or artificial stone-, which is fixed to an existing support by means of anchors in contact with insulation.

-Ventilated façade: This system consists of a rigid or semirigid insulation adhered to the support and an outer protective layer separated from the insulation, forming a chamber where air circulates by simple convection. The external layer is fixed to the wall with substructures designed for this purpose.

These techniques provide many benefits, such as the elimination of thermal bridges and improvement of the thermal stability of the enclosure and the structure. However, these techniques may not be feasible to use in historical buildings –which have a legal protection of their façades–, nor in those cases in which it is not permitted to set forward the existing façade (street alignment). Therefore, they are techniques appropriate for façades basically flat, where the placement of external scaffolding is feasible.

3.1.1.2. Techniques Applicable in Interventions from the Inside of the Façade

This type of action is appropriate in cases where it is not feasible to modify the outside of the façade. In urban areas where it is not possible to set forward the façade, these techniques (along with the injection chamber) are the only viable options. The interventions from the inside, if possible, are the cheapest options, although they are not the most effective.

Also, the occupants need to leave their house until the end of the work, representing a strong limitation in cases of active buildings.

The most common techniques performed from the inside are:

-Placing (over the interior partition of the façade) a rigid insulation panel finished with gypsum plaster: This system is equivalent to the ETICS system used on the outside of the façade. It consists of the application of a rigid insulation on the interior of the envelope. A reinforced direct coating is applied over the insulation with a polymeric or fiberglass mesh.
-Placing (over the interior partition of the façade) plasterboards with insulation material. It consists of gypsum plasterboards and insulation panels fixed to the existing masonry.
-Substitution of windows and exterior doors.

3.1.1.3. Insulating Injection Inside the Air Chamber

In those cases where it is not feasible any of the actions described above, there is the chance to inject an insulation material inside the air chamber of the façade (if any). This technique can be performed both from the inside and from the exterior of the building. Despite its low cost, it is the least effective, being therefore the last technique to be chosen.

3.1.2. Techniques to Improve the Thermal Insulation of a Party-Wall

As it is not possible to act on the outer side of the party-wall, the only viable techniques are those described for the interior -incorporating a new cladding that integrates insulation- or, in the case of having an air chamber, injecting insulating material. Another aspect to consider is that normally there is no full coincidence between the perimeter of the adjacent party-wall and the one to intervene, so there will be areas facing directly to the exterior. Those areas should be treated as an exterior façade, requiring a greater insulation and incorporating waterproof techniques.

Therefore and in summary, the most common techniques in the vertical envelope are:

-External Thermal Insulation Composite System (ETICS)

-Cladding system on insulation layer

-Ventilated façade

-Interior partition with rigid insulation panel lined with gypsum

-Interior partition with plasterboard and insulation material

-Change and substitution of windows and exterior doors

-Insulating injection techniques in chambers

3.2. Identification and Quantification of the Waste Generated in Renovation Works to Improve the Energy Efficiency of the Building

In table (**2**), the waste categories generated in the different techniques to improve buildings' energy efficiency are determined following the methodology explained in paragraph 2.2. Furthermore, the total amount of waste per m^2 rehabilitated generated in each technique is quantified. The ETICS system is the one generating more waste, due to the preparation of the existing layer, which implies removing the finishing layer of the surface. Instead, the solution of ventilated façade generates the less amount of waste. Moreover, regarding the techniques performed from the inside, the option generating less CDW is the injection of insulation in the air chamber (although it is not the most effective solution), and by contrast the one generating the most CDW is the solution of the interior partition of the façade and gypsum plasterboard.

In the above table, certain waste, such as: thermal insulation, plastics and cardboard are common waste categories generated in all the works. In any case, it is very complicated, due to casuistry, to quantify the waste, but if we make an approach without considering the waste generated during the preparation of the existing layer, it can be estimated the waste generated over the total in percentage (Table **3**).

Table 2. Identification and origin of the waste generated in the works conducted in the vertical envelope of the building to improve the EE.

Waste Categories	Interventions From Outside			Interventions From Inside			Replacement of Doors and Windows	From
	ETICS	Cladding on Insulation	Ventilated Façade	Partition with Insul. and Coated with Gypsum	Partition with Insul. + Plasterboard	Injection Insulation in the Chamber		
Toxic waste	✓			✓	✓	✓	✓	Extra paint material
Paper	✓	✓	✓	✓	✓	✓	✓	Packagings
Metal			✓		✓		✓	Leftover of metal structures cuts, fixtures and hardware
Mortar	✓	✓						Leftovers of plasters/material of the exterior finish
Ceramic		✓	✓					Leftover of plated cuts
Wood	✓	✓	✓					Packaging (type pallet)
Glass							✓	Windows and exterior doors
Plastics	✓	✓	✓	✓	✓	✓	✓	Packaging and anchors
Thermal insulation	✓	✓	✓	✓	✓	✓	✓	Cuts of rigid insulation boards
Gypsum				✓	✓	✓	✓	Garnished and coated with plaster
Mixed CDW		✓	✓			✓	✓	Activities for the preparation of the facing
Fiberglass mesh	✓							Reinforcing meshes
Total (kg/m^2)	30.66[a]-2.13[b]	28.50	1.95	0.85	0.77	0.65	0.14	
Total (l/m^2)	20.85[a]-1.81[b]	19.00	1.74	1.00	0.94	0.78	0.20	

[a]ETICS system removing the prior coating layer (mortar).

[b] ETICS system without removing the previous coating layer

Table 3. Percentage of each CDW category over the total generated (in volume). [22]

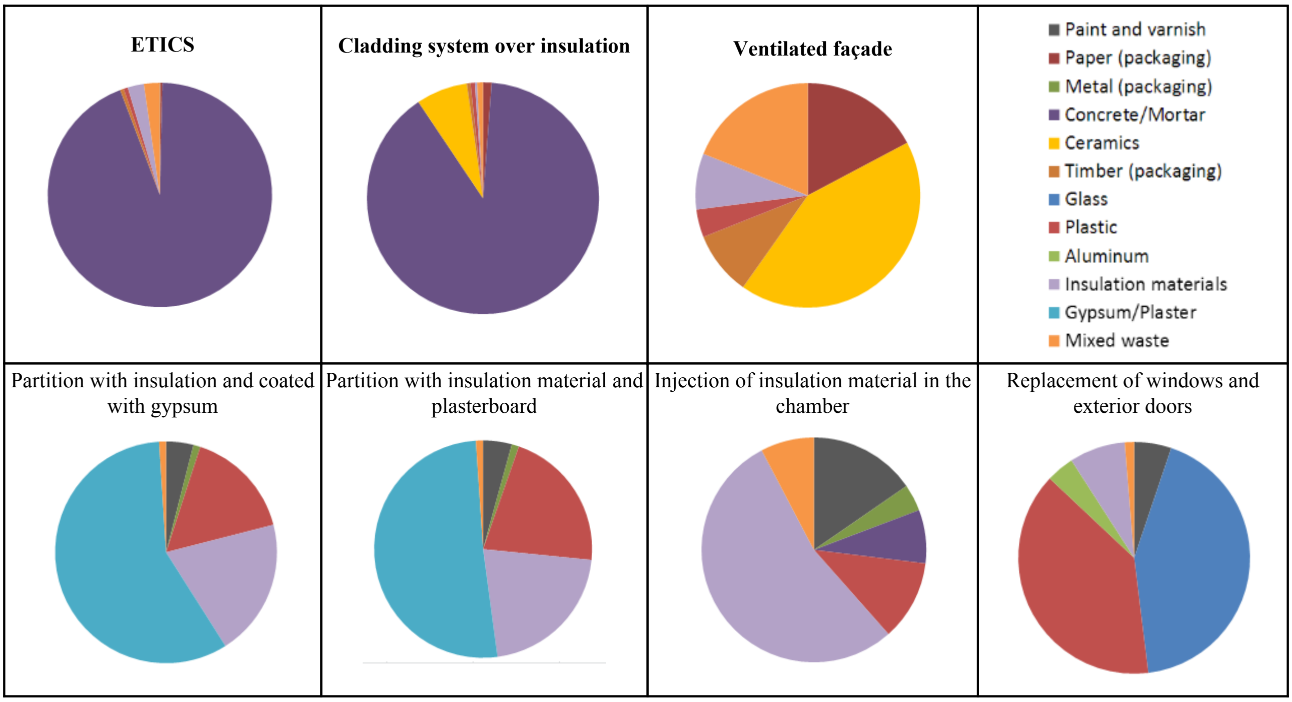
Gypsum Type	Amount of Gypsum (%)	Setting Time (min)		Flexural S. (N/mm2)	Comp. S (N/mm2)	Surface Hardness (N/mm2)	Adherence (N/mm2)
		Manual	Mechanical				
B1	≥ 50	>20	>50	≥1	≥2		Breakage occurs in the support or in the gypsum mass; when it occurs in the interface layer of plaster - support, the value should be ≥ 0.1.
B2	< 50						
B3							
B4	≥ 50						
B5	< 50						
B6							
B7	≥ 50			≥2	≥6	≥2.5	

In the techniques from the exterior, it appears that ETICS and Cladding system over insulation mainly generate two waste categories: concrete/mortar (89-94%) and ceramics (7%). However, the solution with ventilated façade generates less waste than the previous ones, but the waste is more heterogeneous, generating small amounts of different waste categories. In the techniques performed from the inside, it is observed that those techniques with a partition mainly generate gypsum waste (51-71%) followed by plastic materials (16-20%) and thermal insulation (20%). In the case of injecting insulation material in the air chamber, the main waste generated are insulating materials (54%) followed by paint (15%).

3.3. Characterization of New Materials (Binders and Waste) and Possible Applications

In view of the results obtained in the previous section, an experimental plan was developed to determine the feasibility of incorporating insulation and ceramic waste in gypsum composites. These plasters must meet the minimum requirements set by the current regulations Table (**4**) and cause less environmental impact than traditional plasters currently marketed by reducing the raw material and in turn incorporate residues which will not be deposited in landfills.

Table 4. Percentage of each CDW category over the total generated (in volume).



First, aggregates of insulation waste were included in a gypsum matrix, seeking to define a lightweight gypsum (B4) which comply with the regulations and reduce the environmental impact, as it does not include other lightweight aggregates being used today in Spain (perlite and vermiculite). From the results of the experimental plan conducted on a gypsum type B1, were waste percentages of EPS, XPS in percentages over the weight of the plaster of 1%, 2%, 3% and 4% were added, it can be concluded that it is possible to obtain lightweight gypsums (B4) by adding EPS and XPS aggregates in percentages equal or higher than 2%. However in compounds made with coarse gypsum, almost any compound can be considered lightened gypsum, as with additions of less than 2% of total waste the minimum density established in the Standard is exceeded and from 3% of total waste the minimum mechanical strength values are not reached. Therefore, only the compounds made with a mixture of EPS waste in a rate of 1% mixed with XPS in percentages 1% and 2% are able to meet the minimum requirements of the Standard.

As for the results of experimental plan conducted on gypsum compounds (B1) in which part of the raw material is being replaced by ceramic waste (addition percentages of 25% to 50%), results show that when 50% of ceramic is added, gypsums meet the specifications required in the standard for high hardness gypsums (B7).

CONCLUSIONS

From the results obtained, the following conclusions can be drawn:

- The most generated waste in the techniques to improve the energy efficiency of a building match with the most generated CDW in other building construction works.
- The generated CDW in these types of works cannot be rigorously quantified because of the enormous casuistry of each project. However, it is observed that the most generated waste categories are concrete and ceramics, and that wood, glass, plastics and cardboards have a very small impact on the waste generation. These CDW are mainly generated during the preparation of the existing surface where the works are planned to be carried out. Among the waste categories, mixed waste from insulation panels stands out due to their volume.
- Moreover, if we consider only the implementation of measures to improve the energy efficiency, those techniques performed from the inside will always generate less waste. In the case of the vertical envelope either ventilated façade or cladding on insulation, are both recommended.

- It has been found that a possible application of these CDW can be their use as fillers in gypsum and plasters, getting gypsums with less environmental impact and cost.
- It is possible to obtain lightweight gypsums that meet the current regulations when CDW from insulation panels are incorporated in a gypsum matrix.
- Adding ceramic waste in a gypsum compound can achieve the minimum requirements set for high hardness gypsums by the regulations.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

This research was supported by the Ministry of Economy and Competitiveness of the Spanish Government (Project reference number BIA2013-43061-R).

REFERENCES

[1] C. Porras-Amores, C. Viñas-Arrebola, A. Rodríguez-Sánchez, and P. Villoria-Sáez, "Assessing the potential use of strategies independent from the architectural design to achieve efficient ventilation: A Spanish case study", *Build. Serv. Eng. Res. Tech.,* vol. 35, pp. 529-542, 2014. [http://dx.doi.org/10.1177/0143624414524065]

[2] *Royal Decree 235/2013, of April 5, which approves the basic procedure for the certification of the energy efficiency of buildings (Real Decreto 235/2013, de 5 de abril, por el que se aprueba el procedimiento básico para la certificación de la eficiencia energética de los edificios),* vol. 13. 2013.

[3] M. Yeheyis, K. Hewage, M.S. Alam, C. Eskicioglu, and R. Sadiq, "An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability", *Clean Technologies and Environmental Policy,* vol. 15, pp. 81-91, 2013.

[4] A. Cuchí, and P. Sweatman, *A National Perspective of Spain's Buildings Sector: A Roadmap for a New Housing Sector*: Working Group for Rehabilitation" GTR", 2011.

[5] European Commision. (2014, December), *Eurostat statistics for waste flow generation,* 2012. Available: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

[6] C. Fischer, M. Werge, and A. Reichel, "EU as a Recycling Society Present recycling levels of Municipal Waste and Construction & Demolition Waste in the EU", *European Topic Centre on Resource and Waste Management,* Bruselas, .

[7] Spanish Government, *Real Decreto 105/2008, de 1 de Febrero, por el que se Regula la Producción y Gestión de los Residuos de Construcción y Demolición. "Royal Decree 105/2008, of February 1, on the Production and Management of Construction and Demolition Waste, .*

[8] H. Yuan, and L. Shen, "Trend of the research on construction and demolition waste management", *Waste management,* vol. 31, pp. 670-679, 2011.

[9] M. Mália, J. de Brito, M.D. Pinheiro, and M. Bravo, "Construction and demolition waste indicators", *Waste Manag. Res.,* vol. 31, no. 3, pp. 241-255, 2013. [http://dx.doi.org/10.1177/0734242X12471707] [PMID: 23315370]

[10] P. Mercader-Moyano, and A. Ramírez-de-Arellano-Agudo, "Selective classification and quantification model of C&D waste from material resources consumed in residential building construction", *Waste Manag. Res.,* vol. 31, no. 5, pp. 458-474, 2013. [http://dx.doi.org/10.1177/0734242X13477719] [PMID: 23446631]

[11] P. Villoria Sáez, C. Porras-Amores, and M. del Río Merino, "New quantification proposal for construction waste generation in new residential constructions", *J. Clean. Prod.,* vol. 102, pp. 58-65, 2015. [http://dx.doi.org/10.1016/j.jclepro.2015.04.029]

[12] N. González Pericot, P. Villoria Sáez, M. Del Río Merino, and O. Liébana Carrasco, *Production patterns of packaging waste categories generated at typical Mediterranean residential building worksites.,* Waste Management, 2014.

[13] H. Botasso, and E. Fensel, "Proyecto para el uso sistemático de residuos de construcción, demolición y procesos industriales", *Actas del Cuarto Congreso Internacional de Metalurgia y Materiales (Conamet-Sam),* 2004

[14] S. Gutierrez-Gonzalez, J. Gadea, A. Rodriguez, C. Junco, and V. Calderon, "Lightweight plaster materials with enhanced thermal properties made with polyurethane foam wastes", *Constr. Build. Mater.,* 2012.

[15] A. San-Antonio-González, M.D.R. Merino, C.V. Arrebola, and P. Villoria-Sáez, "Lightweight Material Made with Gypsum and EPS Waste with Enhanced Mechanical Strength", *J. Mater. Civil Eng.,* vol. 28, 2015.

[16] M. Morales-Conde, C. Rodríguez-Liñán, and M. Pedreño-Rojas, "Physical and mechanical properties of wood-gypsum composites from demolition material in rehabilitation works", *Constr. Build. Mater.,* vol. 114, pp. 6-14, 2016. [http://dx.doi.org/10.1016/j.conbuildmat.2016.03.137]

[17] J. Benedí Oliver, "La construcción eficiente energéticamente como necesidad de futuro y su aplicación a un edificio en Valencia", In: *Departament d'Enginyeria Mecànica i Construcció, Universitat Jaume I, Valencia,* 2013.

[18] Instituto Valenciano de la Edificación, *Catálogo de soluciones constructivas para la rehabilitación energética de edificios existentes. 1,* .

[19] Wacker Polymers, *Wacker Chemie AG Sustainability Report 2013/2014. Available: https://reports.wacker.com/2014/sustainability-report/ products-safety/ product-safety-product-stewardship/ product-stewardship.html,* 2013.

[20] Cype Ingenieros, *Cype Ingenieros database,* v.2014.c ed. Cype Ingenieros S.A: Spain:, 2013.

[21] *Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación., M. d. vivienda Real Decreto 314/2006,* .

[22] *UNE-EN 13279-2, Gypsum binders and gypsum plasters,* 2013. Part 2: Test methods, S. A. f. S. a. Certification, 2006