VTT Technical Research Centre of Finland

Recyclability and reusability of key waste streams

Bergmans, Jef; Hradil, Petr; Siáková, Alena; Struková, Zuzana; Junák, Jozef; Li, Jiabin

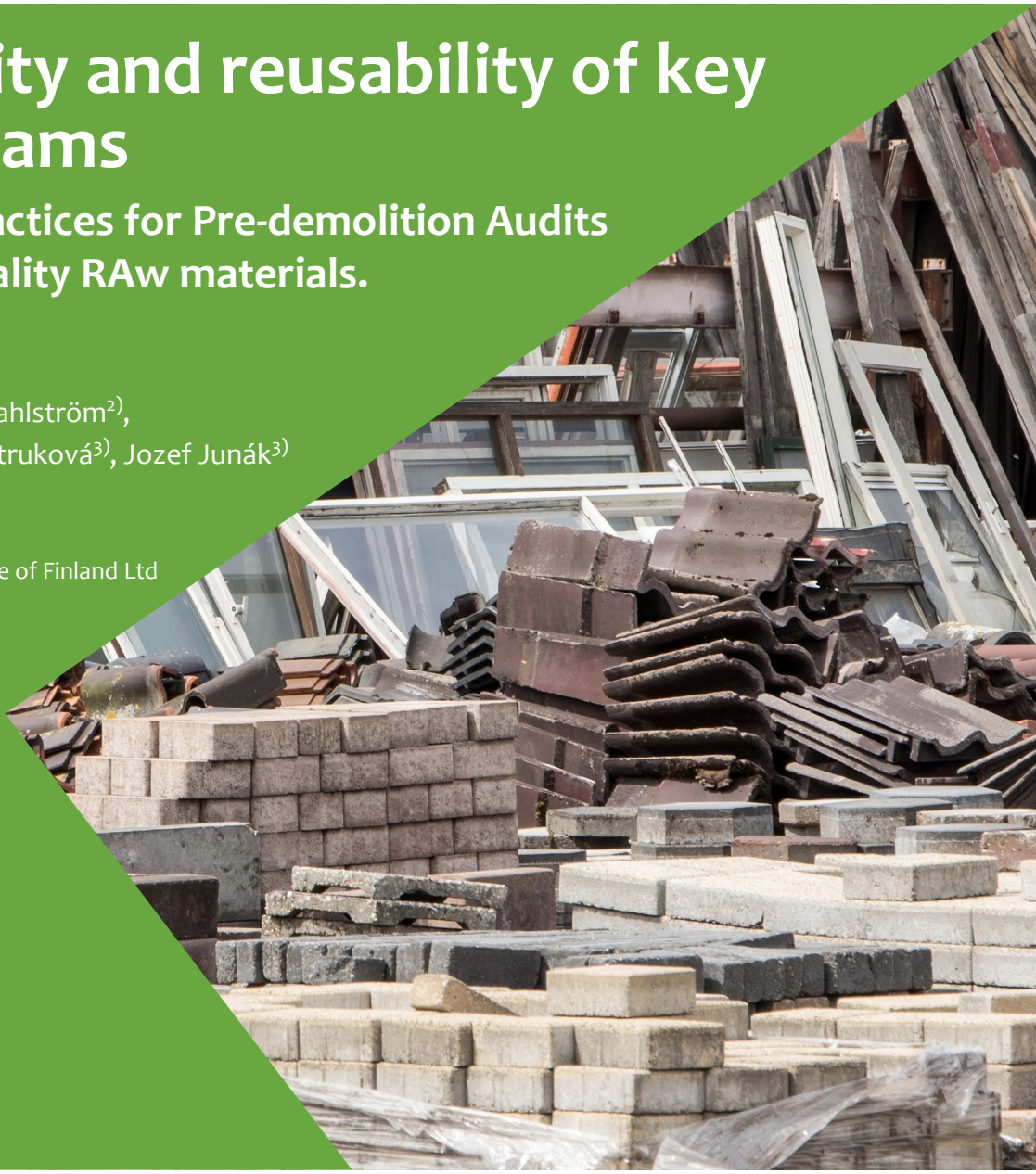
Published: 31/12/2019

Document Version
Publisher's final version

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Recyclability and reusability of key waste streams

PARADE. Best practices for Pre-demolition Audits ensuring high quality RAw materials.



Jef Bergmans[1],
Petr Hradil[2], Margareta Wahlström[2],
Alena Sičáková[3], Zuzana Struková[3], Jozef Junák[3]
Jiabin Li[4]

1) VITO, Belgium
2) VTT Technical Research Centre of Finland Ltd
3) TU of Košice, Slovakia
4) KU Leuven, Belgium

Version December 2019

Content

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

EIT RawMaterials is supported by the EIT, a body of the European Union

1. Introduction

This guidance document aims to inform on the possibilities and requirements related to recycling and reuse of the major waste streams from demolition activities, thus promoting the selection of optimal solutions for recycling and reuse.

The document focuses on the following:

- Non-hazardous materials. The document does not describe decontamination or disposal options for hazardous substances. For the report on hazardous substances: M3.4
- Reuse and recycling options that do not require intensive sorting. Since this project develops materials on best practices for pre-demolition waste audits with the aim of performing selective demolition (sorting at the source), this document focuses on recycling options that only require limited sorting steps (e.g. magnetic separation) of the material fractions after selective demolition.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

2. Reuse of building components

Some building components, usually consisting of different material types, can be reused as such or repurposed. The value of these reusable building components increases in case of: 1) antiquity, 2) authenticity/scarcity, 3) high aesthetics (e.g. decorated mantelpieces), 4) a good condition and quality of the materials (e.g. massive wood), 5) components that are sold in series or assembly kits. The commonly reused architectural components are windows and doors. For windows, double glazing increases the value significantly. Most doors are very quick to remove and store, but it is important to check possible fire resistance criteria. The building structure can also be often disassembled into valuable components such as bricks and blocks, timber or steel beams and panels. Single-materials components will be discussed in the specific chapter of the material.

Figure 1. Doors for reuse[1].

[1] https://opalis.be/nl/handelaars/stef-antiek

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Good practices and inspiring cases

- Rotor Deconstruction, Deconstruction and consulting service for components reuse[2].
- SalvoWeb, network of UK reclamation yards[3].
- Purkutori, a Finnish salvage market[4].
- Harvest Map, a Dutch market place for reuse[5].
- The use of more than 3000 restored wooden window frames in the façade of the Europa Building (Figure 2), Belgium.
- Period Projects, specialised in reuse (e.g. a large collection of internal and external doors)[6], UK.
- Haly-Sklady, Czech consult specialized in reuse of whole buildings[7]
- Harvest Map, a Dutch market place for reuse[8].

Figure 2. Façade of reused window frames in the Europa building, Brussels[9].

[2] https://rotordc.com/
[3] https://www.salvoweb.com/
[4] http://www.purkutori.fi/
[5] https://harvestmap.org/
[6] https://periodprojects.co.uk/
[7] http://www.haly-sklady.cz/
[8] https://harvestmap.org/
[9] http://www.designcurial.com/news/europa-building-in-brussels-by-philippe-samyn-5782988

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

3. Stony fraction

The stony fraction of C&DW exists mainly of concrete, masonry (e.g. fired clay bricks), tiles and natural stones. Asphalt is also a stony material. In this chapter, tar-containing asphalt (an hazardous substance) will be excluded. Tar-containing asphalt can be easily detected by a PAH marker spray. Stony materials are used in several construction applications: e.g. foundations, bearing structures, partitioning walls, roof tiles, flooring.

Figure 3. Stony fraction of C&DW. Concrete fraction (front), mixed stony fraction (back)[10].

3.1. Reuse

Several stony elements can be reused. The value of reusable stony materials increases in case of: 1) antiquity (e.g. hand-moulded bricks), 2) value of the primary material (e.g. marble), 3) high aesthetics (e.g. decorated mantelpieces), 4) a good condition of the materials, 5) scarcity (e.g. materials of which the production stopped). Modular and easily dismantlable materials (e.g. slates or roof tiles) are interesting for reuse.

[10]HISER project. Demolition case study: business-as-usual in Flanders.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Examples of suitable materials

- Cobblestones (e.g. porphyry)
- Curb stones
- Clay pavers
- Fired clay bricks (Figure 4)
- Roofing slates
- Hand-made roofing tiles
- Architectural antiques

Figure 4. Fired clay bricks for reuse[11].

Good practices and inspiring cases

- The REBRICK project of Gamle Mursten [12], Denmark. Old bricks are cleaned, sorted manually, stacked by robots and sold for new building and renovation projects.
- Vandemoortel[13], specialised in reused materials (bricks, tiles, flooring), Belgium
- J. Visser [14], collection, cleaning, sorting and reuse of cobblestones and pavers, The Netherlands.

[11] www.opalis.be
[12] http://www.gamlemursten.eu/
[13] http://www.vandemoortel.com/en/Materials/
[14] http://www.jvisser.nl/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Figure 5. Use of reused bricks from Gamle Mursten in a modern villa, Denmark[15].

- Reuse of neo-Romanesque window elements from natural stone in Klostergarten Lehel[16], Germany
- Reuse of façade bricks in the townhall of Lo-Reninge[17], Belgium
- Reuse of Welsh slates in a passive long house[18], UK
- Restoration of the Sala Beckett theatre[19], Spain
- Reuse of granite floors and walls of the Montagne du Parc building[20], Belgium

3.2. Open-loop recycling

The stony fraction of C&DW can be processed to aggregate and sand fractions. For pure stony fractions, a crushing and sieving process is sufficient to produce qualitative aggregate and sand fractions.

[15] en.gamlemursten.dk
[16] https://www.hildundk.de/project/wohnungen-am-klostergarten/3/
[17] http://noa.wetnet.be/en/projects/1/046-lo-reninge-town-hall
[18] http://www.feildenfowles.co.uk/ty-pren/
[19] http://miesarch.com/work/3497
[20] https://www.montagneduparc-warandeberg.be/en/news/2015/09/03/heritage

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

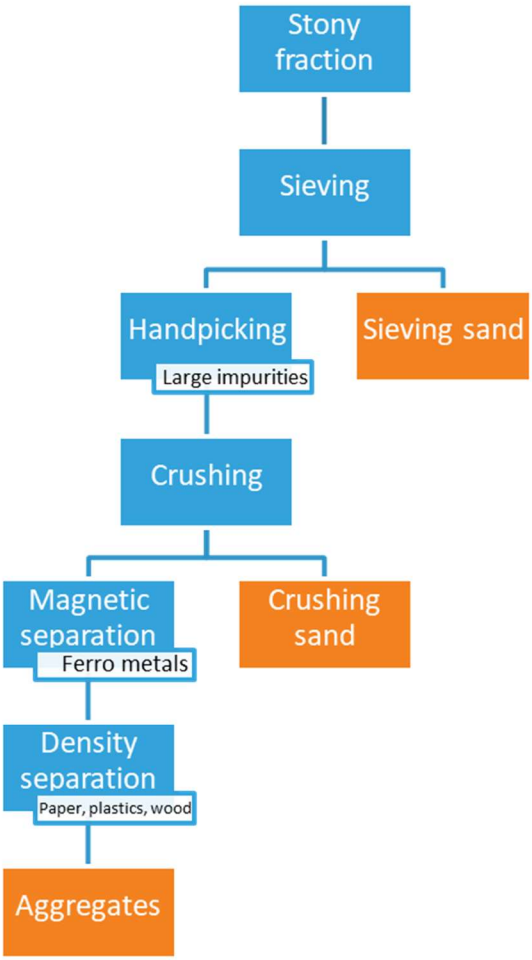


Figure 6. Typical recycling process for the stony fraction of C&DW.

Depending on the composition of the treated stony fractions, different aggregates fractions will be produced: concrete aggregates, asphalt aggregates, masonry aggregates, mixed aggregates.

Less pure aggregate fractions and most of the sand fractions are typically used in more low-grade applications: e.g. (sub) base road layers, cement stabilized sand, surface hardening, foundations, drainage layers, embankments. Unwanted material fractions should also be kept limited for these applications (EN 933-11, XRg < 2 m%). Furthermore, these aggregates must meet environmental legislation (e.g. heavy metal leaching). The aggregates are mainly substituting primary gravel and sand. Aggregates containing high amounts of concrete are valued as higher quality base material.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Table 1 Material preferences for aggregate fractions for recycling

Wanted materials	Unwanted materials
Concrete	Soil
Mortar	Metals
Natural stone	Organic material (wood, plastic…)
Bricks and tiles	Gypsum
Asphalt (no tar)	Autoclaved aerated concrete
	Expanded clay
	Glass
	Bituminous roofing
	Inorganic insulation materials
	Others

Standards and regulations

- EN 933-11: Tests for geometrical properties of aggregates - Part 11: Classification test for the constituents of coarse recycled aggregate
- EN 12457: Characterization of waste - Leaching - Compliance test for leaching of granular waste materials and sludges
- EN 14405: Characterization of waste - Leaching behaviour test - Up-flow percolation test (under specified conditions)

3.3. Closed-loop recycling

High-grade concrete aggregates (e.g. EN 933-11 Type A aggregates: >90 m% concrete) can be used to (partially) replace aggregates in high-grade concrete applications. It is generally accepted that up to 30 m% of natural coarse aggregates can be replaced with coarse recycled aggregate without significantly affecting any of the mechanical properties of the concrete. Compared to natural aggregates, recycled concrete aggregates have a higher water absorption. Therefore, attention should be paid to the effective water-cement ratio and the proper admixtures to produce concrete with the desired properties. For this high-grade recycling, the amount of glass, organic material and other unwanted materials should be kept limited (e.g. EN 933-11 Type A aggregates: XRg < 1 m%).

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

High-grade asphalt aggregates (reclaimed asphalt) can be used to produce new asphalt. Typically, up to 50%-70% of the virgin material can be replaced by asphalt aggregates. Hot mix recycling can deliver a mixture with similar stiffness and mechanical behaviour to this of a conventional mixture[21]. EN 13108-8 describes the properties of the asphalt aggregates that are of importance: particle size, binder content, properties of the binder, the amount of foreign matter in the reclaimed asphalt, the level of homogeneity of the material. The amount of wood, plastics and synthetic should be <0.1 m% (EN 13108-8).

Figure 7. High-grade recycled concrete aggregates[22].

Standards and regulations

- EN 12620: Aggregates for concrete
- EN 13108-8: Bituminous mixtures – material specifications – part 8: reclaimed asphalt

[21] Nosseti et al. (2018). Effect of the recycling process and binder type on bituminous mixtures with 100% reclaimed asphalt pavement. Construction and Building Materials 167:440-448.
[22] http://www.groenbetonvert.be/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Good practices and inspiring cases

- HISER project: Circular demolition and concrete recycling[23], The Netherlands. Recycling of concrete aggregates in new concrete with C2CA technology. The recycled concrete was used to construct a new building at the same site as the old one, closing the loop.
- Recycling of C&D Waste in Belgium: State-of-the-art and opportunities for technology transfer (Vyncke J. & Vrijders J.).[24]
- Comparative site monitoring of field performance of asphalt surface courses with recycled asphalt, RE-ROAD project[25], UK.
- Use of C&DW in construction – examples (Boehme L.), European Symposium Recycling: Cradle to Cradle 2013.
- Concrete recycling, case study in the Port of Antwerp (Figure 8), IRCOW project, Belgium. Recycling of coarse concrete aggregates from selective demolition in foundation concrete (60 m% replacement) and polished flooring concrete (30 m% replacement).

Figure 8. Ready-mixed concrete produced with 30% replacement of the coarse aggregates with recycled concrete aggregates[26].

[23] https://youtu.be/lHp3G-lOoOs
[24] https://goo.gl/vWJZ1A
[25] http://re-road.fehrl.org/?m=48&id_directory=7332
[26] Bergmans J., Broos K., Nielsen P., Dierckx P., Brijsse Y., Jacobs K. (2015). Recycling of construction and demolition waste: case study in the Port of Antwerp. ISWA conference 2015, Antwerp.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

4. Metals

Metals are commonly used materials in almost every type of building products because of their excellent mechanical properties and the well-established metal processing industry in Europe. At least two basic groups of metals should be identified in the process of material assessment in a building: ferrous metals (iron and steel) and non-ferrous metals (such as aluminium, zinc, copper or brass). They can be easily distinguished in most of the cases already by visual inspection, however, more detailed assessment may be needed especially in the cases of structural components made of aluminium alloys and non-magnetic stainless steels.

Ferrous metals

Ferrous metals (including alloys) contain iron as the main element. The most common ferrous metals in buildings are stainless and carbon steel, and cast and wrought iron. Ferrous metals are almost entirely recovered C&DW and prepared for recycling. Steel is the world's most recycled material and steel scrap is one of the most important inputs in today's crude steel production. The relatively high price of scrap makes the separation of ferrous metals economically feasible. For instance, the price of shredded and delivered steel scrap in EU was 300 € per tonne at the end of 2017[27] and over 94 million of metric tonnes of recovered scrap was consumed by steel industry in EU in 2017[28].

Stainless steel is produced in three main forms: austenitic (alloyed mainly with chromium and nickel), ferritic (alloyed with just chromium) and duplex (ferritic-austenitic alloy). Austenitic steel contains non-magnetic forms of iron that are impossible to separate by magnets.

Figure 9. Various steel elements in the demolition waste.

[27] Eurofer Annual Report 2018
[28] Eurofer European Steel in Figures 2018

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Non-ferrous metals

Non-ferrous metals in buildings are mostly copper, aluminium, lead, zinc and brass. Many other metals are used for instance as alloying elements. Non-ferrous metals are used in specific applications, mostly in non-structural parts of the building. They are also non-magnetic (except for cobalt and nickel). Many of them can be easily distinguished visually due to the different colour of their surface (see Figure 10).

Figure 10. Typical copper (top), aluminium (middle) and brass (bottom) scrap.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

4.1. Inspection of materials and coatings

The knowledge of the metal type, its alloying elements and expected material properties can provide valuable information for the decision about its reuse or recycling. Even though over 90% of metallic parts can be recycled with a minimum effort, reuse can be an economically better solution (e.g. if recycling involves difficult material separation like in sandwich panels). Reused elements are generally more valuable than recycling scrap, but require careful deconstruction and quality check, and therefore the decision about reuse must be made early in the pre-demolition planning process. Inspection of the metallic components often involves the assessment of existing coating and painting especially if there is suspicion about their toxicity that can negatively affect the recoverability of the components.

Visual inspection

The colour and surface finish of metallic components are often the easiest way for the assessment of the metal type. Smooth, polished and brushed uncoated surfaces are typically stainless steel (it should be noted that some types of stainless steel may show signs of corrosion) while rough and painted surfaces indicate protective coating applied on carbon steels. Weathering steel and some non-ferrous metals can be recognized by the distinctive colour of their oxidized surface. In the case of painting, its thickness and integrity should be investigated. Decoating, re-coating or stabilization of existing coating can be recommended if the existing layers are insufficient or not acceptable for recycling.

Chemical testing

Chemical testing is mostly used for the identification of hazardous materials in paints (such as lead in the primer, or HBCD in the intumescent painting). The composition of the alloys can be also identified by chemical spot tests. The reaction of metals with different reagents can be directly observed on site or by a quantitative chemical analysis in a laboratory.

Thermoelectric testing

Thermoelectric testing involves using the Seebeck effect to identify materials. These thermoelectric devices contain two probes made of the same metal, one heated and one at ambient temperature. When they contact the scrap, a potential difference is generated that is characteristic of the metal being tested.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Spectroscopic testing

Various optical and X-ray spectrometers can be used to identify the composition of metals. Portable optical emission spectrometers are becoming important tools for on-site sorting and identification. They can recognize most of the different types of steel and steel alloys. X-ray fluorescence (XRF) is used for alloy identification, and several hand-held commercial devices are already available. Laser-induced breakdown spectroscopy (LIBS) is another portable fast and economical technique that can accurately recognize surface metals that are free of coating.

4.2. Reuse and recycling

Metallic parts can be reused as fabricated components (sometimes combined with other materials) or constituent products (such as wires, bars, sheets, plates, tubes or profiles). Fabricated components are often only repaired and over-coated if needed. Their reusability is typically assessed case-by-case according to the specific needs of a new project (e.g. relocation of the part of the building). On the other hand, constituent products may need removal of all attached materials and coatings. The advantage is that the application of constituent products is much wider, and they can be almost always reused.

The following metal components are often reused:

- Cast iron radiators
- Wrought iron (e.g. gates, fences)

If the parts cannot be reused, there is always a possibility to send the metal scrap for recycling. The recycling process is well-established in Europe and the network of scrap collection yards is available in every country. Metal scrap has often high economic value which may prevent metal components from being reused.

The whole process is illustrated in Figure 11.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

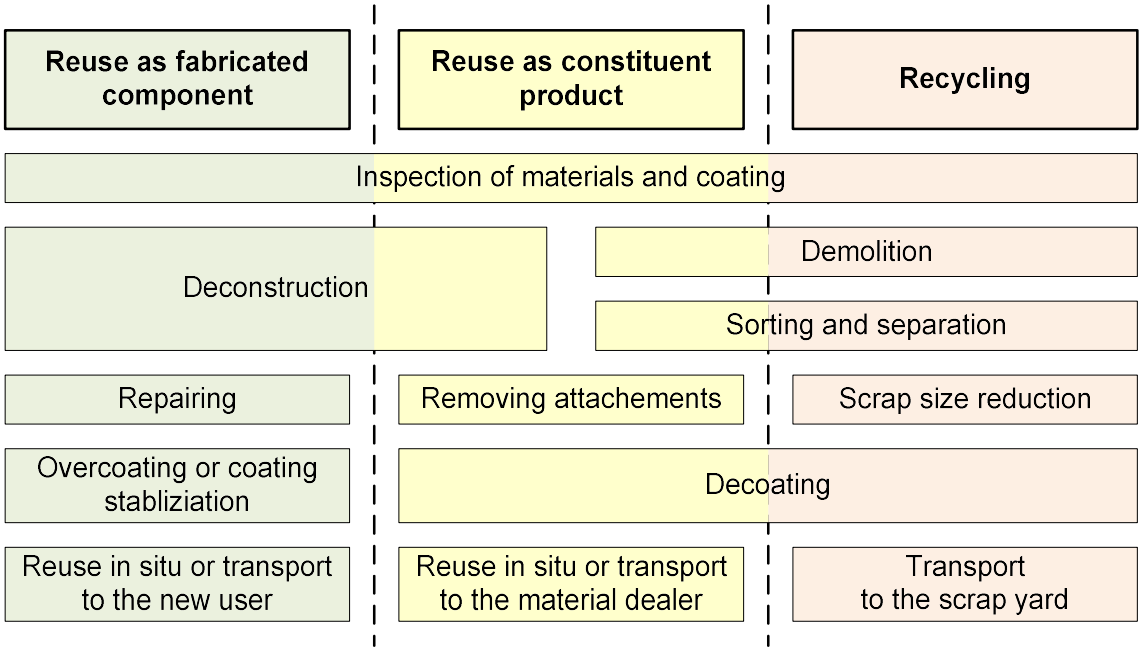


Figure 11. Recovery of metallic components.

Table 2 Material preferences for metals recycling

Wanted materials	Tolerated materials	Unwanted materials
Metals	Paint and coating	Stony materials
	Lubricants	Gypsum
	Adhesives	Soil
		Organic material
		Glass
		Inorganic insulation materials
		Bituminous roofing
		Others

Scrap size reduction

Large pieces of structural steel must be cut to smaller sizes for transport and recycling in steelmaking furnaces. This is typically done using shears or cutting torches. Further consolidation of the metals can be done by shredding and crushing.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Sorting and separation

Manual sorting is mostly used on-site when miscellaneous (e.g. non-metallic) attachments must be removed from the scrap. Basic identification of materials and alloys can be made during manual sorting by recognizing different colours, coatings and surface finishes. For instance, stainless steels are typically uncoated with a smooth surface. Since the most common form of the iron in metals is ferrite (alpha iron) that is ferromagnetic, most of the metals intended for recycling can be easily separated by magnets from the mixed waste in a sorting line. It should be noted that cobalt and nickel are also ferromagnetic metals, and therefore some non-ferrous materials can be attracted by magnetic separators. Magnets can be also used to lift separated steel scrap.

Figure 12. Electromagnetic lifting of steel scrap.

Eddy current separators are used to separate non-magnetic metals from the waste. The process is based on the electrical conductivity of metals and it generally follows the primary magnetic separation. The separation is achieved by passing a magnetic current through the feed stream and using repulsive forces between the magnetic field and the eddy currents in the metals to deflect the stream of metallic (ferrous and non-ferrous) materials.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Decoating

Most of the painted and coated surfaces can be cleaned and smoothed by abrasive blasting. Zinc coating can be removed from the galvanized steel scrap either by heating or chemical techniques. Thermal dezincing involves heating either to the temperature when zinc evaporates or to temperature sufficient to embrittle the coating that is subsequently removed by abrasion or shot blasting. Chemically zinc can be dissolved for instance by ammonia leach or caustic soda. Furthermore, incineration can be used to remove oil, grease, paints, lubricants and adhesives from the steel scrap.

Standards and regulations

The European Commission has already set down end-of-waste criteria (EoW) for scrap:

- End-of-waste criteria for iron, steel and aluminium scrap: EU Commission Regulation n°333/2011. Adopted in March 2011
- End-of-waste criteria for copper scrap: Commission Regulation n°715/2013. Adopted in July 2013

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

5. Glass

Glass is present in buildings in many forms depending on the type of the buildings, the used frame materials, the installation period, the locations (construction code), and so on. In general, recovered building glass can be grouped into three categories:

- Flat glass from large tertiary building (façades)
- Flat glass from windows
- Glass used for interior applications (balustrades, glass walls, mirrors, etc.)

Despite its recyclability, end-of-life building glass is almost never recycled into new glass products. Instead it often ends up in the stony fraction of C&DW, decreasing the quality of the produced recycled aggregates.

Figure 13. Flat glass waste[29].

5.1. Closed-loop recycling

The glass fraction of C&DW can be recycled in new flat glass. However, this recycling is very sensitive to the contamination of stony material.

[29] Inzameling en verwerking van vlakglas. OVAM, 2013.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

In recycling centres, the glass will be manually sorted to remove big impurities. Magnetic and density separation will remove metals and the light fraction (paper, plastics). Afterwards, an automatic optical sorting is applied to remove ceramics, stone and porcelain, and coloured glass. This process leads to a pure flat glass cullet fraction that can be used in the production of new flat glass (Figure 14). The recycling of this glass fraction into new flat glass not only decreases the use of primary materials but also reduces the energy consumption with up to 30%.

Figure 14. Flat glass cullet.

Table 3 Material preferences forclosed-loop flat glass recycling

Wanted materials	Unwanted materials
Flat glass	Fireproof or ceramic glass (cooking plates, Pyrex)
	Stony fraction
	Metals
	Organic material (wood, plastic…)
	Gypsum
	Bituminous roofing
	Inorganic insulation materials
	Others

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

5.2. Open-loop recycling

If the material fraction contains other glass fractions (e.g. container glass), glass wool and/or foam glass, the fraction can be used in the manufacturing of other products: container glass, glass wool, foam glass, fibre glass (Figure 15). Selectively collected flat glas streams from C&DW nowadays most often are recycled in container glass.

Figure 15. Glass fractions and their recycling route[30].

Table 4 Material preferences for glass recycling

Wanted materials	Unwanted materials
Flat glass	Ceramic
(Coloured) container glass	Ceramic glass (cooking plates, Pyrex)
Glass wool	Stony fraction
Foam glass	Metals
	Organic material (wood, plastic…)
	Gypsum
	Bituminous roofing
	Stone wool
	Others

[30] http://www.vgi-fiv.be/environnement-et-energie/le-recyclage/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Standards and regulations

The European Commission has already set down end-of-waste criteria (EoW) for glass cullet Commission Regulation n°1179/2012. Adopted in December 2012.

Good practices and inspiring cases

- Collection and recycling of flat glass waste by Vlakglas Recycling Nederland [31][32], The Netherlands.
- Good practice guide for flat glass collection[33], UK.

[31] www.vlakglasrecyling.nl

[32] https://www.mpo.cz/assets/cz/prumysl/politika-druhotnych-surovin-cr/2018/4/Prezentace----Cor-Wittekoek.pdf

[33] Collection of flat glass for use in flat glass manufacture, a good practice guide. UK Environment Agency.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

6. Wood

The quality of recovered wood from demolition activities varies considerably, which hampers the reuse and recycling of used wood. Wood materials originating from demolition activities are often treated with chemicals and preservatives and typically contain metal fastenings, such as nails and screws. The reuse and recycling of used wood as construction materials is limited by the quality requirements set for construction materials. For these reasons, wood waste has been primarily used for energy recovery. Other possible uses for wood waste is using clean wood waste as raw material in chip board production or production of wood composites.

Contaminants in recovered wood can be divided in mechanical and chemical contaminants. Mechanical contaminants are for example plastic, metals, concrete, gypsum, and glass. These contaminants can usually be removed mechanically by sorting or work up. Chemical contamination, for instance paint, varnishes, coatings, preservative, glues, etc. is permanently adhered to the wood and thus nearly impossible to separate from the wood material.

Figure 16 Wood waste[34].

[34] Alakangas, E., Hurskainen, M., Laatikainen-Luntama, J. & Korhonen, J. 2016. Suomessa käytettävien polttoaineiden ominaisuuksia. VTT Technical Research Centre of Finland Ltd.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

6.1. Classification of wood waste

Classification of demolition wood is a prerequisite for recycling and utilization of wood waste. To classify the demolition wood, it is important to know the properties of wood waste. In some European countries, such as Finland[35], The Netherlands[36], Belgium[37] and UK[32] used wood can be distinguished in different categories (A, B, C…) according to its quality (e.g. untreated wood, non-hazardous treated wood, hazardous treated wood). For recovery, the following aspects are most important: 1) does the wood waste contain hazardous substances?; 2) is the material manufactured with wood chips or fibres?

Figure 17. Examples of the wood waste classes (according to Finnish classification system)[37].

[35] Alakangas, E., Koponen, K., Sokka, L., Keränen, J., 2015. Classification of used wood to biomass fuel or solid recycled fuel and cascading use in Finland. B. Proceeding Bioenergy 2015 79–86.
[36] NL Agency 2013. Competition in wood waste: inventory of policies and markets.
[37] https://www.ovam.be/houtafval

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

6.2. Reuse

Some wooden building components (e.g. doors), structural timber (e.g. beams), wooden floors, façade cladding and panelling (e.g. barn wood) can be reused as such or repurposed (see chapter 2). Rough treatment and mixing with the other materials reduces the value of recovered timber. The strength and possible damages of recovered timber should be assessed before it can be reused. Example of wooden products that have a reuse potential:

- Wooden beams. These can also be remanufactured to woods planks.
- Barnwood (planks from old wooden barns).
- Wooden floors
- Scaffolding wood
- Wooden doors and windows

Mainly solid hardwood products (e.g. oak, beech, chestnut, tropical wood) are interesting for reuse.

Good practices and inspiring cases

- Good practices in the recovery of structural timber[38].
- Reuse of wooden floors at Renier Chalon[39], Belgium.
- BarnWood Concepts UK[40], reuse of wooden siding planks from old farms and stalls (Figure 18).

Figure 18. Barn wood.

[38] Hradil, P., Talja, A., Wahlsrtörm, M. *et al.* 2014. Re-use of structural elements. Environmentally efficient recovery of building components. VTT Technology 200.
[39] https://www.archdaily.com/894574/renier-chalon-mamout-architects-plus-auxau-atelier-darchitecture
[40] https://www.barnwoodconcepts.uk/products/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

6.3. Recycling

Clean wood waste can be used as a raw material in the chip board industry. Chip board production is primarily based on by-products from the wood processing industry (i.e. saw mills, furniture production and forestry), but also source separated, clean wood waste from demolition activities can be used as raw materials in the production of chip boards. Wood waste containing dangerous substances, e.g. impregnated wood is not used in the production. Wood products that are already manufactured with wood chips or wood fibres, cannot be recycled in large quantities in the chip board industry.

Table 5 Material preferences for wood recycling

Wanted materials	Unwanted materials	
Solid wood	Chipboards, fibreboards, OSB	
Triplex/multiplex	Stony fraction	
Laminated wood	Metals	
	Other organic material (rubber, plastic…)	
	Gypsum	
	Bituminous roofing	
	Inorganic insulation	
	Others	

Good practices and inspiring cases

- Novopan Træindustri[41] is a Danish chipboard producer using waste wood as a raw material.
- Increase of wood reuse and remanufacturing by Community Wood Recycling[42], UK.
- Unilin Belgium[43] produces chipboard which comprises 85 % reclaimed wood (Figure 19).
- IMAL-PAL group[44] produces integrated recycling systems for urban wood waste, Italy.
- In the Democles project, wood waste was separated on-site and recycled into wood panels by ECO3BOIS[45], France.

[41] http://www.novopan.dk/
[42] https://www.communitywoodrecycling.org.uk/
[43] http://www.unilin.com/en
[44] http://www.imalpal.com/en/index.php
[45] Resource Efficient Use of Mixed Wastes. Case study: Democles. Deloitte, BRE, RPS, VTT, FCT, ICEDD 2014.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

- The FSC Recycled label[46] means all the wood in the product comes from reclaimed (re-used) material.

Figure 19. Wood waste for recycling at Eco3bois[47].

6.4. Energy recovery

If reuse or recycling is not possible, wood waste can be utilized in energy production. Used wood which includes heavy metals more than virgin wood needs to be burned under waste incineration legislation, but better-quality wood waste can be used to produce solid biofuels[48] or recovered fuels (REF).

Ashes from wood classes A and B (called bio-ashes) fulfilling given quality requirements for the bio-ash can in Finland be used as fertilizers in forests according to the Finnish regulation.

[46] https://ic.fsc.org/en/choosing-fsc/fsc-labels
[47] https://www.serfim.com/en/metier/waste-recycling-and-the-production-of-secondary-raw-materials/
[48] EN ISO 17225-1– Solid biofuel standard

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

7. Gypsum

Gypsum is used in construction works in several applications:

- Gypsum plaster
- Gypsum plasterboards
- Gypsum blocks (for non-structural partition walls)

7.1. Closed-loop recycling

When collected separately, gypsum demolition waste can be recycled into new gypsum applications. Recycling plants can separate the plasterboard paper fraction from the gypsum. This paper fraction can be recycled in the production of new paper. Most recycling plants also contain a manual sorting step (removal of big impurities) and a magnetic separation (removal of ferrous metals).

Table 6 Material preferences for closed-loop gypsum recycling

Wanted materials	Tolerated materials	Unwanted materials
Gypsum plasterboards	Cardboard from plasterboards	Soil
Gypsum blocks		Autoclaved aerated concrete
Gypsum plaster		Metals
		Organic material
		Glass
		Inorganic insulation materials
		Stony material
		Lime, cement
		Straw/hair, cellulose fibres
		Others

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Good practices and inspiring cases

- Closed-loop gypsum recycling by New West Gypsum Recycling (Figure 20), in Belgium, France, Germany & UK.
- Closed-loop gypsum recycling by Gypsum Recycling International[49], in Denmark, Sweden, Norway, The Netherlands.
- Best practices in deconstruction, recycling and reincorporation practices - indicators, GypsumToGypsum.
- Recycled gypsum from waste plasterboard: quality protocol[50], UK.

Figure 20. New West Gypsum Recycling plant[51].

[49] http://gypsumrecycling.biz/15841-1_GypsumRecycling
[50] Recycled gypsum from waste plasterboard: quality protocol. UK Environment Agency, 2015.
[51] http://www.nwgypsum.com/our-process/recycling-process/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

8. Plastics

Several plastic compounds are being used in constructions: e.g. pipes, cables, floorings, insulation, window frames… It is important to note the difference between thermoplastics and thermoharders. Thermoplastics (e.g. PVC, PP, PE, PS) are composed of long chains that are connected with Van de Waals forces. These long chains can be disconnected by heating. In thermosets (e.g. PUR, polyester), the polymer chains are interlinked. The chains cannot be separated by heating the material. They cannot be given another form by heating the material. Around 90% of the plastics are thermoplastic.

8.1. Recycling

Post-consumer plastics from construction that have recycling routes in the EU are the hard plastics PVC, PP and HDPE (e.g. pipes, window profiles) and flexible PVC (e.g. flooring).

For closed-loop plastic recycling, the collection of pure plastic fractions is often required. There are only a few plants in the EU that can sort different types of plastics into pure fractions. An exception is the recycling of plastic pipes. These pipes can easily be sorted on type of plastic and can be collected together.

The material is ground into small pieces (<5 cm) and sorted so that it can be easily processed into new compounds ready to be melted and formed into new products (Figure 21). Colour sorting can sort granulates in different colour fractions.

While most recycling plants require a sorting process that produces pure granulates, the VinyLoop recycling plant use a solvent to selectively dissolve PVC, leaving impurities as a solid fraction. This process also tolerates fibre reinforced PVC material.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

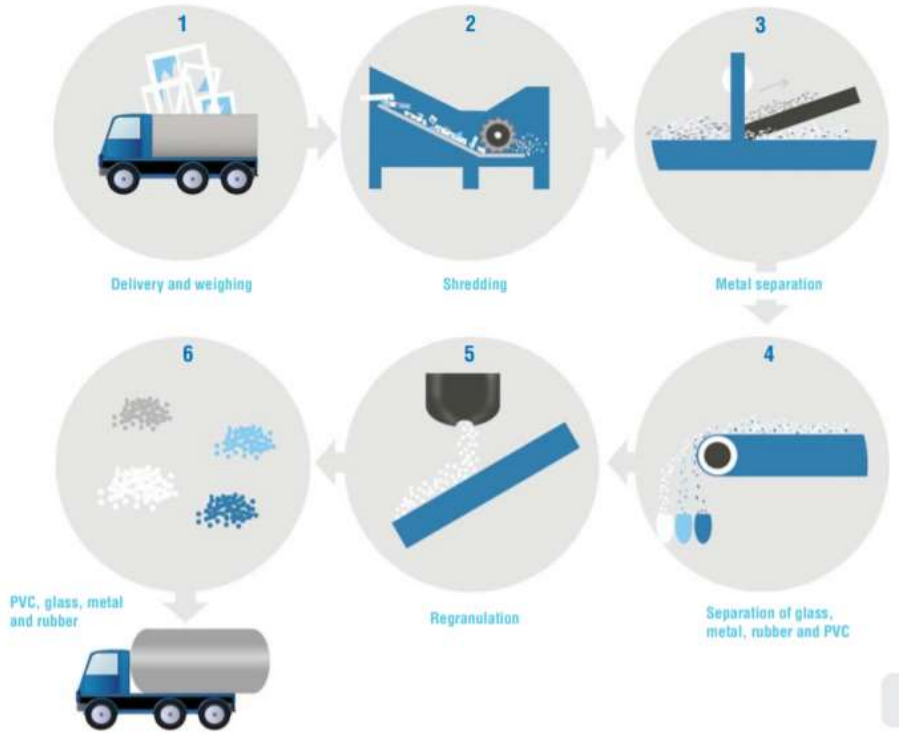


Figure 21. Recycling process of PVC window frames[52].

Table 7 Material preferences for plastics recycling

Wanted materials	Tolerated materials	Unwanted materials
PVC	Mortar	Soil
PE	Assembly foam	Gypsum
PP	Rubber from window frames	Other organic material
		Metals
		Glass
		Inorganic insulation materials
		Stony material
		Glass fibre reinforced pipes
		Others

[52] PVC recycling technologies. VinylPlus, 2015.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Good practices and inspiring cases

- Post-consumer PVC window frame recycling by Reststoftechnik[53], Austria.
- Post-consumer PVC window frame recycling by Deceuninck[54], Belgium (Figure 22).
- Post-consumer PVC window frame recycling by VEKA Recycling[55] in France, Germany, UK.
- Recycling of thermoplastic pipes (PVC, PP, HDPE) by Tönsmeier[56] in Germany and Poland.
- Wavin Recycover technology[57] for the recycling of PVC pipes, The Netherlands.
- The recycling of (mainly) PVC cable and wire waste and flooring by the VinyLoop[58] process of Solvay, in Italy.
- Sorting of mixed thermoplastics and recycling into different plastic fractions (PE, PP, PVC, ABS, PS) (±95% purity) by Van Werven[59] in The Netherlands, Belgium, UK and Denmark.
- Recycling of PVC flooring at AgPR[60], Germany.
- Recycling of PVC roofing membranes by Roofcollect[61], Germany.
- Kurio[62] collection system for thermoplastic pipes (PVC, PE, PP), Belgium.
- BIS[63] collection system for thermoplastic pipes (PVC, PE, PP), The Netherlands.

Figure 22. PVC window frames for recycling at Deceuninck, Belgium.

[53] http://reststofftechnik.at/aufbereitungstechniken/pvc-fensterrecycling
[54] http://www.deceuninck.be/nl/deceuninck-recycling
[55] http://www.veka-recycling.co.uk/
[56] www.toensmeier.com/fileadmin/toensmeier/Presse/Toensmeier_KC_Kunststoffe_02_EN_new.pdf
[57] https://www.wavin.com/en-gb/About/Sustainability/Recycore-Technology
[58] https://youtu.be/b5y0jW6UCMk
[59] https://www.recyclingplastics.co.uk/
[60] http://agpr.de/cms/website.php?id=/en/recycling-process.htm&nid=1&nidsub=3
[61] https://www.roofcollect.com/index.cfm
[62] http://www.kurio.be/recycling/
[63] https://www.bureauleiding.nl/bis-buizeninzamelsysteem/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

9. Inorganic insulation

There exists a wide variety of inorganic insulating materials:

- Mineral wool
  - Glass wool
  - Stone wool
  - Slag wool
- Foam glass
- Natural (expanded) light aggregates: e.g. pumice, expanded perlite, expanded vermiculite
- Synthetic light aggregates: e.g. expanded clay aggregates

Mineral wool is a fibrous material formed by spinning molten minerals. **Glass wool** is typically produced from quartz sand and recycled glass, while **stone wool** generally is produced from volcanic rock material (e.g. basalt, dolomite). **Slag wool** is made from blast furnace slag, a waste by-product of steel production. Mineral wool fibres can be bound together by adhesives, typically phenol formaldehyde resin, in certain insulation products. The binder can account for 10% of the total mass of the finished product[64]. Mineral wool insulation products typically are used in the form of slabs or mats, e.g. in cavity walls, under roofs, as piping insulation.

Foam glass is a porous glass foam material with thermal and acoustic insulating properties. It is made by heating a mixture of crushed or granulated glass and a blowing agent (chemical foaming agent) such as carbon or limestone. Foam glass is used in the form of aggregates (e.g. as filling material for embankments) or as a shape-tailored form (e.g. piping insulation, wall segments).

Lightweight aggregates (<2000 kg/m^3) are thermally insulating because of their porous structure. These aggregates are prepared by expanding, pelletizing or sintering products such as blast-furnace slag, clay, fly ash, shale, or slate, and aggregates prepared by processing natural materials such as pumice, scoria or tuff. Lightweight aggregates can be used as loose product, or bonded (e.g. in a cement matrix).

[64] Müller A, Leydolph B, Stanelle K (2009) Recycling mineral wool waste—Technologies for the conversion of the fiber structure, Part 1. Interceram 58:378–381.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Figure 23. Mineral insulation products (top left: glass wool, top right: expanded clay aggregates, bottom: foam glass).

9.1. Mineral wool: closed-loop recycling

The recycling of mineral wool production waste is widespread, while recycling of the mineral wool production waste much less common.

As glass wool and stone wool are different materials and have different recycling routes, they should be collected separately. The differentiation between glass wool and stone wool can be done both by the colour (stone wool is green-grey) of the product and by the density of the product (stone wool is usually denser). For local possibilities to recycle mineral wool it is preferred to contact a local mineral wool supplier[65]. Because of strict purity requirements, closed-loop recycling is mainly limited to construction waste.

[65] Waste Handling of Mineral Wool Insulation. Eurima Information Sheet, 2016.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Figure 24. Stone wool waste for recycling[66].

Good practices and inspiring cases

- EURIMA: Information on Waste Handling of Mineral Wool Insulation[67]
- Recycling of mineral wool acoustic ceiling tiles by Armstrong[68], UK.
- ROCKWOOL recycling programme[69], UK. Recycling of used ROCKWOOL products at the recycling plants in Bridgend and South Wales.
- Isover recycling programme[70], France. Recycling of used glass wool waste in two pilot regions in southeast France and the Paris region.

[66] https://www.rockwool.nl/tools-en-services/services/rockcycle/
[67] Waste Handling of Mineral Wool Insulation. Eurima Information Sheet, 2016.
[68] https://www.armstrongceilings.com/commercial/en-fr/performance/sustainable-building-design/recycling-programmes.html
[69] https://static.rockwool.com/globalassets/rockwool-uk/downloads/brochures/environment-and-sustainability/recycling-brochure.pdf
[70] https://circulareconomy.europa.eu/platform/en/good-practices/saint-gobains-isover-pioneer-recycling-glass-wool

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

9.2. Open-loop recycling

Recycled mineral wool, glass wool or foam glass can be used as a raw material in the production of clay-fired bricks[71]. Contact your local clay-fired brick manufacturer to discuss possibilities and requirements. Mineral wool is also recycled in the production of ceiling tiles.

Good practices and inspiring cases

- Recycling of stone wool greenhouse substrate into fired-clay bricks[72].

9.3. Other inorganic insulation materials

Lightweight aggregates can be reused if they are collected separately. Because of their lower compressive strength, they decrease the quality of recycled aggregates when present in the stony fraction.

[71] Waste Handling of Mineral Wool Insulation. Eurima Information Sheet, 2016.
[72] www.grodan.com/about-grodan

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

10. Bituminous roofing

Bituminous roofing is mainly used on flat roofs. They are composed of bitumen and synthetic polymers, sometimes fibre-reinforced (e.g. glass or polyester fibre).

In the past, tar-containing bitumen (a hazardous substance) was often used. Tar-containing bitumen can be recognized by a simple PAH-marker spray. This chapter describes the valorisation options of non-tar containing roofing.

10.1. Closed-loop recycling

It is possible to recycle bituminous roofing (up to 25%) in the production of new roofing products. The material is shredded, heated, and sieved (to remove contaminants like glass fibre, wood and stones).

The bituminous roofing must be easily separable from its substructure. Older roofing often exists of several heterogenous layers, obstructing recycling since different types of bitumen need a different kind of treatment temperature.

Table 8 Material preferences for closed-loop bitumous roofing recycling

Wanted materials	Tolerated materials	Unwanted materials
Homogenous bituminous roofing	Reinforcement fibres	Heterogenous layers of roofing
		Tar
		Road asfalt
		Stony materials
		Gypsum
		Metals
		Organic material
		Glass
		Inorganic insulation materials
		Others

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Good practices and inspiring cases

- Recycling of old bitumen roof coverings by Icopal's BiELSo process [73] (Figure 25), The Netherlands. Collection via Roof2Roof[74].
- Recycling of old roofing membranes by Derbigum[75], Belgium.

Figure 25. Shredding of bituminous roofing demolition waste in the BiELSO plant.

10.2. Open-loop recycling

Bituminous roofing waste can be recycled (sorting, shredding) as bitumen binder in the production of asphalt for road layers. The use of recycled material causes a decrease in the use of fossil resources, energy and CO_2 emissions.

[73] http://www.bielso.nl/Sustainability_Project/BiELSo_Recycling_Process.aspx
[74] http://www.roof2roof.nl/
[75] https://www.derbigum.com/en/about-us/recycling

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Table 9 Material preferences for open-loop bitumous material recycling

Wanted materials	Tolerated materials	Unwanted materials
Bituminous roofing	Reinforcement fibres	Tar
	Stony materials	Gypsum
	Sheet metal	Other metals
		Organic material
		Glass
		Inorganic insulation materials
		Others

Good practices and inspiring cases

- Tarpaper[76] recycling plant, Denmark and Finland. Research results achieved in the LIFE+ project 'From roof to road'.
- BituRec[77] recycling plant, The Netherlands (Figure 26).
- Roof2Road[78] recycling plant, The Netherlands

Figure 26. Recycled bituminous roofing waste for use in asphalt, produced by BituRec.

[76] www.tarpaper.eu
[77] www.biturec.nl
[78] http://www.roof2roof.nl/roof2road/697-upcycling-van-asfaltwegen.html

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

11. Autoclaved aerated concrete

Autoclaved aerated concrete (AAC) is a light-weight porous building material with a density of 400-800 kg/m³ and thermally insulating capacities (0.1-0.2 W/mK). It's mainly used for the construction of partitioning walls. Due to its low compressive strength (2-8 MPa) and high amounts of leachable sulphate (>10,000 mg/kg dm), AAC should not be collected together with the stony fraction. If collected as a separate fraction, recycling is possible.

11.1. Closed-loop recycling

It is possible to use recycled AAC, after crushing to <1 mm, in the production of new AAC as a substation of natural sand. For this, a high purity is necessary. Several impurities can be detrimental for the new products. Some elements (e.g. nails, screws) can lead to production damages, other elements (e.g. bitumen-residues) can cause stains and other visual problems in the new products. Recycled AAC can replace up to 15% of the resources for new AAC.[79] In practice, most AAC production plants only accept construction (cutting) waste for recycling.

Figure 27. Sorted AAC from demolition works that is suitable for recycling in new AAC[80].

[79] Kreft O. (2016). Closed-loop recycling of autoclaved aerated concrete. Mauerwerk 20:183-190.
[80] Kreft O. Closing the loop of autoclaved aerated concrete (AAC) Recycling. CESB 2016, Prague.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Table 10 Material preferences for closed-loop ACC recycling

Wanted materials	Tolerated materials	Unwanted materials
Autoclaved aerated concrete	Mortar	Other stony materials
	Calcium silicate blocks	Gypsum
		Soil
		Metals
		Organic material
		Glass
		Bituminous roofing
		Inorganic insulation materials
		Others

Good practices and inspiring cases

Recycling of AAC from demolition waste in the Ytong plant in Wedel[81], Germany.

11.2. Open-loop recycling

AAC demolition waste can be used as a fine aggregate (0-8 mm) for the replacement of sand in floor screed and cement stabilized sand. In these products, the leachable sulphate is immobilized as ettringite in the fresh products. Pollution of AAC waste with gypsum impurities is found to be detrimental to sulphate immobilisation and recycling of the AAC. Stony materials have no negative effect on this recycling route. Recycled AAC aggregate can replace 40% of the sand fraction in floor screed[8283].

In other countries, recycled AAC is sometimes used in non-structural concrete applications.

[81] Kreft O. (2016). Closed-loop recycling of autoclaved aerated concrete. Mauerwerk 20:183-190.
[82] Bergmans et al. (2016). Recycling of autoclaved aerated concrete in floor screeds: Sulfate leaching reduction by ettringite formation. Construction and Building Materials 111:9-14.
[83] Boehme L. (2013). Chap-Yt – recycled aerated concrete aggregates in traditional screed for flooring. CESB13, Grada Publishing, Prague, Czech Republic, p309-312.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Figure 28. Separately collected AAC fraction during demolition works in Belgium, suitable for recycling in floor screed and cement stabilized sand.

Table 11 Material preferences for ACC aggregate recycling

Wanted materials	Tolerated materials	Unwanted materials
Autoclaved aerated concrete	Stony materials	Gypsum
		Soil
		Metals
		Organic material
		Glass
		Bituminous roofing
		Inorganic insulation materials
		Others

Good practices and inspiring cases

EKP Recycling[84] and Chap-Yt[85]: recycling AAC waste as a sand replacement in floor screeds and cement stabilized sand, Belgium. Around 20 kton/year of AAC waste is recycled this way in Belgium.

[84] https://www.jacobsbeton.be/ekp-recycling-nv/
[85] http://chapyt.be/index.php/en/home/

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

PARADE - Best practices for Pre-demolition Audits ensuring high quality Raw materials




www.vtt.fi/sites/parade

rawmaterialsacademy.eu