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Enhanced On-Site Waste Management of Plasterboard in Construction Works: A Case Study in Spain

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Abstract: On-site management of construction waste commonly determines its destination. In the case of plasterboard (PB), on-site segregation becomes crucial for closed-loop recycling. However, PB is commonly mixed with other wastes in Spain. In this context, the involvement of stakeholders that can contribute to reversing this current situation is needed. This paper analyzes on-site waste management of PB in Spain through a pilot study of a construction site, with the main objective of identifying best practices to increase waste prevention, waste minimization, and the recyclability of the waste. On-site visits and structured interviews were conducted. The results show five management stages: PB distribution (I); PB installation (II); Construction waste storage at the installation area (III); PB waste segregation at the installation area (IV) and PB waste transfer to the PB container and storage (V). The proposed practices refer to each stage and include the merging of Stages III and IV. This measure would avoid the mixing of waste fractions in Stage III, maximizing the recyclability of PB. In addition, two requisites for achieving enhanced management are analyzed: 'Training and commitment' and 'fulfilling the requirements established by the current regulation'. The results show that foremen adopted a more pessimistic attitude than installers towards a joint commitment for waste management. Moreover, not all supervisors valued the importance of a site waste management plan, regulated by the Royal Decree 105/2008 in Spain.

Keywords: sustainable construction; post-consumer waste; C&D waste; circular economy; plasterboard; gypsum; waste prevention; recycling; stakeholders; construction agents

1. Introduction

Sustainable management of materials, products, and waste in construction works contribute to resource efficiency and quality recyclates. It involves the adoption of measures for waste prevention, on-site segregation of the unavoidable waste and separate collection. This sustainable management fits within the European strategy for the sustainable competitiveness of the sector [1], the European Union (EU) action plan for the Circular Economy [2] and the EU targets on construction and demolition (C&D) waste [3].

Among the many waste fractions, gypsum plasterboard (PB) has been proven to be a recyclable construction product when appropriate on-site and off-site management practices are conducted. At the construction site, on-site segregation of gypsum waste has been identified as a best practice for a high-quality recovery [4], being the starting point of this work. PB consists of a gypsum core encased with facing paper to form flat rectangular boards [5]. Gypsum waste is processed into recycled gypsum through a series of mechanical steps such as crushing and sieving. Crushing converts the PB waste into gypsum powder and sieving separates the paper waste and potential impurities from the recycled gypsum.

Simply shifting from traditional partition walls (e.g., bricks) to PB partition walls can lower the consumption of non-renewable resources [6] and the production of waste [6,7]. The study from Villoria-Saez et al. showed a reduction of waste of around 16% by weight when using PB partition walls instead of brick walls [7]. However, the production of PB waste could be much lower, as it is estimated that, on average, between 3% and 10% of PB becomes waste at construction sites [8]. This is mainly due to poor management practices by agents in the design, planning, and construction phase (see [9] for further insights on the importance of reliable construction plans in waste prevention).

Following this current fundamental role that agents play in waste management, other authors have studied the perspectives and attitudes of agents along the value chain. In the design phase, Osmani et al. examined British architects' views on construction waste reduction during the design process [10]. In the construction phase, the attitudes and behaviors of Malaysian contractors on waste management were explored by Begum et al. [11]. Also in this phase, Kulatunga et al. surveyed contractors and their employees (e.g., foremen, laborers) to understand and assess the attitudes and perceptions of the workforce towards waste management in Ski Lanka [12]. Lu and Yuan also focused on the construction phase, identifying seven factors for managing C&D waste, of which "awareness of C&D waste management" and "vocational training in waste management" ranked third and seventh respectively [13]. Villoria-Sáez et al. assessed measures in both phases, targeting C&D waste management in the Spanish construction sector [14]. Moreover, Gangollels et al. also underlined the planning phase [15]. The results include the necessity of raising the awareness of agents [11,13–15] and point the limited training on waste management of agents [10,12,13,15].

These management shortcomings add up to a high rate of post-consumer gypsum products (e.g., PB) commonly sent to landfills in the EU and particularly in some non-gypsum recycling countries. Examples of non-gypsum recycling countries are Italy, Poland, or Spain, where a market for post-consumer recycled gypsum does not exist yet. In Spain, this is due to a number of influencing factors at the macro level (e.g., low landfill tax, availability of natural gypsum) [16] and other barriers at the micro level (e.g., lack of control over C&D waste management plans, lack of coordination between agents) [17]. Spain is still far away from complying the 70% EU target by 2020 on C&D waste, as only 14% of the C&D waste was estimated to be reused or recycled in a EU report published in 2011 (more recent reliable information has not been found) [8]. Overall, 87.2% of PB was estimated to be landfilled in the EU in 2013 [18]. PB landfilling typically produces higher hydrogen sulphide and greenhouse gas emissions from landfills. Furthermore, unsorted gypsum contaminates inert waste.

At the construction site, practices adopted by construction agents can determine the amount of waste generated and its final fate. For instance, PB waste with impurities (e.g., plastic) higher than 2% and free moisture above 10% make PB waste unsuitable for closed-loop recycling [19]. Standard, good, and best practices are distinguished in the report '*Achieving good practice Waste Minimization and Management*' by Waste & Resources Action Programme (WRAP) [20]. In this report, a best practice is described as the one that "reflects the leading approach currently undertaken in the industry, but may bear a cost premium or require a significant change in working practice in some projects". The possible extra cost can be eliminated through economies of scale and learning [20]. This paper is based on such a definition of best practice.

Given this context, the objective of this paper is to propose best practices for an enhanced management of PB, through the analysis of a case study of a construction site in Spain. The case study was framed by the Spanish project "Nuevas actuaciones de reciclado de yesos para aumentar la eficiencia y sostenibilidad del proceso" (New Initiatives in Gypsum Recycling to Increase the Efficiency and Sustainability of the Process), funded by the Spanish Centre for the Development of Industrial Technology (CDTI) in 2012 and coordinated by Saint-Gobain Placo Ibérica, a PB manufacturer. The construction works were executed between 2013 and 2014 by Arpada, a Spanish construction company. This experience aims at detecting the construction agents' perceptions of this novel sequence of works in Spain (see Section 2), which includes the use of small containers for the segregation of PB waste from the rest of C&D waste. It should be remembered that Spain is not a gypsum recycling country at present [16], and therefore gypsum waste is typically mixed with other C&D waste for landfilling. In this sense, this investigation would not have been possible without the framework of the above-mentioned research project, in which a pilot study was set (the case study object of this paper), being the same PB manufacturer the one in charge of subsequently processing the gypsum waste into recycled gypsum. This manufacturer has recently started to offer this recycling service in Spain [21].

Although most of the proposed best practices could be replicated in other waste fractions (Section 3, summary of best practices in Table 3), some of them relate to the nature of PB (i.e., being non-inert) and its shape (i.e., variable rectangular sizes). Documenting the views of the construction agents involved was crucial to identify adequate practices considering the current context. Based on the results from the interviews (Section 2), data is analyzed per management stage in Sections 3.1–3.5. In addition, Sections 3.6 and 3.7 focus on training, commitment of the agents ,and the fulfilling of the current regulations on C&D waste management, which are influencing factors at the micro-level (i.e., the construction phase) to achieve an enhanced on-site management.

2. Materials and Methods

The best practices influencing the management of PB in construction sites were investigated through a case study, including site visits and face-to-face structured interviews with construction agents. The case study was a residential building project consisting of 81 dwellings, commercial premises, storage rooms, garage, a swimming pool, and external urbanization, located in the Spanish town of Tres Cantos, in Madrid. Around 420 tonnes of PB were supplied by the manufacturer, of which around 81 tonnes become PB waste. This equals to 19% of PB waste generated during the construction works. As for the interviews, these were designed, carried out, and analyzed in order to document the views of construction agents regarding on-site PB waste management. The interview is included in Appendix A. The respondents (11 in total) can be classified into four categories: PB installers (five responses), supervisors (two responses from construction foremen and one from the project manager), general laborer (one response), and crane operators (two responses). A greater number of agents performing similar waste management practices in additional case studies could not be found, as PB in Spain is commonly disposed of in landfills and therefore on-site management practices are not commonly performed. As stated in the Introductory part of this paper, this pilot study was set in the framework of a Spanish project as a novel approach. In order to broaden the findings from this case study, the discussion includes the relationship between the results of this study and those from previous research.

In this case study, PB installers, foremen and general laborers were part of the subcontracted PB installation company. While installers carried out the PB installation works and stored the PB waste mixed up with the rest of waste fractions at the installation area, construction foremen supervised the works. General laborers were appointed to segregate and store PB waste from the rest of waste fractions at the installation area, by means of small containers. For its part, crane operators and the project manager were part of the construction company. Crane operators were in charge of transferring and emptying the small containers, by means of a crane, from the installation area to the specific PB container at the construction site. It should be noted that the use of such small containers has been already identified as a best practice in the literature [14,20,22]. The installation works were carried out according to the following sequence:

- PB was distributed and stored at the installation area according to the planning of the construction works.
- At the installation area, the PB installers executed the first side of the partitions and left the PB waste on the floor, mixed up with the rest of construction waste as they were being generated.
- A first cleaning of the installation area was carried out by the general laborers. It is at this point that the PB waste was segregated from the rest of construction waste and loaded into small containers.

- The small containers with the PB waste generated in the installation area were transferred by the crane operator, who emptied the small container into the specific PB container at the construction site.
- The PB installers executed the second side of the partitions while they left the PB waste generated mixed up with the rest of waste fractions in the installation area.
- A final cleaning of the installation area was carried out by the general laborers, loading the PB waste segregated from the rest of waste into the small container.
- Once again, the small container was transported by the crane operator and emptied into the specific container for PB waste at the construction site.

3. Results and Discussion

Five stages have been identified as affecting the on-site production and management of PB waste (Figure 1): (I) PB distribution (in Figure 1 PB is transferred from the storing place at the construction site to the installation area in the second floor by using the crane); (II) PB installation; (III) Construction waste storage at the installation area (it can be seen in Figure 1 that metal and insulation waste are mixed up with PB. Beneath, stockpiled PB is waiting to be installed); (IV) PB waste segregation at the installation area (in Figure 1, the small container is waiting in the first floor to be transferred to the PB container); (V) PB waste transfer to the PB container and storage. These are discussed in Sections 3.1–3.5. In addition, two factors affecting the whole process are examined in Sections 3.6 and 3.7: 'Training and commitment' and "Fulfilling the requirements established by the current regulation".

3.1. Plasterboard Distribution (I)

This stage includes three activities: the unloading of the PB batches from the truck, their storing at the construction site and the transfer of PB to the installation areas. One installer explains that, when using the crane, the last PB of the pallet is in contact with the slings (Figure 1), producing damage in the product that eventually becomes waste. Two practices can prevent the generation of waste: the transport of whole and packaged PB pallets and the use of appropriate means to transport the pallets within the construction site (Table 3).

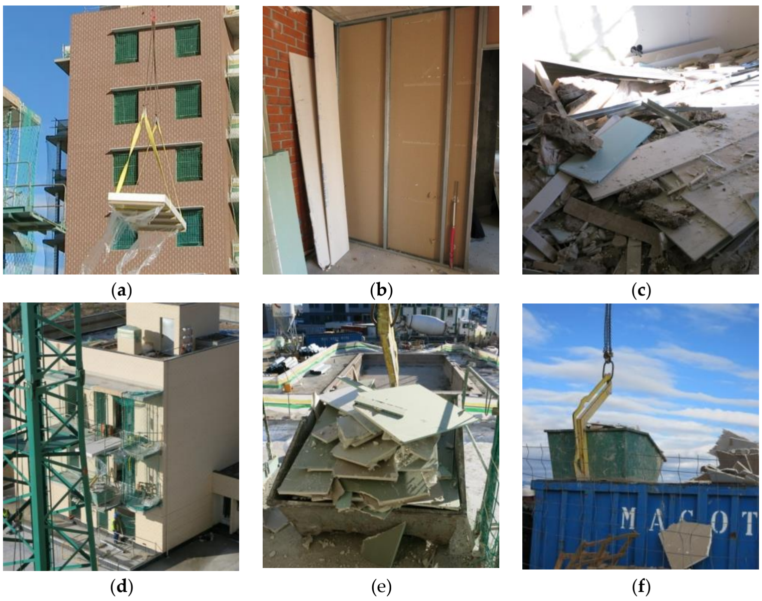

Figure 1. Stages in the on-site waste management of plasterboard in this case study. (**a**) Plasterboard distribution (I); (**b**) Plasterboard installation (II); (**c**) Construction waste storage at the installation area (III); (**d**,**e**) PB waste segregation at the installation area (IV); (**f**) PB waste transfer to the PB container and storage (V).

3.2. Plasterboard Installation (II)

Size adjustments in PB height and width are usually needed during PB installation, due to the particular characteristics of the buildings, mainly in terms of space distribution. The amount of offcuts becomes even higher when designed complex shapes within the project are executed on-site. In most of the cases, installers are not allowed to install the offcuts, leading to material being wasted. For instance, offcuts can be used in the internal face of systems with double PB per face (4 PB per partition).

Installers and supervisors were asked about the importance they give to the minimization of PB waste generation on-site. The mean value of both agents was quite similar (Table 1). In particular, 80% of installers and 100% of supervisors considered that the minimization of PB waste is of high importance or fundamental. Despite this statement, 40% of installers and 67% of supervisors recognized not implementing any minimization measure on-site. In the case of installers and foremen, this can be mainly due to their type of contract, which rewards the amount of m^2 installed. Examples of minimization measures listed by respondents (question in Appendix A) were to properly organize the works to make the most of the PB and to make the most of the offcuts whenever possible.

The best practices proposed cover the use of incentives for producing minimum scrap and minimum waste (Table 3). These incentives already have been considered by previous studies [12,23]. For instance, a reward scheme examined by Tam and Tam achieved up to 23% waste reduction in a case study in Hong Kong [23]. The implementation of such reward schemes could translate into higher waste prevention and fewer impurities in the unavoidable waste.

Table 1. Importance given by the construction agents to distinct actions part of the studied stages.

Action	Agent	Number of Responses Scoring [a] and %										M
		1		2		3		4		5		
Minimization of PB waste	Installers	0	0%	1	20%	0	0%	3	60%	1	20%	3.8
	Supervisors	0	0%	0	0%	0	0%	2	67%	1	33%	4.3
On-site segregation of PB waste from the rest of C&D waste	Installers	0	0%	0	0%	2	40%	2	40%	1	20%	3.8
	Supervisors	0	0%	0	0%	0	0%	1	33%	2	67%	4.7
	Crane op.	0	0%	0	0%	0	0%	1	50%	1	50%	4.5
	Laborer	1	100%	0	0%	0	0%	0	0%	0	0%	1.0
Training on C&D waste segregation and storage	Installers	0	0%	0	0%	0	0%	3	60%	2	40%	4.4
	Supervisors	0	0%	1	33%	2	67%	0	0%	0	0%	2.7
	Crane op.	0	0%	0	0%	1	50%	1	50%	0	0%	3.5
	Laborer	1	100%	0	0%	0	0%	0	0%	0	0%	1.0
SWMP elaboration	Supervisors	0	0%	0	0%	1	33%	2	67%	0	0%	3.7
C&D waste estimation	Supervisors	1	33%	0	0%	0	0%	2	67%	0	0%	3.0
Monitoring of the SWMP	Supervisors	0	0%	0	0%	0	0%	3	100%	0	0%	4.0
Appointment of a person responsible on C&D waste	Supervisors	0	0%	0	0%	1	33%	1	33%	1	33%	4.0

[a] 1 = No Importance; 2 = Minor Importance; 3 = Relative Importance; 4 = High Importance; 5 = Fundamental. M: mean value; PB: plasterboard; C&D: construction and demolition; Crane op.: crane operator; SWMP: site waste management plan.

3.3. Construction Waste Storage at the Installation Area (III)

Installers left the distinct fractions all together on the floor while installing the PB system. This means that PB waste generated was mixed up with other C&D waste fractions, mainly metal frames and insulation materials.

Two possible management options relate to the present Stage III and the Stage IV ("PB waste segregation and loading at the installation area", see Section 3.4). The option applied in this case study consists on maintaining the role of installers (they are working for m^2 executed) and appointing an additional worker (a general laborer in this case) responsible for carrying out a subsequent segregation of PB waste and loading into the small containers. Under this management option, the PB waste is mixed with other construction waste and it may even end up mixed up with stockpiled material waiting to be installed. Therefore, the quality of both products (i.e., PB waiting to be installed and PB waste) might be clearly affected (see Figure 1c). An alternative management option has been entitled 'PB on-site segregation and separate collection at the installation area'. This would imply changing the traditional contract of installers based on early completion and introduce incentives to enhance waste management practices (Table 3).

When installers and foremen were asked about their opinion on both management options (Appendix A) 80% of installers argued that they were not in charge of segregating the waste and loading it into the small container, that this was the task of the general laborers and that they were not paid for it. Only one foreman identified the alternative management option as beneficial. Their opinion on the difficulty of segregating at the source was also explored. It was valued as very easy or easy by the general laborer, 100% of installers and 67% of supervisors (Table 2).

Installers, supervisors, and crane operators were asked about the importance they give to the segregation of PB. 100% of installers and supervisors considered that the on-site segregation of PB is of high importance or fundamental. The general laborer for their part did not give importance to the segregation (Table 1), expressing concerns on the final destination of the segregated waste once the waste leaves the construction work.

Table 2. Level of difficulty given by the construction agents to distinct actions part of the studied stages.

Action	Agent	Number of Responses Scoring [a] and %										M
		1		2		3		4		5		
Commitment of agents on C&D waste prevention	Installers	2	40%	0	0%	1	20%	1	20%	1	20%	2.8
	Supervisors	0	0%	0	0%	0	0%	2	67%	1	33%	4.3
	Crane op.	0	0%	0	0%	1	50%	1	50%	0	0%	3.5
	Laborer	1	100%	0	0%	0	0%	0	0%	0	0%	1.0
Commitment of agents on C&D waste minimization	Installers	1	20%	1	20%	1	20%	2	40%	0	0%	2.8
	Supervisors	0	0%	1	33%	0	0%	1	33%	1	33%	3.7
	Crane op.	0	0%	0	0%	1	50%	1	50%	0	0%	3.5
	Laborer	0	0%	0	0%	0	0%	0	0%	0	0%	- [b]
Commitment of agents on C&D waste segregation	Installers	1	20%	3	60%	0	0%	1	20%	0	0%	2.2
	Supervisors	0	0%	0	0%	0	0%	1	33%	2	67%	4.7
	Crane op.	0	0%	0	0%	1	50%	1	50%	0	0%	3.5
	Laborer	0	0%	0	0%	0	0%	0	0%	0	0%	- [b]
On-site segregation of PB waste from the rest of C&D waste	Installers	1	20%	4	80%	0	0%	0	0%	0	0%	1.8
	Supervisors	0	0%	2	67%	0	0%	0	0%	1	33%	3.0
	Laborer	1	100%	0	0%	0	0%	0	0%	0	0%	1.0

[a] 1 = Very easy; 2 = Easy; 3 = Intermediate difficulty; 4 = Complex; 5 = Very complex. M: mean value; [b] No answer as the laborer considers that a commitment is not possible. C&D: construction and demolition; Crane op.: crane operator; PB: plasterboard.

3.4. Plasterboard Waste Segregation at the Installation Area (IV)

As explained in Section 3.3, general laborers in this case study were specially appointed by the installation company to segregate the PB and load it into the small container located at the installation area. This is not considered an effective sequence of works as on-site segregation and separate collection is not favored. The merging of Stages III and IV is therefore recommended as detailed in Table 3 (new stage 'PB on-site segregation and separate collection at the installation').

3.5. Plasterboard Waste Transfer to the PB Container and Storage (V)

Two shortcomings are identified in this stage related to the planning of the works and the monitoring of the process. In Stage V, crane operators performed the transfer of the small containers located in the installation area to the PB container once small containers had been loaded by the general laborers.

As the general laborer expressed, their productivity was affected as they had to wait for the crane to be available for the transfer of the waste from the small container to the PB container. Once the waste was stored in the PB container, there was no appointed responsible for monitoring the quality of the waste before being transferred for recycling. Advanced planning for waste according with the SWMP and the appointment of a person responsible for monitoring the PB containers would enhance the process efficiency (Table 3).

Moreover, the site visits for the case study unveiled that the PB containers were not commonly covered. This might diminish the quality of the waste in terms of quantity of impurities (e.g., workers of even passers-by can use containers as waste bins) and moisture (e.g., potential wet weather). To keep impurities below 10% and free moisture below 2% by weight is part of the waste acceptance criteria of the gypsum recyclers [19]. The use of closed-top PB containers is already recommended at the EU level [4] and it is hence a proposed best practice on-site (Table 3).

Table 3. Summary of observed practices (further described in Sections 3.1–3.5) and proposed best practices for plasterboard waste management in construction sites.

Stage	Observed Practice	Proposed Best Practice
I	Partial and/or unpackaged PB batches are transported to the installation areas	To transport whole and packaged PB pallets whenever possible in order to minimize the damage at the bottom of the pallet
II	The crane slings cause damage in the last PB of the batch	To use forklifts or similar means as an alternative to crane slings whenever possible
	PB is not always optimally cut to produce minimum scrap. As a result, unnecessary offcuts are generated	To incentivize the production of minimum scrap. For instance, replacing the current piecework pay by a remuneration scheme that would reward the minimum production of waste
	Offcuts typically become waste, as installers might not spend time figuring out where it is feasible to use them	To incentivize the production of minimum waste through the reward scheme. This could promote the use of offcuts whenever technically feasible, for instance in the case of internal faces in systems with double PB per face
III–IV	Installers leave mixed C&D waste on the floor	To incentivize the production of clean waste through the reward scheme. This can lead to segregate waste while installing the PB systems, thus merging stages III and IV into a new proposed stage 'PB waste storage in small containers at the installation area'
V	Lengthy waiting periods until the crane unloads the container in the PB container	To better plan coordination of waste management activities (e.g., improved project schedule, increased amount of small containers)
	PB containers are loaded without ensuring the quality of the waste to be transferred for recycling	To appoint a person responsible for conducting periodic visual inspections of the PB containers
	Uncovered PB containers are used	To use closed-top PB containers in order to protect PB waste from wet weather and potential external impurities

3.6. Training and Commitment

Installers and supervisors were asked about the importance of training on C&D waste segregation and storage, the required number of training hours per year of training that they considered relevant and the actual hours received last year. All installers considered the training to be of high importance or fundamental (Table 1). However, 60% of them were of the view that less than 24 h per year would be appropriate, of which 40% answered that one hour per year would be enough. As regards the actual training received, 80% claimed to have received less than one hour in the past year, which was not even specific to PB segregation. As for the supervisors, 100% of them reported that training on C&D waste segregation and storage have relative or minor importance. Moreover, all of them considered that less than 6 h per year of training would be effective. Besides, they affirmed not having received any training concerning C&D waste management in the last year, except the one at this construction site (specifically organized because of the development of this case study, dealing with the management of gypsum PB). These findings are in line with those of Lu and Yuan in Shenzhen (China), where the usual training time was also limited and C&D waste management was not part of the training programs [13].

Although only one general laborer could be interviewed, it is worth mentioning the response received on the 'Training on C&D waste segregation and storage' (Table 1). The general laborer rated the training in C&D waste as not important, arguing that everyone knows how to do it. This perception could also be influenced by the repetitive functions inherent to his role in this construction work (as explained in Section 2).

The views on the level of difficulty to achieve a commitment of workers on waste prevention, minimization and segregation were also explored (Table 2). Prevention is seen as complex or very complex by 40% of installers, but by 100% of supervisors. Similarly, 40% of installers saw minimization of C&D waste as complex or very complex, compared to 67% of supervisors. The commitment on waste segregation was seen as complex or very complex by 20% of installers, but by 100% of supervisors. This indicates a more negative attitude from supervisors towards enhanced waste management, being the man value of supervisors up to 2 points below the man value of installers (Table 2). The proposed new reward scheme (Table 3, Stages II–IV) would also contribute to achieving a higher commitment of construction agents.

3.7. Fulfilling the Requirements Established by the Current Regulation

In Spain, Royal Decree 105/2008 [24] specifically regulates C&D waste management. It requires the development of particular waste management models for each construction project based on the drawing up of a waste management report (WMR, developed during the design phase) and a site waste management plan (SWMP, developed during the planning of the construction work). These imply a detailed study of the C&D waste to be generated and particular measures to perform on-site waste management. In this case study, the SWMP foresaw 56.01 tonnes of gypsum products, which deviates at least 45% from the real waste generated, as 81.28 tonnes of PB waste were produced (as explained in Section 2). Although some generic measures for waste management were listed in the SWMP, it did not provide any particular measure for PB. Moreover, "landfill" was specified as the final destination for PB waste. This is probably because the SWMP was drafted before agreeing to conduct this PB case study. However, this document should be updated regularly during the course of the construction works [25].

The supervisors, as agents in charge of enforcing the SWMP, were asked about the importance given to the SWMP elaboration, C&D waste estimation and the monitoring of the SWMP. Of the supervisors, 67% agreed on the importance of the SWMP elaboration and the estimation of construction waste. With respect to the monitoring of the SWMP, 100% saw it as an important task. However, only 67% found necessary to have a person responsible for monitoring and control waste management on-site. In the analyzed case study, there was not anyone responsible for such monitoring and control. However, one of the foremen explained that 2 or 3 containers out of 10 are revised at the installation area in order to check that the PB waste was properly segregated. Villoria-Sáez et al. and Lu and Yuan have also studied the supervision of C&D waste on-site, as a factor for the successful C&D waste management [13] and as a best practice measure in the form of periodic checks on the use of C&D waste containers [14].

This lack of proper supervision of PB waste on-site, together with the deficiencies of the SWMP described above, demonstrate the poor elaboration and performance of SWMP in the case study. Legislative measures (e.g., increased fiscal measures and reward systems for waste prevention as proposed by Osmani et al. [10] in the design phase) could improve this situation. Other measures cover agreements between contractors and subcontractors. These include a written commitment on waste management [15], contractual clauses to make subcontractors responsible for their waste [26], and the inclusion of waste targets for subcontractors [26,27].

4. Conclusions

This paper has identified the management stages affecting the on-site production and management of plasterboard in a construction work and proposed best practices for an enhanced on-site waste management. Data from site visits and interviews with construction agents from a Spanish case study together with findings from previous research have framed the analysis.

As for the management stages, five have been identified: Plasterboard distribution (I); Plasterboard installation (II); Construction waste storage at the installation area (III); Plasterboard waste at the installation area (IV); and Plasterboard waste transfer to the PB container and storage (V). The most relevant best practice proposed is the merging of Stages III and IV into one stage entitled PB on-site segregation and separate collection at the installation area. This measure would avoid the storage of mixed construction waste and would thus optimize the recyclability of the plasterboard waste. The analysis of each stage results in a set of best practices for an enhanced on-site waste management of plasterboard. The main conclusions can be summarized as follows:

- Waste can be even produced during plasterboard distribution (I), mainly due to the transportation of unpackaged pallets and the use of crane slings. This can be prevented by transporting unpacked pallets and using appropriate means (e.g., forklifts).
- 40% of installers and 67% of foremen did not implement minimization measures on-site during plasterboard Installation (II). For instance, the production of minimum offcuts is not commonly considered. Once offcuts are produced, their use when technically feasible is not a common practice. The introduction of a reward scheme based on the production of minimum and clean waste is proposed to enhance waste prevention.
- 80% of installers did not conceive the separate collection of plasterboard while installing the systems, as they are typically remunerated by the m^2 installed. They thus perceive separate collection as an extra activity. The consideration of the said reward scheme could therefore lead to plasterboard on-site segregation and collection at the installation area (III–IV).
- Poor planning and monitoring of the waste management process was identified in the stage plasterboard waste transfer to the PB container and storage (V). The best practices proposed to improve the recyclability of the waste cover the advanced planning for waste according with the site waste management plan, the appointment of a person responsible for monitoring the PB containers and the use of closed-top PB containers.

Moreover, two factors affecting the whole process have been discussed: 'training and commitment' and 'fulfilling the requirements established by the current regulation'. It was found that installers hold a more positive attitude towards training and commitment, more highly valuing the importance of training and the easiness to achieve a commitment of construction agents on waste prevention, minimization, and segregation. Regarding the site waste management plan as established in the Spanish Royal Decree 105/2008, deficiencies were found in the estimation of the waste and the establishment of measures for waste management. In addition, only 67% of the supervisors agreed on the importance of the elaboration of the site waste management plan and the estimation of construction waste. Poor monitoring of the waste produced was also encountered. The poor performance of the site waste management plan is considered to be a limiting factor for waste prevention and recyclability of the waste.

Although the paper achieved its objectives, the analysis of a unique case study is a limitation of the present work. Additional case studies could not be engaged in this novel study due to the scope of the project that frames this work. It should be remembered that most plasterboard in Spain is landfilled, and therefore plasterboard is typically mixed with other C&D waste for landfilling. It is worth noting that site visits and interviews in a higher number of case studies might have enabled a wider discussion and conclusions as well as the investigation of significant differences between the views of agents. Nevertheless, the findings from the case study have been linked with those from previous research, providing a broader possible picture and analysis of alternative practices.

In any case, the proposed set of best practices is considered to be relevant for a more sustainable management of plasterboard. These best practices are designed to guide stakeholders towards higher waste prevention and enhanced recyclability of the unavoidable waste produced. Moreover, they set the basis for future research lines (e.g., implementation of the best practices, quantitative comparison of the improvements obtained).

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Appendix A

Please rate the following aspects in terms of importance, considering that 1 = No Importance; 2 = Minor Importance; 3 = Relative Importance; 4 = High Importance; 5 = Fundamental.

Table A1. Importance given to distinct actions part of the studied stages.

Aspect	Agent	Level of Importance According to Your View				
		1	2	3	4	5
Minimization of plasterboard waste	Installers & Supervisors					
On-site segregation of plasterboard waste from the rest of C&D waste	All					
Training for C&D waste segregation and storage	All					
Site waste management plan elaboration	Supervisors					
C&D waste estimation	Supervisors					
Monitoring of the site waste management plan	Supervisors					
Appointment of a person responsible on C&D waste	Supervisors					

Please rate the following aspects in terms of difficulty, considering that 1 = Very easy; 2 = Easy; 3 = Intermediate difficulty; 4 = Complex; 5 = Very complex.

Table A2. Level of difficulty to distinct actions part of the studied stages.

Aspect	Agent	Level of Difficulty According to Your View				
		1	2	3	4	5
Commitment of agents on C&D waste prevention	All					
Commitment of agents on C&D waste minimization	All					
Commitment of agents on C&D waste segregation	All					
On-site segregation of plasterboard waste from the rest of C&D waste	Installers, Supervisors & General Laborers					

Related questions:

- What do you think is the best option?

  (1) To load the small container at the time the waste is being generated or,
  (2) To leave the waste on the floor until the work in an area is finished.

Justify your response.

- Number of hours of training on C&D waste management for workers that you consider necessary.
- Number of hours of training, on C&D waste management, that you received in 2013.
- Number of hours of dedication of a person responsible to monitor waste management that you consider necessary.
- Did you receive specific information on plasterboard on-site segregation and separate collection?
- List specific measures of plasterboard waste minimization that you perform in your work.

References

1. European Commission Strategy for the Sustainable Competitiveness of the Construction Sector and Its Enterprises (SWD(2012)236 Final). *Communication from the Commission to the European Parliamente and the Council*; COM(2012)433 Final; European Commission: Brussels, Belgium, 2012.
2. European Commission Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. *Closing the Loop—An EU Action Plan for the Circular Economy*; European Commission: Brussels, Belgium, 2015.
3. European Parliament and the Council of the European Union Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF (accessed on 12 April 2015).
4. GtoG Project DA2: Inventory of Best Practices LIFE11 ENV/BE/001039. Available online: http://gypsumtogypsum.org/documents/da2-inventory-of-best-practices.pdf (accessed on 17 July 2016).
5. ISO. *ISO 6308-1980. Gypsum Plasterboard—Specification*; ISO: Geneva, Switzerland, 2004.
6. Condeixa, K.; Qualharini, E.; Boer, D.; Haddad, A. An inquiry into the life cycle of systems of inner walls: Comparison of masonry and drywall. *Sustainability* **2015**, *7*, 7904–7925. [CrossRef]
7. Villoria Sáez, P.; del Río Merino, M.; Porras-Amores, C.; San-Antonio González, A. Assessing the accumulation of construction waste generation during residential building construction works. *Resour. Conserv. Recycl.* **2014**, *93*, 67–74. [CrossRef]
8. European Commission (DG ENV) Service Contract on Management of Construction and Demolition Waste—SR1. Final Report Task 2. A Project under the Framework Contract ENV.G.4/FRA/2008/0112. Available online: http://ec.europa.eu/environment/waste/pdf/2011_CDW_Report.pdf (accessed on 17 January 2016).
9. Jeong, W.; Chang, S.; JeongWook, S.; Yi, J.-S. BIM-Integrated Construction Operation Simulation for Reliable Production Management. *Sustainability* **2016**, *8*, 1106. [CrossRef]
10. Osmani, M.; Glass, J.; Price, A.D.F. Architects' perspectives on construction waste reduction by design. *Waste Manag.* **2008**, *28*, 1147–1158. [CrossRef] [PubMed]
11. Begum, R.A.; Siwar, C.; Pereira, J.J.; Jaafar, A.H. Attitude and behavioral factors in waste management in the construction industry of Malaysia. *Resour. Conserv. Recycl.* **2009**, *53*, 321–328. [CrossRef]
12. Kulatunga, U.; Amaratunga, D.; Haigh, R.; Rameezdeen, R. Attitudes and perceptions of construction workforce on construction waste in Sri Lanka. *Manag. Environ. Qual. Int. J.* **2006**, *17*, 57–72. [CrossRef]
13. Lu, W.; Yuan, H. Exploring critical success factors for waste management in construction projects of China. *Resour. Conserv. Recycl.* **2010**, *55*, 201–208. [CrossRef]
14. Villoria Saez, P.; Del Río Merino, M.; San-Antonio González, A.; Porras-Amores, C. Best practice measures assessment for construction and demolition waste management in building constructions. *Resour. Conserv. Recycl.* **2013**, *75*, 52–62. [CrossRef]
15. Gangolells, M.; Casals, M.; Forcada, N.; Macarulla, M. Analysis of the implementation of effective waste management practices in construction projects and sites. *Resour. Conserv. Recycl.* **2014**, *93*, 99–111. [CrossRef]
16. Jiménez-Rivero, A.; García-Navarro, J. Exploring factors influencing post-consumer gypsum recycling and landfilling in the European Union. *Resour. Conserv. Recycl.* **2017**, *116*, 116–123. [CrossRef]
17. Calvo, N.; Varela-Candamio, L.; Novo-Corti, I. A dynamic model for construction and demolition (C&D) waste management in Spain: Driving policies based on economic incentives and tax penalties. *Sustainability* **2014**, *6*, 416–435.

18. Jiménez Rivero, A.; Sathre, R.; García Navarro, J. Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union. *Resour. Conserv. Recycl.* **2016**, *108*, 171–181. [CrossRef]
19. Jiménez-Rivero, A.; García-Navarro, J. Indicators to Measure the Management Performance of End-of-Life Gypsum: From Deconstruction to Production of Recycled Gypsum. *Waste Biomass Valoriz.* **2016**, *7*, 913–927. [CrossRef]
20. WRAP Achieving Good Practice Waste Minimisation and Management. *Practical Solutions for Sustainable Construction*; WRAP: Oxfordshire, UK, 2014.
21. Saint-Gobain Placo Ibérica Reciclaje de Placa de Yeso Laminado PYL | Placo. Available online: http://www.placo.es/es-es/sostenibilidad/reciclaje-yeso-laminado (accessed on 7 February 2017).
22. Audus, I.; Charles, P.; Evans, S. *Environmental Good Practice on Site Guide*, 3rd ed.; Construction Industry Research and Information Association (CIRIA): London, UK, 2010.
23. Tam, V.W.Y.; Tam, C.M. Waste reduction through incentives: A case study. *Build. Res. Inf.* **2008**, *36*, 37–43. [CrossRef]
24. Ministerio de la Presidencia. *Real Decreto 105/2008, de 1 de Febrero. Por el Que se Regula la Producción y Gestión de los Residuos de Construcción y Demolición*; Ministerio de la Presidencia: Madrid, Spain, 2008; pp. 7724–7730.
25. WRAP. *WRAP Site Waste Management Plan Template Version 2.0*; WRAP: Oxfordshire, UK, 2011.
26. Ajayi, S.O.; Oyedele, L.O.; Bilal, M.; Akinade, O.O.; Alaka, H.A.; Owolabi, H.A. Critical management practices influencing on-site waste minimization in construction projects. *Waste Manag.* **2017**, *59*, 330–339. [CrossRef] [PubMed]
27. Marinelli, M.; Dolan, M.; Spillane, J.; Konanahalli, A. Material waste in the Northern Ireland construction industry: On-site management, causes and methods of prevention. In Proceedings of the 30th Annual ARCOM Conference, Portsmouth, UK, 1–3 September 2014; pp. 113–122.