Research Article

Closed-loop Organisational Models for Post-consumer Recycling of Dry-assembled Interiors

Cinzia Maria Luisa Talamo[1], Nazly Atta[1], Michele Laurante[1], Giancarlo Paganin[2]

1. Department of Architecture, Built Environment and Construction Engineering (DABC), Politecnico di Milano, Italy
2. Department of Architecture and Urban Studies (DAsTU), Politecnico di Milano, Italy

Correspondence: cinzia.talamo@polimi.it

Abstract

In Europe, Construction and Demolition Waste (CDW) accounts for 38% of all waste generated (EC, 2020). A significant portion of it relates to dry-assembled interiors (plasterboard partitions, suspended ceiling, raised flooring, etc.). Despite their propensity to closed-loop cycles, these components are often characterised by linear delivery and consumption models.
In recent years, the recycling shares of dry-assembled interiors remained stagnant, particularly for post-consumer waste. This may be due, among various causes, to the lack of a clear definition of stakeholders' roles and responsibilities within recovery chains, issues in capturing recyclables, difficulties in assessing the quality of products to be recycled, regulatory issues, etc.
To overcome these barriers, the paper proposes – as results of ongoing European research at Politecnico di Milano (Italy) – three innovative organisational models for recovering dry-assembled interiors:

- Producer-centric model. Internal recycling, with a short supply chain managed by the manufacturer.
- Reseller-service model. Authorised resellers act as distributed collection points, offering take-back services.
- Third-party recycling model. Decentralised recycling process to increase the manufacturer's recycling capacity.

The models have been applied to a pilot case focusing on plasterboard partitions and tested through the support of CDW recycling stakeholders operating in Italy. Their technical and logistical feasibility has been further discussed.
The proposed models, by outlining new organisational approaches to "high-quality" (EEA, 2024) recycling of post-consumer waste based on a logic of "reverse quality traceability", also promote transparency within the recycling chain, enhancing the quality of Secondary Raw Materials.

Keywords: Circular Economy, Recycling, Construction Sector, Dry-Assembled Interiors, Reverse Quality

Highlights

- Establishing three organisational models based on recycling to achieve a closed-loop approach in the management of tertiary architectures;
- Provide three innovative paradigm shifts towards the attainment of circularity and sustainability objectives in line with recent European policies;
- Establishing responsible schemes to overcome linear models of consumption in fit-out systems.

1 Introduction

The Construction Sector (CS) is a significant contributor to today environmental, economic and social challenges. In Europe, the CS is annually responsible for 35% of greenhouse gas emissions, 35% of waste generated and 50% of all extracted materials (EC, 2020), making it a key priority sector within the European (EU) Green Deal. The resource-intensive nature of the CS affects both domestic and non-domestic building typologies. Non-domestic buildings, including wholesale and retail spaces, offices, and other tertiary typologies, constitute 25% of the total European building stock (BPIE, 2011). These buildings are often subject to frequent interior renewal, repeated maintenance activities, excessive energy consumption, and waste generation, all of which significantly contribute to carbon emissions. Within the built environment, non-domestic building renovation – known as interior fit-out - has the highest turnover of material and component replacement along the life cycle of the building (Casas-Arredondo, Croxford, & Domenech, 2018). This poses a considerable challenge to the overarching objective of resource efficiency and waste minimisation.

In the field of tertiary management, fit-outs refer to types of renovations or refurbishments (Casas-Arredondo, 2021) that involve the removal and disposal of existing interior dry-assembly systems before new ones are reinstalled. These systems include flooring, partitions, doors, furniture, and false ceilings (Cole and Kernan, 1996; Forsythe, 2010; Casas-Arredondo, Croxford, & Domenech, 2018), which typically have a shorter service life than average and follow linear models of production and consumption. The frequent replacement cycle, which ranges from 3 to 10 years (Forsythe and Wilkinson, 2015), has a significant impact on energy use, carbon emissions, and waste throughout the building's lifespan. Among the non-domestic typologies, commercial buildings – including offices and retail – exhibit a higher rate of interior change and customisation (Forsythe, 2017). These commercial spaces are characterised by short lease terms and tenant-driven customisations, which contribute to recurrent cycles of waste generation, environmental impact, and unnecessary procurement costs. Following the end of the lease term, tenants are contractually required to restore the space to its pre-lease condition. Hence, the finishings and furniture are often disposed of to allow the new tenant to configure the space according to its needs. These short lease terms lead to the premature disposal of interior elements that still retain a high percentage of residual performance and an economic value that could be maintained (Forsythe and Wilkinson, 2015; Ahmadian Fard Fini and Forsythe, 2020; Talamo, 2022).

Normally, common systems involved in the fit-out processes offer considerable potential for material recovery, reuse, and recycling. However, the demolition waste arising from fit-out activities typically ends up in landfills (70–80%), with only a small fraction (20–30%) directed toward recycling and reuse practices (Ahmadian Fard Fini and Forsythe, 2020). This is particularly relevant to gypsum-based products, such as plasterboard partitions and false ceilings, which fail to be recovered and recycled despite their propensity. Gypsum board, also known as plasterboard or drywall, is a manufactured building product used in dry-assembled interiors such as walls and ceilings. It consists of a gypsum core sandwiched between facing paper sheets. Because of its combination of technical properties (e.g., fire resistance, sound insulation, and thermal efficiency) and functional advantages (ease of installation and cost-effectiveness), gypsum board is largely used in the CS, particularly in renovation projects. Nonetheless, its recyclability remains one of the critical topics in the circular economy debate.

The gypsum industry accounts in Europe for 1% of all Construction and Demolition Waste (CDW) (Bumanis, Zorica, Korjakins, & Bajare, 2022). The primary sources of gypsum waste are (1) manufacturing processes (referred to as pre-consumer waste), (2) construction and (3) renovation debris (known as post-consumer waste). Post-consumer gypsum waste represents a small percentage of the total C&D waste. Yet, its disposal faces challenges related to waste contamination, landfill gas emissions, and hydrogen sulphide release (Jiménez-Rivero & García-Navarro, 2017). Despite the full recyclability of gypsum products and the availability of recycling technologies, a significant amount ends up in landfills. This is mainly due to building demolition practices that, unlike dismantling, combine recovered gypsum with other material waste streams. In addition, the lack of a clear definition of stakeholders' roles and responsibilities within recovery chains, issues in capturing recyclables, and difficulties in assessing the quality of products to be recycled fail to support the potential for closed-loop recycling.

In CDW management, a closed-loop approach seeks to transform process waste into resource input for other processes (Brennan, Ding, Wonschik, & Vessalas, 2014). In contrast to a linear "take-make-waste" model of consumption, closed-loop recycling relies on the collective involvement of all stakeholders across the entire value chain, from dismantling, separation and collection, through process recycling and reintegration of the recycled material into the manufacturing process (Fig.1).

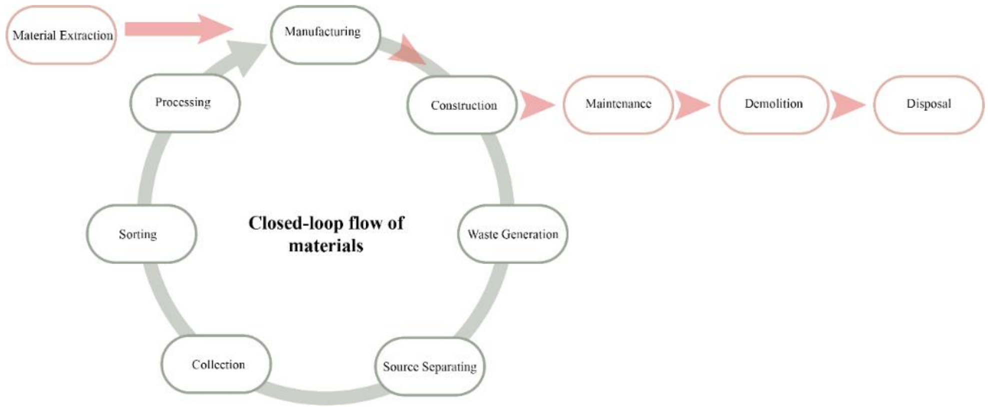

Figure 1. Comparison between linear and closed-loop models of CDW waste. Adapted from: Brennan, Ding, Wonschik, & Vessalas, 2014.

Currently, it is estimated that only 6% of post-consumer gypsum waste is recycled (Jiménez Rivero, Sathre, & García Navarro, 2016). Only a few European countries, including Denmark, Belgium, Finland, Sweden, and the Netherlands, have already established gypsum recycling programmes. Nonetheless, with the strengthening of EU regulations – particularly the Waste Framework Directive (WFD) – European member states will be required to raise the recovery rate of non-hazardous CDW to at least 70% by weight (EC, 2008). As a result, the recycling rate of gypsum waste is projected to increase. From this perspective, however, increasing the quantity of recycled material within building products should not be the only strategy, as the structure needed for effective recycling remains largely underdeveloped. While current studies have primarily focused on technologies, processes and barriers to gypsum recycling, limited attention has been paid to the coordination of actors necessary to enable high-quality closed-loop recycling pathways.

To address this gap, the paper – as part of ongoing European research (Horizon funding programme) carried out at the Department of Architecture, Built Environment and Construction Engineering (DABC) of Politecnico di Milano – investigates the organisational and logistical conditions necessary to activate closed-loop recycling chains. Through interviews and roundtable discussions with key industry stakeholders, including producers, recyclers, and waste managers, the study identifies the organisational conditions necessary for improving high-quality material recovery. By mapping current practices and barriers in closed-loop recycling, the paper proposes and develops practical models for enhancing circularity in gypsum-based products in line with recent approaches to high-quality recycling (EEA, 2024).

2 Methodology

The present research adopts an iterative and qualitative approach that systematically investigates existing and innovative closed-loop organisational models for recycling dry-assembled interiors, particularly in gypsum-based products. The methodology is based on the following steps:

1. Map the key stakeholders involved in the post-consumer gypsum recovery chain;
2. Outline existing and innovative organisational models for closed-loop recycling;
3. Refine and validate the proposed models within the Italian gypsum recycling context.

The involvement of stakeholders is operationalised through semi-structured interviews, roundtable discussions and focus groups, organised according to the roles covered in the recycling chain. A total of ten stakeholders were interviewed, contributing to the development and validation activities of the organisational model, including gypsum board producers, certified recycling companies, resellers and demolition contractors. The chosen stakeholders have been selected according to three main criteria:

- Active involvement in post-consumer recycling initiatives in Italy
- Direct operational role in at least one phase of the recovery chain (e.g., dismantling, logistics, sorting, processing, or reintegration)
- Demonstrated interest or experience in circular business models or material recovery initiatives

Preliminary roundtable discussions were held to clarify roles, practices, challenges, and interrelationships within the existing gypsum waste management chain. These were followed by focus group sessions aimed at developing and refining the organisational models with detailed attention to stakeholder roles, material flow, responsibilities, and coordination processes. Relevance has been attributed to on-site visits to internal and external recycling facilities to gain a direct understanding of the involved operational processes.

As a result, some paradigm shifts emerged which led to the definition of three organisational closed-loop models, namely: Producer-centric, Reseller-service and Third-party recycling.

Each model reflects a configuration discussed and validated by stakeholders and is defined by the central actor responsible for coordinating the recycling process. All the models were formalised using system mapping techniques, aimed at visualising material flows, decision points, and actor responsibilities within the recycling process. Following this, the models were submitted for validation by all stakeholder groups through additional follow-up sessions to ensure accuracy in reflecting present constraints and possible prospects.

2.1 Closed-Loop Recycling: proposal of innovative organisational modelsNew Paradigm Shifts

From the active dialogue with key sector stakeholders on possible strategies to overcome the organisational barriers described in Section 1 – including fragmented supply chains, short-term decision-making, and limited accountability in post-consumer recycling – the following "paradigm shifts" emerged:

1. From "Consumer" to "Extended Producer" responsibility;
2. From "Localised" to "Decentralised" waste collection;
3. From "Traditional" to "Service-based" recycling;

These paradigm shifts set the ground for the development of innovative organisational models (Section 3.2), supporting the recovery of post-consumer gypsum products characterised by a high residual value and a robust propensity to be recycled.**Paradigm Shift 1 – From Consumer to Extended Producer Responsibility**

The first paradigm shift is grounded on the principle of Extended Producer Responsibility (EPR). EPR represents a major policy approach, which attributes both organisational and financial responsibility to producers for the complete lifecycle management of their products (OECD, 2024), including end-of-life collection and recycling. At the European level, EPR is embedded within the Waste Framework Directive and implemented through specific directives targeting precise waste streams. These include the Waste Electrical and Electronic Equipment (WEEE) Directive, the End-of-Life Vehicles (ELV) Directive, the Batteries and Accumulators Directive, and, more recently, the Packaging Waste Regulation (Mallick, Salling, Pigosso, & McAloone, 2024).

Although construction products are not subject to a dedicated EPR directive, producers are encouraged to design products and systems that facilitate recovery, reuse, and recycling, shifting the end-of-life responsibility upstream in the supply chain (OECD, 2016). This change results in new reverse supply chain configurations, characterised by a reverse mobility flow of waste from construction sites to internal or external recycling facilities, that limit forms of downcycling (e.g. backfilling, energy recovery) while increasing recovery rates and transparency.

Equally central to achieving transparency and high-quality recycling in EPR schemes is the implementation of information support tools such as Digital Product Passports (DPPs) and Digital Building Logbooks (DBLs). These tools act as common information repositories, enabling clear traceability of products, components, and materials (BPIE, 2024) throughout the end-of-life phase. The integration of traceability tools within recycling processes and reverse logistics practices operationalises the concept of reverse quality traceability. This new paradigm supports material recovery standards by ensuring that crucial information about product composition and condition remains accessible during the post-use life. By preserving detailed product information throughout reverse logistics processes, stakeholders can pursue higher-value recycling practices that limit forms of low-grade recovery and contribute to achieving circular economy objectives. Reverse quality traceability consequently emerges as a critical driver for CDW management and the overall efficacy of Extended Producer Responsibility schemes.

2.2.2 Paradigm Shift 2 – From Localised to Decentralised Waste Collection

A second complementary paradigm shift involves the transition from a centralised waste facility to a decentralised network of waste collection points. Normally, recycling is performed in large, centralised venues, which collect and recycle the income CDW, to transform it into secondary raw material. Centralised waste facilities are commonly dispersed throughout the territory, converging incoming waste from short to long transportation hauls. Although well-established, centralised recycling facilities can be frequently located far away from the building site, resulting in long distances to be covered and incessant trips to move large volumes of waste. This latter aspect is further intensified when considering the movement of secondary raw materials to different markets for product reintegration. As a result, there is a chance that the positive outcomes of recycling practices could be outweighed by the negative environmental and economic impact of long transportation distances (Alarcon-Gerbier, Linß, & Buscher, 2023). To face this issue, a possible solution involves the introduction of decentralised temporary hubs for collecting CDW before recycling.

According to Italian waste management legislation – specifically Legislative Decree 116/2020 – temporary collection hubs for CDW are formally recognised in two contexts:

a) at the site where the waste is generated;

b) within the areas associated with points of sale – known as resellers – for the corresponding building products.

The latter scenario identifies the professional figure of the reseller as having a dual role: (1) as suppliers of building products and (2) as temporary collectors of construction and demolition waste. Given the widespread presence of resellers supplying building products to clients and construction sites, these entities are strategically positioned to act as potential temporary hubs for collecting and storing CDW. The identification of the reseller as a decentralised waste collector opens different opportunities. Firstly, it improves logistical efficiency. The collection of waste closer to the generation site leads to shorter transportation distances, fewer transport trips, and a reduction in carbon emissions. Secondly, the specialised knowledge that resellers possess regarding building materials facilitates more effective sorting and preliminary processing of CDW. This contributes to an improvement in the quality of recyclable materials, along with a reduction of both operational costs and processing times. Finally, the involvement of resellers in the collection phase can increase the local circular economy. Indeed, due to the proximity to both waste sources and potential recycling facilities, resellers can stimulate regional recycling markets towards the adoption of improved circular economy practices.

2.2.3 Paradigm Shift 3 – From Traditional to Service-Based recycling

Building on the foundations presented in the previous two subsections, the last paradigm focuses on the shift from traditional to service-based recycling. This approach closely relates to the concept of servitization (Vandermerwe and Rada, 1988), which involves integrating services into product offerings to generate new value (Stabler, Hakala, Huikkola, & Mention, 2024). Within the recycling sector – particularly in construction and demolition waste (CDW) – servitization is achieved in the provision of specialised recycling services suited to client needs. From this perspective, rather than treating waste management as a mere disposal activity, service-based recycling integrates collection, handling, sorting, pre-processing, and logistics into one single service.

To ensure this, a key aspect of this service-based model lies in the role of the environmental manager. These authorised actors assume responsibility for the collection, transportation and sorting of CDW, acting as strategic intermediaries between construction sites and recycling facilities. Unlike conventional models, where waste management tasks tend to be scattered, environmental managers offer a specialised service that consolidates the whole recycling chain.

This approach can lead to several advantages, such as: (i) improved operational efficiency by end-to-end, integrated management of waste streams, that minimises logistic burden; (ii) enhanced material quality and regulatory compliance through specialised sorting, pre-treatment that enable high-value recycling; (iii) delivery of client-focused, value-added waste management solutions.

By including "servitization" approaches into CDW recycling, this paradigm shift supports the development of new circular business models in the CS, where recycling is no longer a mere downstream activity, but an integrated service offering within the life cycle of building products.

2.3 New organisational models for Closed-Loop Recycling

Building on the three paradigm shifts outlined in Section 3.1, this paragraph introduces three organisational models for managing closed-loop recycling. The proposed innovative models aim to extend the residual technical life of post-consumer gypsum components by facilitating recovery, processing, and reintegration into manufacturing cycles. By defining coordinated stakeholder roles, the models establish new circular options for managing end-of-life treatments in fit-out system waste.

Each model is characterised by a specific actor responsible for managing key activities along the recycling chain, hence reflecting its structure and denomination.

- Producer-centric model. The gypsum board producer is the main coordinator, managing recovery logistics and material reprocessing;
- Reseller-service model. Resellers oversee collection and recovery coordination, acting as intermediary hubs of collection and distribution to the end recycler;
- Third-party recycling model. Independent recycling companies manage sorting and recycling, providing recycled feedstock to producers or the open market.

Although the applicability of the models was primarily assessed on gypsum-based products, their application can be extended to other dry-assembled interior systems used in commercial fit-outs. These systems may also include modular flooring systems and certain types of resilient wall and floor coverings.

The preliminary development of the models was informed by a review of the literature on closed-loop recycling, current policy and regulatory initiatives, as well as best practices in the construction sector. Following a preliminary outline, the models were further developed through active engagement with the involved stakeholders (e.g. gypsum board producers, certified recycling companies, resellers and demolition contractors), including focus groups and roundtable discussions. The aim was to gather feedback and validate their feasibility in effectively closing the loop.

2.3.1 Model 1 - The Producer-Centric Model

The first model, named "producer-centric," involves the role of the producer in managing the collection, storage and recycling of the gypsum-based waste generated during the construction phase. After supply and installation, significant on-site waste is commonly generated due to material cutting, re-fitting, and over-ordering. Normally, this waste would be sent to landfill despite its potential for recyclability and recovery, consequently representing a lost opportunity for circular resource management.

To address this, the model restructures logistics and organisational roles by placing responsibility on the original producer (Fig. 2). Following the concept of EPR, the producer oversees the whole recycling post-consumer chain: from collection to reprocessing. Through an established agreement with the construction client, outlining the specifics of post-consumer waste collection, the producer supplies recycling containers to enable on-site collection and segregation of various waste streams. The containers for collection are organised following the European Waste Code (EWC) catalogue (EC, 2000), which identifies and categorises waste types according to a six-digit code divided into three pairs that respectively identify (1) waste sector, (2) material group and (3) exact waste type. For instance, gypsum-based products (not containing hazardous substances) are classified under the code 170802 (EC, 2000).

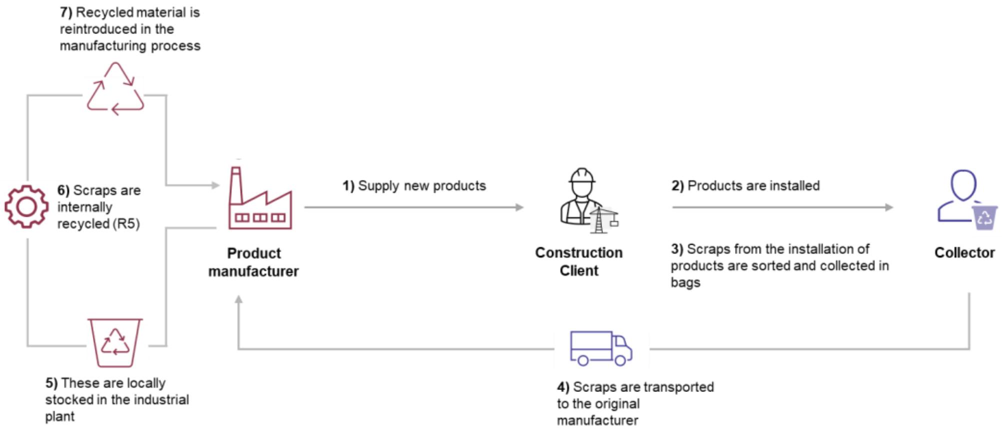

Figure 2. Producer Centric Model. Authors' elaboration

This process – referred to as waste characterisation – involves identifying all the features of the waste, including type, origin, composition, consistency, and properties relevant to the producer before recycling. Within this context, during demolition activities, the construction client holds responsibility for ensuring a proper segregation of waste materials on site. To support this, the producer provides an analytical protocol outlining the required steps, which include: (i) provide fundamental information about the waste (type and origin, composition, consistency and other characteristics); (ii) provide information on the EWC code assigned; (iii) verify that the waste is not classified as hazardous waste. Following this, the segregated gypsum scraps are returned to the original producer for recycling. Notably, the original producer may collect both waste from their products and waste from other manufacturers. The latter depends on the availability of two factors: (1) commercial agreements with clients authorising the recovery of gypsum scraps waste and (2) the capacity of recycling facilities to reprocess "external" waste.

Upon receiving the material, the producer verifies that the conferred gypsum waste complies with quality and contamination standards before introducing it to the recycling process. In particular, the waste is subject to a rigorous document review, including a waste technical sheet, chemical analysis and waste registration. Following this, a visual inspection is conducted to confirm that the income waste is consistent with the documentation and meets the necessary standards for mechanical reprocessing. Chemical sample testing may be performed externally to verify the conformity of the waste. Following the quality inspection, the waste is sent for internal recycling.

The recycling of gypsum-based products involves the crushing, separation, and purification of the gypsum core from the facing paper sheets. Once separated, the recovered gypsum is reintroduced into the manufacturing process as secondary raw material, hence increasing the level of recycled content in new gypsum-based products. The separated paper fraction, instead, is typically sent to external paper mill companies for processing waste into secondary raw material.

The success of this model depends on a variety of factors, including the producer's capacity to establish and manage a closed-loop recycling process, the availability of established logistics, and the presence of well-organised supply chains with dedicated actors – authorised environmental managers – responsible for collection, transportation, and delivery of waste back to production facilities. Consequently, its application is predominantly suited to large producers possessing the necessary resources, technical expertise, and network capabilities to implement closed-loop recycling processes. Additionally, these producers require a robust supply chain network composed of actors capable of managing the collection, transportation, and delivery of waste materials to the production facility.

2.3.2 Model 2 - The Reseller Service Model

The second model, referred to as the "reseller-service" model, involves the dual role of the reseller both as a supplier of building products and as an authorised collector of post-consumer waste. This model is particularly supported by the Italian Legislative Decree 116/2020, which, through the addition of Article 185-bis to the existing waste management legislation, explicitly allows resellers to temporarily store CDW materials at their points of sale before collection and transport to recycling facilities.

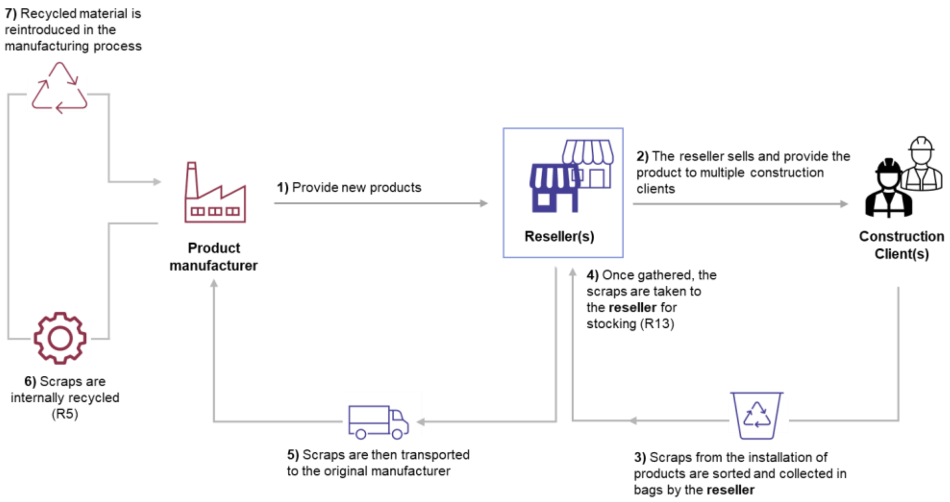

Figure 3. Reseller Service Model. Authors' elaboration

In contrast to the producer-centric model, where the original producer oversees on-site waste recycling, the reseller-service model expands the waste collection capacity by involving a network of authorised resellers (Fig. 3). Here, the reseller is responsible for collecting, transporting, and temporarily stocking different material waste streams sourced from one or more construction sites. In doing so, resellers act as intermediary collection hubs. This decentralisation guarantees a distributed network of collection points which, on one hand, improves accessibility for construction clients, and on the other, it increases the volume and the quality of the collected waste.

Following separation, in line with the European Waste Code (EWC) catalogue, the consolidated gypsum waste is subsequently transported from reseller facilities to the original manufacturer. Afterwards, the producer must then verify quality and contamination standards before internally reprocessing the material to produce new gypsum products.

The introduction of temporary resellers presents a novelty within CDW management. These collection points – although not constituting a mandatory element within the waste recovery chain – can streamline the "waste-processing plant-consumer" path (Manukhina & Ivanova, 2017) contributing to the achievement of: (i) reduction of logistical burden on producers; (ii) improvement of collection efficiency; (iii) better segregation of waste streams at an earlier stage; (iv) provision of localised points for quality control.

It is important to mention that the application of this model becomes necessary in contexts where transportation distances between construction sites and centralised recycling facilities are significant. In such cases, decentralised collection hubs highly contribute to minimising the environmental and economic impact of long-haul waste transportation by aggregating and pre-checking waste to its recycling facility source.

2.3.3 Model 3 - The Third-party recycling model

The third-party recycling model involves outsourcing the recycling process of gypsum waste to specialised external facilities. This model differs from the previous ones in terms of the recycling actor involved in the process. Indeed, following the collection of scraps from the building site, an external collector or third-party recycling centre is identified to recycle the waste material (Fig. 4). Once treated, the recycled gypsum material – as secondary raw material – is either returned to the original manufacturer for reprocessing or commercialised. This model offers great market flexibility. Indeed, the recycled material can be sold by the external recycling facility to multiple producers, who in turn can reintegrate it into their production lines, thus expanding the potential beneficiaries of gypsum recycling.

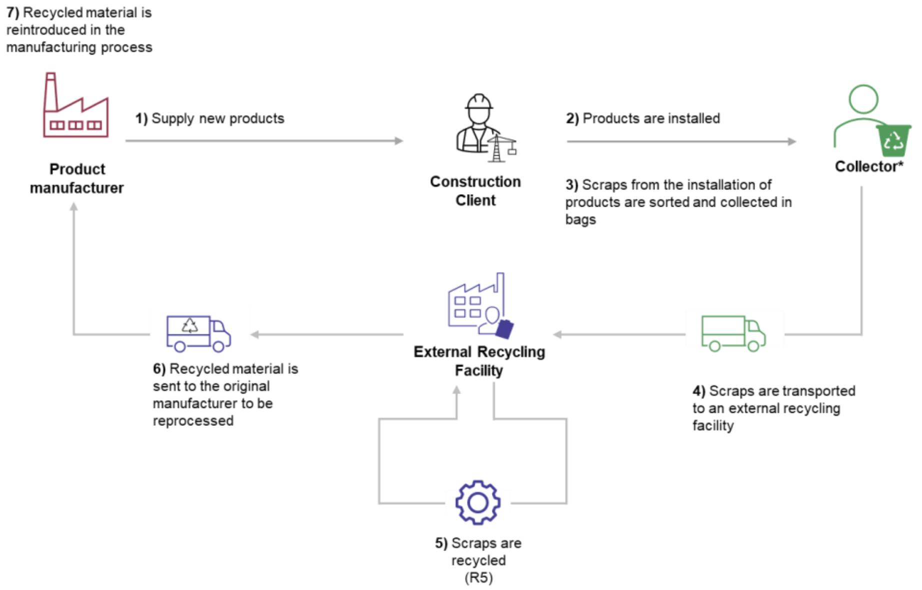

Figure 4. Third-Party Recycling Model. Authors' elaboration

The key advantages of this model can be summarised as follows:

- third-party recyclers can handle a wider variety of waste from multiple sources;
- managing the recycling process enables delivery of high-quality service, supported by skilled personnel with specialised expertise;
- It fosters the development of a structured and strategic approach to gypsum waste recovery by defining the roles and responsibilities of external recycling operators.

In addition, the third-party recycling model enhances the overall volume and quality of material recovery while removing much of the logistical and operational pressure traditionally placed on producers. This relieves producers of directly managing waste collection and preliminary processing, allowing them to focus on product manufacturing.

3 Discussion and Conclusion

The proposed three models were then applied for validation purposes, thanks to the active involvement of key sector stakeholders.

The following considerations emerged from the application of the three organisational models:

- The establishment of a collaborative "supply network" represents a precondition for the feasibility of the implementation of the proposed organisational models.
- The quantities of post-use products to be collected are often uncertain in terms of volume, timing, location, and state of conservation, and often they come in small batches. This can negatively affect the feasibility of virtuous recycling practices, hindering the implementation of the proposed organisational models. However, the issue related to the geographical localisation of the small batches of post-use products is overcome in the proposed organisational model 2

"The Reseller Service Model". Indeed, according to Model 2, resellers become the "linking nodes" of a wide network of actors – sources of post-use products – spread across the territory able to act synergistically for collection and transport activities.

- The economic and environmental impact of the "collection-transport-treatment" process is a function of the distance between the collection point and the treatment site in Models 1 and 3, that can only act at a local level with quantities of post-use products that can risk to not reach the critical mass needed to activate economically viable circular processes.
- Conversely, Model 2 allows an expansion of the geographic scope since the resellers can be widely distributed across the territory. This increases the possibility of intercepting small batches and thereby raises the total quantity of post-use products available for recycling (Fig. 5).

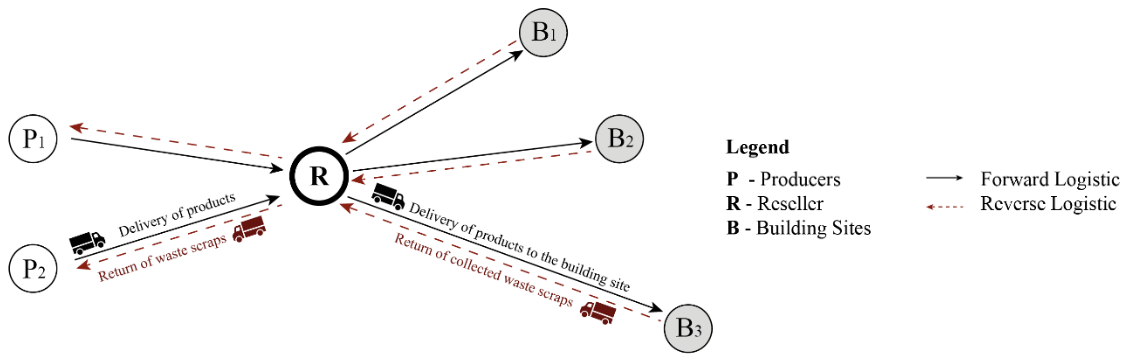

Figure 5. Dual logistic role of the reseller. Authors' elaboration

- Moreover, it is possible to highlight that in Model 2 – under organised logistic conditions – the environmental and economic impact of transport of post-use products is minimised downstream by exploiting the transfer with the empty truck performed by the construction company from the construction site to the reseller site for the procurement of products for the construction. Upstream, the transportation of post-use products from the reseller site to the treatment site is performed by the manufacturer with the truck that supplied new material to the reseller and would have come back empty to the treatment site.
- Regardless of the model, information support tools such as Digital Product Passports (DPPs) and e-marketplace platforms are fundamental for streamlining the implementation of the circular processes promoted by the proposed organisational models. These tools already exist at both the Italian (e.g. Circularity, etc.) and European (e.g. Opalis, Madaster, etc.) levels.
- Producer actions to inform and promote awareness within downstream stakeholders on the modalities of disassembly and collection of post-use products in the worksite can contribute to enhance the overall quality of the material in input to the recycling processes.
- In all the proposed organisational models, the roles of the traditional stakeholders are valorised. The downstream actors acquire new functions and, consequently, new profiles of competences can enrich the overall supply chain.
- New professional figures can arise acting as facilitators (consultants) with different roles, for example, carrying out activities as resource mapping, pre-demolition audit, selective demolition, sorting of scraps, permits and certifications, etc.

Concluding, the proposed organisational models can support the shift from linear to circular processes in the management of post-use dry-assembled products, contributing to the achievement of sustainability and circularity objectives set by EU for the design and management of tertiary buildings. These models promote the creation of a "networked" recycling supply chain, based on collaborative partnerships that overcome the fragmentation of traditional organisational structures and open up opportunities for win-win collaboration among different stakeholders (including manufacturers, artisans, resellers, construction companies, etc.), identifying new synergies necessary to establish the business preconditions needed to implement circular processes in tertiary building practices.

Acknowledgements

This work was carried out in the framework of the European Horizon RE-SKIN Project, Grant agreement ID: 101079957

Conflicts of Interest

The authors declare no conflict of interest.

4 References

Ahmadian Fard Fini, A., & Forsythe, P. (2020). Barriers to reusing and recycling office fit-out: An exploratory analysis of demolition processes and product features. Construction Economics and Building, 20(4). https://doi.org/10.5130/AJCEB.v20i4.7061

Alarcon-Gerbier, E., Linß, F., & Buscher, U. (2023). Waste recycling through a decentralized network of mobile facilities. Journal of Cleaner Production, 415, 137773. https://doi.org/10.1016/j.jclepro.2023.137773

Brennan, J., Ding, G., Wonschik, C.-R., & Vessalas, K. (2014). A Closed-Loop System of Construction and Demolition Waste Recycling. Proceedings of the International Symposium on Automation and Robotics in Construction (IAARC). Presented at the 31st International Symposium on Automation and Robotics in Construction, Sydney, Australia. Sydney, Australia: International Association for Automation and Robotics in Construction (IAARC). https://doi.org/10.22260/isarc2014/0066

Buildings Performance Institute of Europe (BPIE). (2011, October). Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings. Buildings Performance Institute of Europe (BPIE).

Buildings Performance Institute Europe (BPIE). (2024, June). Extended producer responsibility in the construction sector: Exploring the potential. Buildings Performance Institute Europe (BPIE). https://www.bpie.eu/publication/extended-producerresponsibility-in-the-construction-sector/

Bumanis, G., Zorica, J., Korjakins, A., & Bajare, D. (2022). Processing of Gypsum Construction and Demolition Waste and Properties of Secondary Gypsum Binder. Recycling, 7(3), 30. https://doi.org/10.3390/recycling7030030

Casas-Arredondo, M., Croxford, B., & Domenech, T. (2018). Material and decision flows in non-domestic building fit-outs. Journal of Cleaner Production, 204, 916–925. https://doi.org/10.1016/j.jclepro.2018.08.328

Casas-Arredondo, M. (2021). Circular economy and office fit-out: An analysis for office fit-out processes based on material flows (Doctoral thesis, University College London). University College London.

Cole, R. J., & Kernan, P. C. (1996). Life-cycle energy use in office buildings. Building and Environment, 31(4), 307–317. https://doi.org/10.1016/0360-1323(96)00017-0

EC - European Commission. (2000). Commission Decision 2000/532/EC of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste. Official Journal of the European Communities, L 226, 3–24. Retrieved from https://eur-lex.europa.eu/eli/dec/2000/532/2015-06-01/eng

EC - European Commission. (2020). A new Circular Economy Action Plan for a cleaner and more competitive Europe – Final (COM (2020) 98 final). Brussels: European Commission.

EC - European Parliament and Council. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Waste Framework Directive). Official Journal of the European Union, L 312, 3–30.

EEA- European Environment Agency. (2024). Measuring the quality of recycling. LU: Publications Office. Retrieved from https://data.europa.eu/doi/10.2800/9302034

Forsythe, P., & Wilkinson, S. (2015). Measuring office fit-out changes to determine recurring embodied energy in building life cycle assessment. Facilities, 33(3/4), 262–274. https://doi.org/10.1108/F-08-2013-0065

Forsythe, P. J. (2010). Office buildings – The importance of "make-good" fitout and recurring embodied energy. In Proceedings of the CIB SB10 Conference (25–28 May, Wellington, New Zealand).

Forsythe, P. (2017). Quantifying the recurring nature of fitout to assist LCA studies in office buildings. International Journal of Building Pathology and Adaptation, 35(3), 233–246.

Legislative Decree No. 116 of 3 September 2020. Implementation of Directive (EU) 2018/851 amending Directive 2008/98/EC on waste and Directive (EU) 2018/852 amending Directive 94/62/EC on packaging and packaging waste. Official Gazette of the Italian Republic, General Series, No. 226, 11 September 2020. https://www.gazzettaufficiale.it/eli/id/2020/09/11/20G00135/sg

Jiménez-Rivero, A., & García-Navarro, J. (2017). Exploring factors influencing post-consumer gypsum recycling and landfilling in the European Union. Resources, Conservation and Recycling, 116, 116–123. https://doi.org/10.1016/j.resconrec.2016.09.014

Jiménez Rivero, A., Sathre, R., & García Navarro, J. (2016). Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union. Resources, Conservation and Recycling, 108, 171–181. https://doi.org/10.1016/j.resconrec.2016.01.014

Mallick, P. K., Salling, K. B., Pigosso, D. C. A., & McAloone, T. C. (2024). Designing and operationalising extended producer responsibility under the EU Green Deal. Environmental Challenges, 16, 100977. https://doi.org/10.1016/j.envc.2024.100977

Manukhina, L., & Ivanova, I. (2017). Management of construction and demolition wastes as secondary building resources. IOP Conference Series: Earth and Environmental Science, 90, 012166. https://doi.org/10.1088/1755-1315/90/1/012166

OECD. (2016). Extended producer responsibility: Updated guidance for efficient waste management. Paris: OECD Publishing. https://doi.org/10.1787/9789264256385-en

OECD. (2024). Extended producer responsibility: Basic facts and key principles (OECD Environment Policy Papers, No. 41). Paris: OECD Publishing. https://doi.org/10.1787/67587b0b-en

Stabler, D., Hakala, H., Huikkola, T., & Mention, A.-L. (2024). Aligning servitization and circularity: The role of institutional confluence in sustainable business models. Journal of Cleaner Production, 462, 142666. https://doi.org/10.1016/j.jclepro.2024.142666

Talamo, C. (2022). Re-NetTA. Re-manufacturing networks for tertiary architectures. Milan: FrancoAngeli. ISBN: 9788835142232

Vandermerwe, S., & Rada, J. (1988). Servitization of business: Adding value by adding services. European Management Journal, 6(4), 314–324. https://doi.org/10.1016/0263-2373(88)90033-3