GOOD PRACTICES ON THE END-OF-LIFE OF GYPSUM PRODUCTS

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This document provides an overview of the identified practices contributing to an efficient closed-loop supply chain.

DEC1. Implement an effective pre-deconstruction audit for gypsum-based systems

An essential step for both deconstruction planning and for the quality assurance of the materials is the pre-deconstruction audit, which reduces the uncertainty on what systems will be found when dismantling [1], identifying the range of materials and products expected to be generated from the deconstruction of the existing buildings and structures. Such waste prediction will set the basis for the development of a sound Site Waste Management Plan (SWMP), which in turn, will result in maximising the reduction, reuse, recycling and recovery options of materials, and the potential cost savings associated.

An accurate (i.e. minimum deviation between waste foreseen and generated) pre-deconstruction audit (i.e. desk study, site visit, quality assessment of materials, etc.) should cover at least the location, amount, type and cost of gypsum waste (GW) to be generated (this enables the identification of recyclable GW), as well as the expected recycling targets.

The Singapore standard SS 557:2010 [2] is an example of good practice in this field. It takes into account issues which affect the environment including a set of procedures to help demolition contractors to maximize recovery of waste materials, known as Demolition Protocol [3].

Another example is the Site Methodology to Audit Reduced Target Waste (SMARTWaste^{TM}), a tool, developed by the Building Research Establishments (BRE), which helps to perform pre-demolition audits by which potential wastes arising can be benchmarked and categorized by source, type, amount, cause and cost [4].

DEC2. Draft a precise SWMP and implement it

Apart from a pre-deconstruction audit, a SWMP is also crucial, to the extent that in many countries it is already a legislative requirement prior to the implementation of construction work (e.g. Spain, the UK). A typical SWMP consist in a detailed description of the waste management strategies that will be adopted during and after the construction activities [5], usually containing at least a precise waste forecast, specify waste carriers, plan waste destinations, record waste management and recovery, actual waste movements as well as estimated costs arising from its management [6], [7] .Besides, a SWMP will be updated during the course of the project as a live document recording how waste is actually managed and the deviation with the foreseen. .

DEC3. Plan coordination and review meetings about C&D waste

A robust coordination between agents involved in C&D waste management in the building and construction sector is uncommon [8], being its lack in certain countries even a barrier for a successful waste supply chain, and the cause of unnecessary delays and extra cost [9]. However, this measure might be under-valued by stakeholders, as already occurred in a previous questionnaire survey targeting Spanish agents [10].

On the contrary, a smooth coordination, undertaken periodic meetings between design and construction agents, leads to an improved performance of the supply chain.

DEC4. Plan number and size of containers

Planning the number and size of containers needed have been previously studied as a best practice measure for C&D waste management [10]. To do this, the estimated volume of waste, calculated in the pre-deconstruction audit and SWMP prior to commence of the deconstruction works, is a valuable datum, because from it the number and size of skips considering the amount of storage space needed can be planned [11] for an efficient collection frequency. This way GW storage and roundtrips to its final destination are optimized at the same time that recycling and recovery are increased. This entails economic and time savings. This recommendation is usually implicitly covered by DEC2.

Closed-top skips are preferentially recommended for GW storage in order to minimize free moisture.

DEC5. Perform GW traceability, from source to final destination

Tracking waste materials guarantee transparency and quality assurance. Proper traceability of waste involves planning in advance waste carriers and recovery routes, register and keep records of GW

amounts as well as control them. A voluntary initiative, called TRACIMAT vzw, has been found in the Flemish region (Belgium), aiming to help with C&D waste fractions traceability from January 2016 [12]. This recommendation is usually implicitly covered by DEC2.
Close-covered transport trucks should be preferable used in order to minimize free moisture.

DEC6. Appointment of trained workers in gypsum products dismantling, as well as sorting and storing of GW
Deconstruction works require more skilled workers than demolition [13]. Skill improvements in waste handling should be promoted for an efficient source separation and subsequent storage. By way of example, something as simple as placing GW straight into the bins or skips that will be collected by the waste carrier, rather than stockpiling it first and collect it later on, represents noticeable time savings [14], In addition, a quality and satisfactory gypsum products when dismantling is ensured.

DEC7. Appointment of a worker responsible for the follow-up of the waste management
There should be always at least one person in charge of supervising waste management, in order to carry out periodic checks [10], [15]–[17] on the use of GW skips, which involves: covering the waste skips at the end of the day in order to reduce the potential of moisture, removal of impurities if any, and tracking records among others.

DEC8. Perform an on-site segregation of GW
The on-site segregation of C&D materials has been largely studied as a waste management measure [10], [16]–[20], and implies higher quality and the generation of greater amounts of recyclable GW, as it is not contaminated with other waste fractions and therefore the presence of impurities is minimized.
If the waste owner cannot perform this operation (e.g. due to a lack of physical space), a transfer station, where segregation can be applied, should be used.

DEC9. Effective planning of GW capture systems
Effective planning and implementation of GW capture systems (e.g. chute to skip system, hoist and bag system, tower crane to hoist out full gypsum bags, etc.) limits manual handling operations. Successful application of such capture systems depends on peculiarities of each construction site. Thorough consideration of all relevant factors is essential to ascertain the feasibility and ease of application of the considered system [14].

DEC10. Train workers concerning gypsum products dismantling, as well as sorting and storing of GW
The development of C&D waste management awareness is a lengthy process that requires vocational worker's training and education [17]. Periodic training programmes can help in enriching waste management knowledge and providing proper training for different levels of employees. [18]. However, this measure might be under-valued by stakeholders, as already occurred in a previous questionnaire survey targeting Spanish agents [10].

DEC11. Minimize number of roundtrips to recycling
The frequency for containers' *collection* should be planned in advance, ensuring that, whenever possible, only full container load is transported.

REC1. Recycling plant or warehouse strategically located
Distance from the C&D waste source and distance to the receiving manufacturing plants have to be considered for the development of recycling facilities. A suitable route is chosen when the impacts from a social, economic and environmental perspective are taken into consideration (e.g. local ecosystem disturbance, land value degradation, traffic burden, etc.[21].

REC2. Operate a Quality Management System (QMS)
A quality assurance system is an important tool to demonstrate compliance with the RG quality criteria established and to create reliability on the end-of-waste criteria, if existing. For this purpose, an internationally recognized and externally verified QMS, such as ISO 9001 or similar may be operated.
Using the example of the criteria laid down in other industries [22]–[24], a suitable QMS for GW is expected to include:

- Acceptance control of GW: The procedure for identifying impurities (i.e. non-GW, hazardous materials, etc.) shall be documented under the QMS [25].

- Monitoring quality of the RG resulting from the processing operation and record keeping of the results from monitoring.
- Monitoring the treatment processes, techniques and record keeping of the results from monitoring.
- Feedback from costumers concerning compliance with RG quality.
- Review and improvement of the management system.
- Training of staff.

REC3. Set clear waste acceptance criteria (WAC)
Upon reception, the recycler assesses the GW load to ascertain whether it meets the criteria for acceptance or not [26]. In case of rejection, the load can be sent to a transfer station where segregation is applied and afterwards it is forwarded to the recycler. WAC should be communicated to costumers to develop their management system in line with the WAC, at the same time that facilitates the acceptance control of GW.

REC4. Have an adequate warehouse for GW and RG storage
A properly dimensioned storage place should be set up in order to guarantee a constant GW feedstock. In addition, a covered warehouse keeps GW and RG as dry as possible.

REC5. Perform effective sorting and drying operations prior to GW processing
The GW source usually determines the level of impurities. This is the case of pre-consumer GW or post-consumer GW from new construction, which requires less sorting prior to waste storage than post-consumer GW. The presence of impurities in the accepted waste load is typically limited to 2%, however the admissible content is defined by each recycler in their respective WAC. Although recycling units are usually equipped with separation technology, prior sorting is typically required in order to minimize the risk of machine breakdown or avoid lower RG quality. Sorting techniques reported by current gypsum recyclers consist on visual manual sorting performance by skilled operators.
When especially humid loads, they can be mixed with dryer loads to lower it, or keep the load stored for a period of time until it gets dry.

REC6. Prepare a schedule of sampling and test frequencies for each quality criteria parameter
The process of determining monitoring frequencies in accordance with RG quality criteria should be documented as part of the QMS and should be available for auditing. In addition, sampling results should be recorded, kept for the competent authorities and made available on their request. The sampling procedures and calibration methods shall be also made available to auditing [25], [26].

REC7. Agree suitable supply contracts between recyclers and manufacturers
The required information should be obtained, supplied and retained in order to demonstrate, when requested, that RG supplied is destined for appropriate use [26].

MA1. Set clear RG quality criteria
Existing quality criteria for RG are country-specific and even company-specific. Some examples of different quality criteria currently found in the European context can be: the RG initial test for recycling plants, quality management, quality requirements and analysis methods from the German Gypsum Association (BV Gips) in Germany [27], PAS 109:2013 in the UK [26], as well as other commercial specifications developed by gypsum recyclers, plasterboard manufacturers or Eurogypsum Member Associations. It is also worth mentioning the GtoG project, which is now working to reach harmonized voluntary guidelines to establish quality parameters for the RG, covering technical and toxicological criteria.

MA2. Promote plasterboard take-back schemes
Increasingly, countries in Europe and Asia are putting in place “take-back” laws, which require that the manufacturer takes-back the used product at its EoL [28], as recovery and recycling are guaranteed this way. Currently, gypsum products’ take-back is not mandatory, and thus only voluntary take-back schemes exist [29], [30]. These initiatives respond to the construction industry’s need to find an easy to implement alternative to C&D waste landfilling.

MA3. Set a RG reincorporation target
The establishment of corporate objectives on environmental sustainability, particularly addressing RG content, promotes closed-loop gypsum recycling. This target may be part of the manufacturer's corporate social responsibility.

MA4. Address the EoW status
The GtoG project aims at obtaining the EoW status according to article 6 of the WFD, which would mean gypsum waste ceasing to be waste, laying down EoW criteria that provide a high level of environmental protection and an environmental and economic benefit (European Parliament and the Council of the European Union 2008). The removal of the waste status can promote the production of higher quality secondary products by defining technical and environmental minimum requirements to be fulfilled by the materials. In addition, potential users of RG that satisfies a set of EoW criteria should be able to have increased confidence on the quality standards of the material, thus helping to alleviate any user prejudice against material simply because it is derived from waste (Delgado et al. 2009).
EoW criteria for the production and use of RG from plasterboard waste are only a reality in the UK, governed by the Quality Protocol (WRAP and Environment Agency 2013). In addition, PAS 109:2013 sets out the specification for the production of RG (WRAP and BSI 2013).

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