SAFE USE OF CIRCULAR CONSTRUCTION PRODUCTS

Information package for producers

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1. Introduction to circular and low carbon building materials

Civil engineering significantly affects the natural environment and resources, mainly due to the high consumption of raw materials (e.g. wood, steel, cement, and soil) and energy for production, transport, and building heating and cooling. Moreover, it generates vast amounts of waste that is difficult to neutralize and recycle at the production, demolition and renovation stages. Sustainable construction concepts develop in response to the issues above. They strive to minimise the negative impact of civil engineering on natural resources through circular economy, i.e. introducing recycling and re-use of building materials and minimising waste quantities by designing durable and modular structures.

Carbon dioxide (CO_2) emissions related to construction are a significant factor in global emissions, although the exact percentage may vary depending on the region and data source. According to the 2019 report of the Global Alliance for Buildings and Construction [1], construction and use of buildings contributed to ca. 39% of global CO_2 energy-related emissions in 2018. The previous economy model based on a linear approach where we produce, use and dispose of is not sustainable from the point of view of the Earth's carrying capacity. New mindsets and measures shall be implemented to replace linear economy with circular economy where waste and raw materials are re-used. The circular economy involves reducing the consumption of primary resources and energy and minimising waste quantity by closing them in a use-recycle process loop.

The European Green Deal [2] is a package of political initiatives aiming to orient the EU towards green transition and finally to reach climate neutrality by 2050. It is meant to combat climate change, protect biodiversity, improve air quality and increase the effective use of resources. It covers several communication strategies, initiatives, and policies, as illustrated in Fig. 1 [3]. For the EU to reach its 2030 objective, in 2021, the European Commission proposed a package of new and updated regulations known as "Fit for 55". The first six months of 2023 brought the approval of the following regulations: revision of the EU Emissions Trading System (EU ETS), implementation of the instrument to combat fugitive emissions (fees for greenhouse gas emissions for imported goods), a project guaranteeing that new passenger vehicles and trucks in the EU shall generate zero net emissions in 2035, and amended emission authorisations for aviation [4].

Fig. 1: Overview of policies, initiatives and communication under the European Green Deal for construction (based on [3]).

The "Circular Economy Action Plan" [5], meant to promote circular economy in the European Union, is among the Green Deal initiatives. The key assumptions of the "Circular Economy Action Plan" include preventing resource wasting, promoting recycling and recovery, developing a secondary market and promoting green innovations. As part of measurable support for the circular economy, in March 2023, the European Commission presented, e.g. a new project to support the repairs and re-use of goods (manufacturers would be obliged to repair products under legal guarantee unless their replacement is cheaper), new EU regulations on packaging (eliminating unnecessary packaging, limiting packing in too many packaging items) or comprehensive EU strategy on critical raw materials [6].

Climate changes boosted EU countries to implement policies and directives to improve the energy efficiency of buildings in the member states to reduce energy consumption and greenhouse gas emissions. For instance, the key objectives of the Energy Performance of Buildings Directive [7] include improving the energy efficiency of buildings, promoting the use of renewable energy sources and introducing energy certification of buildings. The member states shall align their national regulations with the Directive's requirements and regularly report progress in reaching the related goals.

2. Purpose of the Guidebook

The key purpose of the Guidebook is to increase awareness of circular economy practices that shall focus on strengthening market activities aimed to maximise the use of secondary raw materials, waste reduction, and developing new environmentally friendly products designed to consider the life-cycle prospects of construction products. The study shall provide systematised knowledge and offer practical solutions for manufacturers and consumers interested in using recycled and post-recycled building materials - with no safety concerns - to improve waste management and environmental protection.

The Guidebook outlines guidelines and requirements concerning assessing technical characteristics and environmental and health impacts of using secondary materials, construction products containing them, and recycled and re-marketed materials. Moreover, the Guidebook presents an overview of national and European regulations, standards and requirements to help stakeholders in the construction sector launch construction products according to circular economy principles and use them safely. It also identifies areas where regulations should become more specific.

Finally, the Guidebook provides vital information on using secondary materials from construction, renovation and demolition (CRD). It presents detailed knowledge and orients persons and entities interested in the effective use of CRD waste.

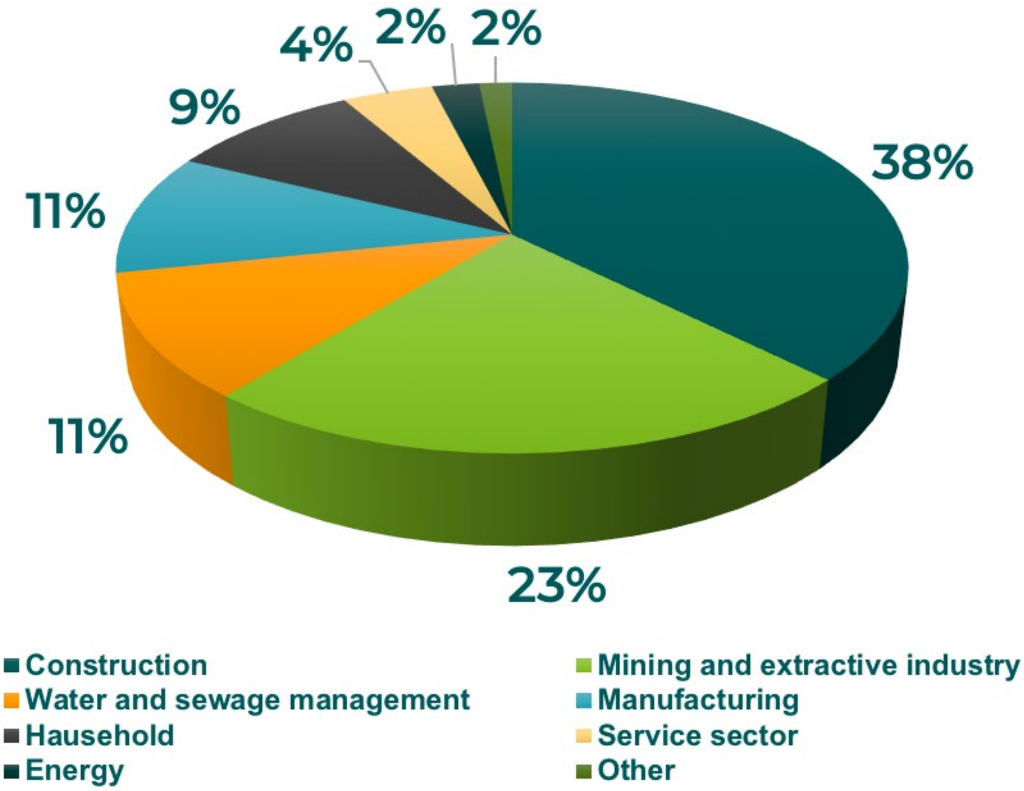
The level of recycling and recovery of construction and demolition waste in the EU varies from less than 10% to over 90%. The member states use various definitions of construction and demolition waste (CDW), which makes comparisons between countries difficult. The EU strives to ensure CDW management in an environmentally sustainable way. Secondly, using the full potential of CDW shall contribute to shifting to a circular economy [8].

This guideline is related to other guidelines regarding circular procurement, circular design strategies, low carbon materials and material cadasters.

3. Construction waste management

Construction is an economic sector causing a significant environmental burden due to the high consumption of natural raw materials. Construction activities generate vast amounts of waste at the stages of construction, use (renovation, refurbishment), and demolition. Construction waste is a problem for each European country, and its amount has gradually increased. Eurostat data for 2020 shows that the EU generated over 2.1 billion tons of waste. Construction was responsible for 37.5% of the whole, followed by waste produced by the mining and extractive industry (23.4%), water and sewage management activities (10.8%), manufacturing (10.6%), and households (9.4%); the rest belonged to waste originating from other business operations (Fig. 2) [9].

Fig. 2: Percentage of waste generation by economic activities in EU (2020 data; source: Eurostat online data [9])



The EU policy strives to prevent waste generation and promotes product reuse. If not possible, recycling (including composting) is preferred, followed by using waste for energy generation. Waste storage in landfills is one of the cheapest solutions but also most harmful to the environment and human health.

The Directive of the European Parliament and of the Council 2008/98/EC [10] on waste is among the critical legal acts regulating waste management, including construction waste, in the European Union. A holistic approach based on the whole life-cycle analysis shall contribute to preventing waste generation according to the waste handling hierarchy included in the Directive.

The Directive [10] regulates the general waste management principles, e.g. waste handling, including hazardous waste, collecting, transport, storage, removal and handing over, waste management costs, waste processing in systems and equipment and detailed rules of some waste types management (including construction and demolition waste). In reference to construction waste, the Directive [10] obliges the owners of building structures to, e.g.:

- separate construction waste from other waste and to segregate, collect and pick it selectively according to waste type;
- submit construction waste for processing in authorised plants. The plants shall process waste in an environmentally friendly manner;
- draw up documentation concerning the generated waste quantity and type and the method of its management;
- obtain a permit to store construction waste on their premises, if willing to do so.

Legislation

ESSENTIAL LEGISLATION REGULATING WASTE MANAGEMENT:

EU: The Directive of the European Parliament and of the Council 2008/98/EC of 19 November 2008 on waste and repealing some Directives [10]

PL: Act of 14 December 2012 on waste [11]

CZ: Zákon o odpadech. Zákon č. 541/2020 Sb.[12]

SL: Uredba o odpadkih (Uradni list RS, št. 37/15, 69/15, 129/20, 44/22 – ZVO-2 in 77/22) [13]

DE: Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen Kreislaufwirtschaftsgesetz - KrWG) Vom. 24. Februar 2012 [14]

There are two basic sources of construction waste generation, i.e. (1) construction, renovation and demolition waste from works done in households and treated as municipal waste, and (2) industrial waste.

Construction, renovation and demolition waste is characterised by high material diversity. Its essential components include concrete, brick, ceramics, natural and varnished or impregnated wood, metal, glass, plastics, roofing material, and soil, sand and stone mixtures. In accordance with the European Waste Catalogue (EWC) Code [15], CRD waste is classified as group 17 - Waste from construction, renovation and demolition (including excavated soil from contaminated sites) of building structure and road infrastructure.

Legislation

WASTE CODES ARE ASSIGNED BASED ON THE FOLLOWING LEGISLATION:

EU: Guidance on classification of waste according to EWC-Stat categories [15]

EU: Decision of the Commission of 18 December 2014 amending Decision No. 2000/532/EC on the list of waste in accordance with the Directive of the European Parliament and of the Council 2008/98/EC [16]

Waste from construction, renovation and demolition of building structures and road infrastructure is typically generated by specialised construction companies that are obliged to recover or neutralise it.

Waste generators/owners are responsible for collecting and transporting construction, renovation and demolition waste; they include private persons, construction and renovation companies, and specialised waste collecting and transporting entities. Waste owners shall regularly keep a record of its quality and quantity, according to the catalogue of waste specified in the waste register.

3.1. Construction waste handling hierarchy

Directive 2008/98/EC [10] introduces waste handling procedures, meaning waste management rules and guidelines aimed to minimise the negative impact of waste on the environment and human health. It ranks waste management processes from the most environmentally beneficial to those that should be minimised. Waste generation prevention, reuse and recycling comply with the fundamental rules of circular economy (Fig. 3).

Fig. 3: Construction waste handling hierarchy

The construction waste handling hierarchy covers the following stages:

1) WASTE MANAGEMENT PREVENTION

The primary objective is to minimise construction waste volumes, e.g. by designing structures based on robust and practical building materials and optimising construction processes.

2) PREPARING FOR REUSE

Construction waste that can be reused should be segregated, renewed and submitted for reuse.

3) RECYCLING

Building material waste should be recycled for secondary materials and to reduce environmental burden.

4) OTHER RECOVERY PROCESSES

If recycling or other processing methods are not possible, energy from waste can be used by incineration, i.e. energy recovery.

5) NEUTRALISATION

If other methods cannot be applied, waste should be neutralised safely for the environment and human health.

3.2. Demolition of buildings

Demolition of buildings is an intrinsic stage of every building structure's life. Demolition may be necessary if the building's technical condition is poor, its modernisation too costly or impossible or if the plot of land is meant for founding a new building. Proper demolition of a building structure ensures human safety, environmental protection and effective use of materials.

According to good practice, demolition of building structures should consist of the following stages:

- **Preparation - inspection/audit of the structure before demolition**

This stage covers an inventory of materials and building's elements that will become post-demolition waste, planning their further handling and getting all necessary approvals and permits.

Pre-demolition inspections are meant to optimise demolition waste management actions, including determining the number of containers for specific waste fractions, their sorting methods and investigating the waste management opportunities in the demolition area ***(see: Material Cataster Guide)***. The post-demolition waste management plan should include segregating materials into safe and dangerous ones ***(item 3.3.2 Safe and hazardous waste segregation)***, dividing them into relevant fractions, and determining their suitability for circularity (reuse, recovering, recycling).

In many EU countries, a real estate owner can conduct a pre-demolition audit, but an external expert's assistance is recommended. After an audit, a concluding document shall be enclosed with the tender for a demolition company to consider the selective demolition criteria (i.e. what elements should be recovered and what materials should be recycled, possibly indicating the expected recovery rate, e.g. how many and which bricks can be classified for reuse) and material handling criteria (e.g. preventing disposal of bricks).

Best practice

Sweden has had over twenty years of experience in post-demolition waste management. The Swedish Construction Federation plays a significant role in the sector. The organisation issued the first guidelines on post-demolition material handling in 2007. The document has been updated ever since, and its latest revision was published in 2019 [17].

ÖNORM B3151 [18] is the Austrian standard for demolition of building structures. It thoroughly describes materials harmful to health and the environment that shall be removed from the building before demolition.

Best practice

The CityLoops project [19] is an example of implementing circular economy assumptions. The EU-funded project brings together seven European cities striving for a more circular approach. It aims to close the cycles of Europe's two most significant waste streams, i.e., construction and biowaste, and maximise closed circulation in cities. The process covered an entire chain of activities, from spatial planning to selective demolition and creating a secondary materials market [19].

The key information on pre-demolition audits and selective demolition can be found in the following European guidebooks:

(1) "Guidelines for the waste audits before demolition and renovation works of buildings" from 2018 [20]

(2) "Construction and Demolition waste and materials. User manual: overview, guidance and instructions" from 2020 [21] – European initiative Level(s) (see Fig. 1)

(3) „Baurestmassen - Verwertung und Entsorgung" from 2023 [22]

(4) "Improving quality of construction & demolition waste – Requirements for pre-demolition audit" from 2019 [23]

- **Planning and determining the demolition area**

Isolating the area around the building is intended to keep the staff and surroundings safe. The area should be fenced and protected to prevent unauthorised access. A detailed demolition plan should include such information as identification of the items to be demolished, demolition sequence, and equipment to be used. Moreover, the plan should specify selective segregation of post-demolition waste, its processing, removal and use of safety measures at each demolition step.

- **Demolition**

Depending on the building's size and condition and demolition purpose, the process can be carried out using various methods. Manual demolition applies only to buildings that are not highly derelict and where materials can be recovered. Traditional demolition, i.e. mechanical demolition using heavy-duty machinery, is used when the structure poses no hazard to the surroundings and its condition allows for relatively safe removal. Controlled demolition is more complex and accurate. It is used when a building is situated in a limited space, surrounded by other buildings or infrastructure, or when vibrations and dusting shall be minimised as much as possible. In such cases, the structure is demolished by explosions or precise cutting to enable the building's controlled fall. Removal of hazardous materials, e.g. asbestos, should be carried out in accordance with applicable regulations and procedures.

- **Demolition completion**

The last demolition stage involves waste segregation by type/code for further recycling or neutralisation. Any waste classified as hazardous should be adequately secured to prevent penetration of harmful substances into groundwater and soil. The demolition area shall be levelled and hardened after removing the waste.

3.3. Handling demolition waste

3.3.1. Waste segregation into fractions

Construction and demolition waste constitutes the most significant waste stream in the European Union. Even though a substantial part of construction and demolition waste can be recycled, a lack of confidence in the quality of secondary products derived from it poses the primary constraint preventing a full-scale use of such procedures.

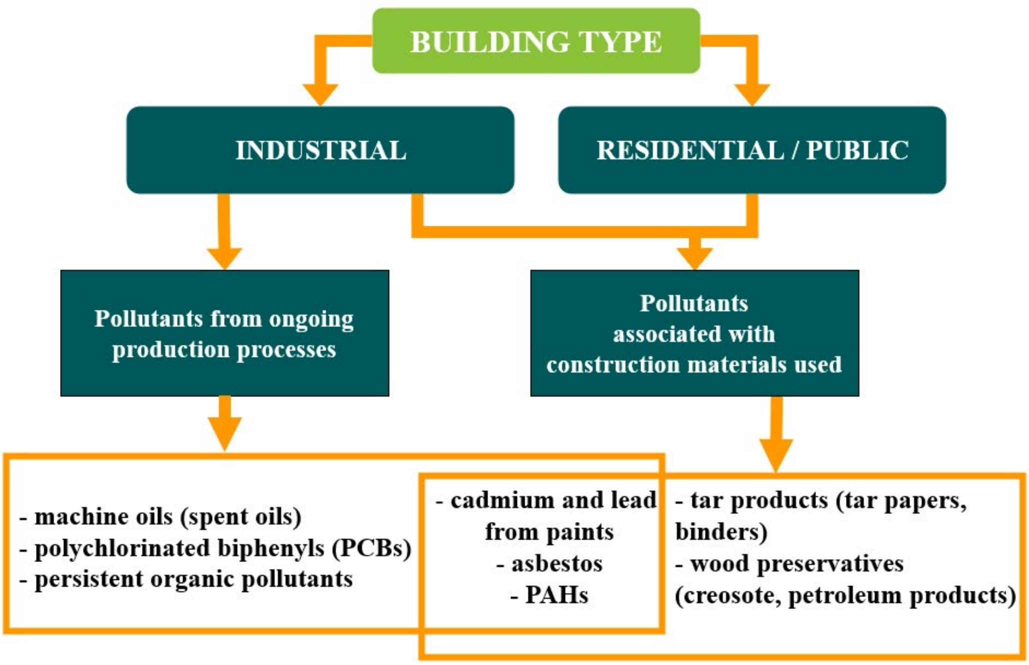
The Waste Framework Directive obliges the member states to selective collection and pickup of construction and demolition waste, divided at least into such fractions as wood, metal, glass, plastics, gypsum, and mineral waste, including concrete, bricks, tiles, ceramic materials, and stones.

Optimising a closed circulation of building materials requires early removal of hazardous materials and segregating/separating individual material fractions to ensure the highest waste handling hierarchy level (reuse, recycling, recovery). The first demolition stage shall be carried out after the last tenant has left the premises. Reuse of objects shall be ensured as quickly as possible to prevent their damage by dampness and acts of vandalism. Selective demolition can be more time-consuming and costly than traditional, but savings occur in waste management and recovered materials. Financial and management models should take into consideration the redistribution of costs and savings [19].

3.3.2. Safe and hazardous waste segregation

Contamination from the applied building materials that might contain hazardous substances concerns residential and public buildings and industrial facilities (Fig. 4).

Fig. 4: Sources of contamination in building structures



Contamination of building materials with hazardous substances related to previous production or operation is highly likely in industrial facilities. Laboratory tests should be carried out before demolition to identify dangerous substances. When removing hazardous waste, applicable regulations and guidelines for its demolition shall be followed.

In the buildings where industrial equipment was used, e.g. production machinery, refrigerating equipment or various industrial transformers, the presence of polychlorinated biphenyls (PCB) occurring in spent oils should be evaluated.

Asbestos is among the most common hazardous substances originating from building materials. It used to be applied as roofing (Eternit or corrugated asbestos-cement panels) and heating systems insulation in places requiring improved high-temperature resistance (coating and cladding of boilers and pipes). Moreover, flat asbestos and cement panels were used in lightweight sandwich partitions and as fireproofing material.

Lead and cadmium, typically present in paints, are common chemical compounds in post-demolition materials.

Moreover, tar-based insulation barriers and products to protect from dampness were often embedded in old constructions. The products included tar paper and tar adhesives. Hydrophobic insulations based on bitumen glues applied as solutions in organic solvents were used in highly damped rooms and basements. Wood and wood-based panels were protected from biological corrosion by-products based on tar derivatives, e.g. creosote and oil-based products [24].

Quick tips

SAMPLE CONTAMINATIONS RELATED TO BUILDING MATERIALS:

Asbestos - roofs, thermal insulation (Eternit), pipe and boiler coating, and sandwich panels

Lead and cadmium - lead-based paints (LBP)

Polychlorinated biphenyls (PCB) - present in insulation, energy-saving lamps, capacitors and other electric devices, vacuum pumps, hydraulic drives, and heating systems - as lubricant additives

Polycyclic aromatic hydrocarbons (PAH) - bitumen, tar, tar paper, adhesives, rubber- and gravel-based materials

Phenols - impregnated wood, cardboard, railway sleepers, masts

Polychlorinated dibenzodioxins and dibenzofurans (PCDD/PCDF), hexachlorobenzene (HCB) and chlorofluorocarbons ((H)CFC).

Persistent organic pollutants (POPs) [25]

In order to determine waste recovery possibility and method through recycling, waste type should be first identified (inert, hazardous, non-inert and non-hazardous). Waste type is determined based on laboratory tests in reference to the criteria set out for every type of waste stipulated in the Council of the UE Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills [26].

In accordance with the Council of The UE Decision [26], some waste is considered inert. Its basic characteristics are developed without tests. The following waste codes fall into this group:

- 1701 01 Concrete
- 1701 02 Bricks
- 1701 03 Tiles and ceramics
- 1701 07 Mixtures of concrete, bricks, tiles and ceramics
- 1702 02 Glass
- 1705 04 Soil and stones (except for arable layer and peat; except for soil and stones from contaminated areas)

For other fractions of waste, i.e., wood, metals, plastics, plaster, tests should be performed to classify them as inert waste in accordance with the Council of the UE Decision [26].

The scope of tests for inert waste covers leaching of elements (As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn), chlorides, fluorides and sulphates; phenol index; dissolved organic carbon (DOC); total dissolved solids (TDS), and such additional parameters as total organic carbon (TOC), volatile aromatic hydrocarbons (BTEX), mineral oil (C10 to C40), polycyclic aromatic hydrocarbons (PAH), and polychlorinated biphenyls (PCB).

The scope of tests for hazardous, non-inert and non-hazardous waste covers leaching of elements (As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, and Zn), chlorides, fluorides, sulphates, dissolved organic carbon (DOC), and total dissolved solids (TDS). Additionally, hazardous waste shall be tested for loss on ignition (LOI), total organic carbon (TOC), acid neutralising capacity (ANC) and pH.

The testing methods above are described in the standard series EN 12457-1, -2, -3 Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges [27-29].

Moreover, one shall consider the requirements of the Regulation of the European Parliament and of the Council (EU) 2019/1021 of 20 June 2019 on persistent organic pollutants (POP) [30] aimed to reduce quantities of hazardous chemicals in waste and production processes. Waste containing or contaminated with substances listed in Annex IV to the above-mentioned legal act are disposed of or recovered in accordance with the provisions of Part 1 of Annex V to this Regulation in a way that ensures the destruction or irreversible transformation of the POP content so that the remaining waste and releases do not exhibit the characteristics of POPs.

Best practice

A "selective demolition certificate" issued by the independent non-profit organisation "Traimant" in Belgium is an example of good practice in circular economy [31]. The certificate is issued for two waste categories: with low or high environmental risk. It is shared throughout the waste supply chain. If a waste processing entity handles waste classified as having "low environmental risk", it is definitely safe. "Materials with high environmental risk" require a thorough inspection of waste due to the presence of dangerous substances. The actions above result in an increased confidence for post-demolition materials.

4. Construction products vs circular economy

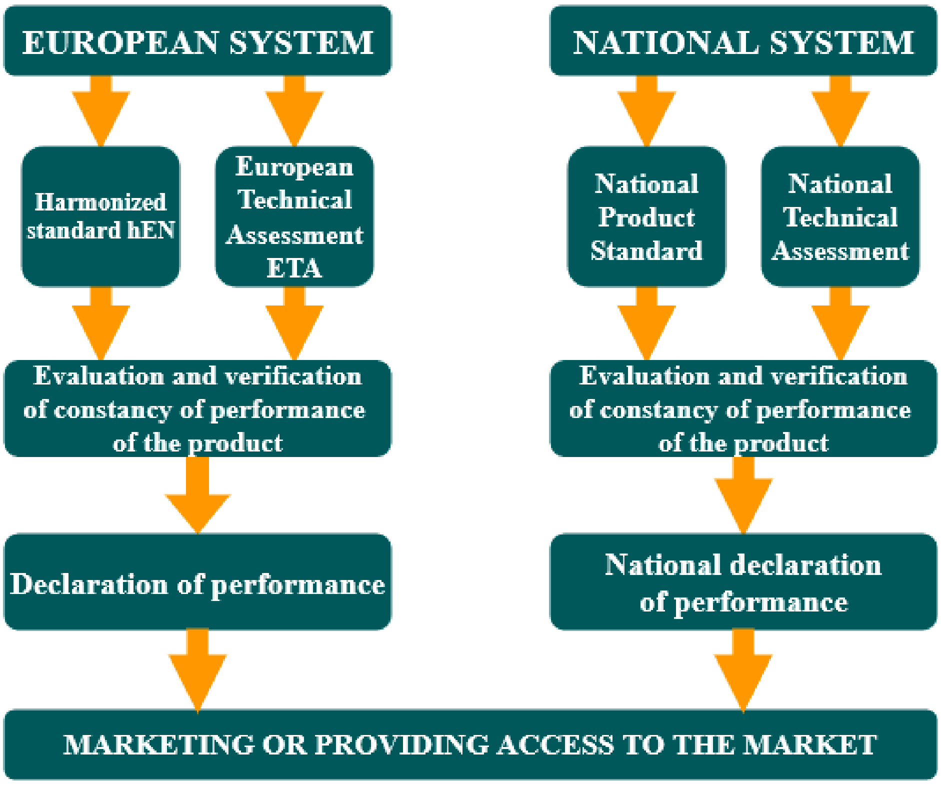
4.1. Marketing of construction products

The member states establish requirements for building structures and consequently, for construction products. They refer not only to their durability or strength but also to health impacts, environmental protection and other aspects of safe use. The requirements are included in the Regulation (EU) of the European Parliament and of the Council No. 305/2011 of 9 March 2011, establishing harmonised conditions for marketing construction products and repealing the Council's Directive 89/106/EEC (Construction Product Regulation, CPR) [32]. The document lays down the rules for the marketing of construction products in the EU in accordance with a dedicated harmonised standard (hEN) or the European Technical Assessment (ETA) (Fig. 5).

Quick tips

The applicable regulations do not prevent manufacturers from labelling construction products simultaneously with the CE mark and construction product label.

Fig. 5: Simplified diagram for marketing a construction product in accordance with Regulation (EU) No. 305/2011



In accordance with the CPR [32], harmonised standards (hEN) and European Assessment Documents (EAD) are types of technical specifications meant for assessing the functional performance of construction products, enabling their marketing in the EU. Harmonised standards determine the performance assessment methods and criteria for construction products in reference to their essential characteristics.

An authorised Technical Assessment Body develops the European Assessment Documents on the manufacturer's request if a harmonised standard or another EAD does not cover the product and is typically used for new and innovative products (including those containing recyclates). The EAD contains a general description of a construction product, a list of essential characteristics vital for the product's intended use and the methods and criteria for assessing the product's performance in reference to the characteristics. A positive assessment of constancy of performance with the requirements of harmonised standards or European technical assessments authorises the issuing of the European Declaration of Performance and labelling of the construction product with the CE mark.

Quick tips

The CPR [32] introduces the definitions of the following:

- a construction product as any product or set produced or marketed to be permanently embedded in building structures or their parts that affect the performance of building structures versus basic requirements for them,
- essential characteristics as a construction product's feature referring to the basic requirements for building structures,
- a construction product's performance as a property referring to the relevant essential characteristics expressed as a level or grade or descriptively.

Moreover, the CPR [32] imposes mandatory, developing the instructions for use, manuals and information on health and safety hazards that the product poses during application and use. The information should comply with Article 31 or 33 of Regulation (EU) 1907/2006 of the European Parliament and of the Council of 18 December 2006 on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) [33]; the information is enclosed with the declaration of performance. Information about dangerous substances in construction products is contained in the safety data sheets are intended for professional users to ensure high safety and health protection.

Legislation

THE KEY LEGISLATION CONCERNING THE MARKETING OF CONSTRUCTION PRODUCTS INCLUDES THE FOLLOWING:

EU: Regulation of the European Parliament and of the Council (EU) 305/2011 of 9 March 2011, laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC [32]

PL: The Act of 16 April 2004 on construction products [34]

DE: Verordnung zur Einführung einer Ersatzbaustoffverordnung, zur Neufassung der Bundesodenschutzund Altlastenverordnung und zur Änderung der Deponieverordnung und der Gewerbeabfallverordnung1,Vom 9. Juli 2021 [35]

CZ: Nařízení vlády, kterým se stanoví technické požadavky na vybrané stavební výrobky. Nařízení vlády č. 163/2002 Sb. [36]

SL: Zakon o gradbenih proizvodih (ZGPro-1) (Uradni list RS, št. 82/13) [37]

If a construction product is not covered by a harmonised standard or the European Technical Assessment has not been issued the product can be marketed in the domestic market based on the national technical assessment or a non-harmonised domestic standard. Then, the construction product is labelled with a construction mark in accordance with national legislation.

The Regulation (EU) of the European Parliament and of the Council No. 305/2011 of 9 March 2011 [32] and the Decision (EU) of the European Parliament and of the Council No. 768/2008/EC of 9 July 2008 on a common framework for the marketing of products [38] are applicable in all member states concerning placing products on the market.

Quick tips

The marketing path of construction products containing recyclates shall always be analysed individually by the manufacturer and technical assessment body, considering the national or European path.

The reference documents shall include the information about the recyclate content (percentage), its origin and physical characteristics.

Legislation

SAMPLE REFERENCE DOCUMENTS FOR CONSTRUCTION PRODUCTS CONTAINING SECONDARY MATERIALS:

- EN 1519-1 Plastics piping systems for soil and waste discharge (low and high temperature) within the building structure. Polyethylene (PE). Part 1: Requirements for pipes, fittings and the system [39]
- CEN/TS 14541-2 Plastics pipes and fittings - Utilisation of thermoplastics recyclates - Part 2: Recommendations for relevant characteristics [40]
- CEN/TS 14541-2 Plastics pipes and fittings - Utilisation of thermoplastics recyclates - Part 1: Vocabulary [41]
- EN 197-6 Cement - Part 6: Cement with recycled building materials [42]
- EN 12620 Aggregates for concrete [43]
- EAD 170005-00-0305. Recycled Clay Masonry Units, EOTA 2017 [44]
- EAD 010028-00-0103. Shallow and Reusable Foundation Kit for Lightweight Structures, EOTA 2017 [45]
- EAD 180022-00-0704. Prefabricated Plastic Fitting Made from Recycled Waste Plastics and Designed for Drainage of Land and Civil Engineering, EOTA 2018 [46]

4.2. Environmental requirements for construction products

4.2.1. Declaring the natural environmental burden

The CPR's [32] essential requirement No. 7 Sustainable use of natural resources refers to fundamental principles of circular economy assuming that building structures shall be designed, made and demolished in a way ensuring sustainable use of natural resources, including:

A. reuse or recycling of building structures and their structural materials and parts after demolition,

B. durability of building structures,

C. using environmentally friendly raw and secondary materials in building structures.

The tasks are vital for the EU Sustainable Development Goals ***(see point 1)***, circular economy, current needs, and granting European strategies, e.g., alleviating and adapting to climate change and life-cycle analysis of building structures and their structural materials.

Implementing sustainable development principles in the market of construction products, technologies, and structures requires the support of an adequately extended system of engineering standards and specifications. Works on amending and completing the existing specifications and developing new documents in the referenced area were entrusted to the European Committee for Standardisation (CEN). The CEN/TC 350 Technical Committee - Sustainability of Construction Works was established under the CEN. The Committee is responsible for developing horizontal European standards used as the foundation for assessing building structures' compliance with sustainable development principles in the following areas:

- environmental effectiveness assessment: principles of closed-loop circulation in civil engineering, energy efficiency and decarbonisation, sustainable use of resources (e.g. waste minimisation), environmental protection and biological diversity;
- evaluation of social outcomes: health, comfort, safety and protection, adaptation capacity and availability in response to users' needs;
- evaluation of economic outcomes: the cost of construction products' entire life cycle and their impact on the economic value, implementing standards in response to digitalisation trends (e.g. BIM, CAD).

The CEN committees mentioned above work towards standardising circular economy in civil engineering. The guidelines and requirements are meant to support the shift from linear to circular economy by presenting tools and processes covering scenarios from designing to demolition ***(see "Circular design strategies" guideline)***. Such solutions and information on environmental characteristics are provided by construction products' environmental declarations, including but not limited to the following:

- type I declarations - voluntary labelling (certification) programmes containing a product's multi-criteria environmental assessment;
- type II declarations - developed according to EN 14021 [47], are individual environmental statements distinguishing the product due to its environmentally sustainable features;
- type III declarations (EPD - Environmental Product Declaration) - a collection of quantified data of the product's environmental impact, expressed numerically, according to EN 15804 [48], in reference to the product's entire life cycle, i.e. "from cradle to grave'.

The EPD declarations contain quantitative environmental information on construction products based on their life cycle analysis. The environmental product declarations are meant to provide a basis for construction products assessment and enable comparing and identifying those exerting lower environmental impact. Environmental product declarations are a component of the assessment of the environmental performance of buildings in accordance with EN 15978 [49].

4.2.2. Release of dangerous substances from construction products

Quick tips

The assessment of construction products' performance should consider the health and environmental protection aspects related to using the products throughout their life cycle.

Release and content of dangerous substances related to the intended use are among the key characteristics of products determining their health and environmental impacts. The requirements of CPR [32], REACH [33], and EU Regulation 2019/1021 on persistent organic pollutants [30] are pivotal in this area. Moreover, one should consider the requirements for individual product groups applicable in the countries where the product will be used and marketed.

The CPR's [32] basic requirement No. 3 Hygiene, Health and Environment, defines dangerous substances that can be released from a construction product. In accordance with the requirement, building structures shall be designed and made so that their construction, use and demolition do not pose - throughout their life cycle - any hazard for the hygiene, health or safety of employees, dwellers or neighbours and so that throughout the life cycle they do not exert excessive impact on the environment or climate, especially as a result of the following:

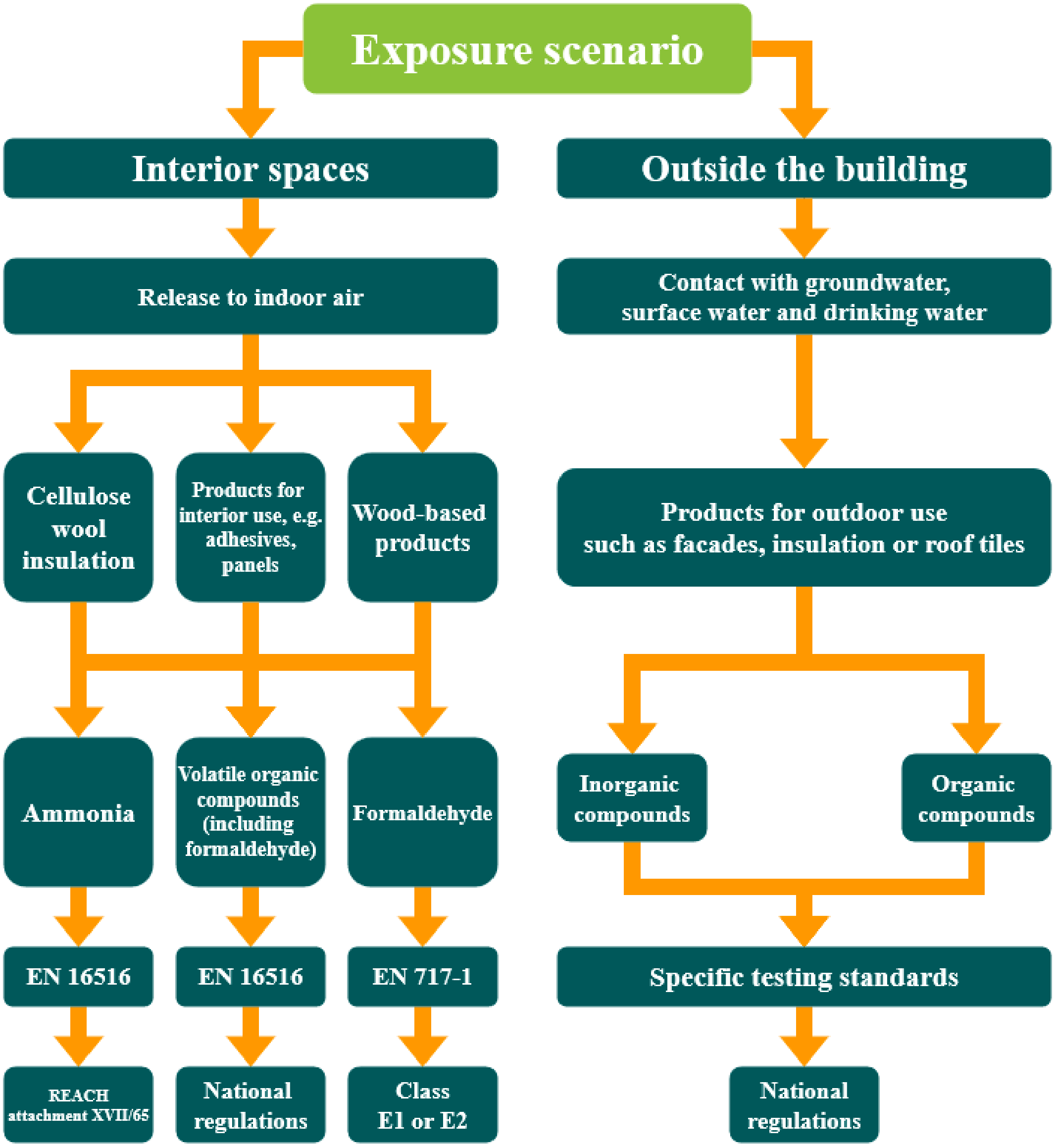
A. release of toxic gases;
B. emissions of dangerous substances, volatile organic compounds, greenhouse gases or hazardous air particles into or out of the building structure;
C. emissions of hazardous radiation;
D. release of dangerous substances into groundwater, marine waters, surface waters or soil;
E. release of dangerous substances or substances into potable water, which negatively affects potable water in another way;
F. inadequate wastewater discharge, flue gas emissions or inadequate removal of solid and liquid waste;
G. dampness in parts of building structures on the surfaces within the structures.

The CEN/TC 351 Construction Products - Assessment of release of dangerous substances develops horizontal testing methods, gradually implemented in the standards for construction products, referring to the release (and/or content) of dangerous substances, including the products' intended conditions of use.

Quick tips

The tests for dangerous substances released from products should consider relevant exposure scenarios (Fig. 6) and include laboratory tests. There are two basic exposure scenarios: release of dangerous substances into the indoor air (1) and to groundwater, marine waters, surface waters and soil (2).

Fig. 6: Exposure scenarios for the release of dangerous substances from construction products.



EXPOSURE SCENARIO: EMISSION OF DANGEROUS SUBSTANCES INTO INDOOR AIR

Products that use organic chemical compounds such as solvents, bitumens and polymers are subject to assessment. Ceramic, glass and metal products are excluded from testing.

The emissions of volatile organic compounds and volatile aldehydes from construction products often cause indoor air pollution. That is why it is recommended to assess the release of dangerous substances according to EN 16516:2017+A1:2020 [50] for indoor construction products. The tests apply to volatile organic compounds and volatile aldehydes emissions into indoor air. The aim is to assess the release of substances during the product's intended use. Air samples from the emission chamber are collected three and twenty-eight days after placing the product in the chamber and analysed with chromatographic methods.

Quick tips

With regard to a lack of harmonised requirements and classification for emissions of volatile organic compounds into indoor air, the test results are assessed based on national requirements.

For wooden and wood-based construction products such as wood-like HPL/siding panels, components of suspended ceilings, wood-based boards, wooden floors, flexible, and textile and laminated flooring, harmonised standards introduce the obligation to test formaldehyde emissions according to EN 717-1:2006 [51]. The test is aimed to evaluate formaldehyde release into indoor air during the product's intended use. The test result applies to the relevant emission class, i.e. either E1 or E2.

EXPOSURE SCENARIO: RELEASING DANGEROUS SUBSTANCES TO GROUNDWATER, MARINE WATERS, SURFACE WATERS AND SOIL

Dangerous substances released from construction products in contact with water pose a potential environmental hazard when the product is used. In order to evaluate the environmental impact of construction products used outside buildings, it is recommended to test the release of dangerous substances into surface waters and soil based on the methods included in the EN 16637-1:2023 [52] i EN 16637-2:2023 [53]. The leaching process and mechanism characteristics are determined throughout the test, along with the possibility of evaluating the release of substances during the product's intended use. The test applies to homogenous [52] and porous [53] materials.

The exposure surface of monolithic and stable materials, whose matrix is insoluble in water, is fully coated with the leaching liquid. The set volume of the leaching liquid is introduced into a vessel; the volume shall comply with the surface coefficient determined in EN 16637-2:2023 [53]. In porous materials, substances are released through diffusion. The products are slightly pressed and placed in a cylindrical vessel. Exposure to the leaching liquid occurs only through the top layer. The leaching liquid is replaced for all material types according to the schedule presented in the abovementioned technical reports.

Moreover, there are standard methods for specific product groups. They are intended for testing the release of dangerous substances into the environment. The EN 1744-3 Testing for chemical characteristics of aggregates - Part 3: Preparation of eluates by leaching of aggregates [54] provides a good example. The standard determines the method of preparing eluates for further physical and chemical tests. The next stage involves thorough testing of dangerous substances as specified in national regulations.

The test results in obtaining eluate where the following can be assessed:

- **inorganic substances:**

EN 16637-2:2023 Construction products: Assessment of release of dangerous substances - Analysis of inorganic substances in eluates [55]

EN 17195:2023 Construction products: Assessment of release of dangerous substances - Analysis of inorganic substances in digests and eluates - Analysis by Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) [56]

EN 17200:2023 Construction products: Assessment of release of dangerous substances - Analysis of inorganic substances in digests and eluates - Analysis by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) [57]

- **organic substances:**

Legislation

EN 17332:2023 Construction products: Assessment of release of dangerous substances - Analysis of organic substances in eluates [58]

Quick tips

With regard to a lack of harmonised requirements or classification concerning the release of dangerous substances to groundwater, marine waters, surface waters or soil, the results are assessed based on national requirements.

PRODUCT EVALUATION BASED ON CHEMICAL COMPOSITION AND/OR ORIGIN OF RAW MATERIALS

In order to evaluate the content and release of dangerous substances from circular products, the chemical composition and origin of raw materials the products are made from shall always be assessed individually. To that end, one shall refer to the European and national requirements for the components of secondary materials. Some examples are presented below.

Radioactivity assessment applies to construction products that contain radioactive ingredients listed in Directive of the Council 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom [59].

Legislation

LEGISLATION CONCERNING RADIOACTIVITY ASSESSMENT:

EU: Directive of the Council 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom [59].

The presence of persistent organic pollutants that accumulate in the environment prevents the reuse and recycling of CWD products. The Regulation of the European Parliament and of the Council (EU) 2019/1021 of 20 June 2019 on persistent organic pollutants (POP) [30] limits the application of toxic chemicals in recycled materials. The Regulations bans using, e.g. construction waste such as concrete, bricks, panels and ceramics containing unacceptable quantities of compounds mentioned in Annex V to the document [30].

The REACH regulation [33] also applies to assessing dangerous substances in construction products. Annex XVII to the Regulation contains requirements for specific chemical compounds. Item 23, Annex XVII to the REACH regulation [33] on cadmium is a good example for circular economy. It states that plastic mixtures and products must not be marketed if cadmium concentration (expressed as metallic cadmium) equals or exceeds 0.01% of the weight of plastic. For mixtures produced from PVC waste, hereinafter called “recovered PVC”, products and mixtures containing recovered PVC can be marketed if cadmium concentration (expressed as metallic cadmium) does not exceed 0.1% of the weight of plastic. Moreover, before mixtures and products containing recovered PVC are first marketed, the suppliers shall label the products and mixtures visibly, legibly and durably in the following way: “Contains recovered PVC” or a relevant pictogram.

4.3. Technical requirements for construction products

The basic CPR [32] requirements include technical requirements for products, regardless of whether they are produced according to linear or circular economy principles, but which are fundamental for fulfilling the products' intended use and function. They include:

- load-bearing capacity and stability,
- fire safety,
- safety of use and accessibility of structures
- protection against noise,
- energy saving and thermal insulation.

Quick tips

Construction products whose manufacturing does not employ primary raw materials or requires their significantly reduced amounts shall fulfil the same technical requirements as products manufactured in accordance with linear economy principles.

If secondary processing of construction products is intended, it should be considered whether their recovery shall be environmentally and economically beneficial. In other words, if it improves or deteriorates the product's characteristics (upcycling or downcycling). Good quality secondary construction products, with parameters not inferior to the primary products, which are safe for use and environmentally friendly, shall guarantee an increased social trust in recycled products.

Determining the product type in the context of CPR [32] requirements is vital for secondary construction products. This means the product should be homogenous and produced from a repetitive combination of raw materials with the same characteristics. Hence, the physical characteristics of recyclates should be confirmed based on the current production control. Standards for recyclates, determining their technical characteristics, are helpful. The same is true for reusable construction products.

Quick tips

At the current stage of legislative work, there are no standard requirements for the reuse of construction products.

Examples of standards for plastics that contain recyclates:

- EN 15347:2008 Plastics - Recycled Plastics - Characterisation of plastics wastes [60]
- EN 15343:2010 Plastics - Recycled Plastics - Plastics recycling traceability and assessment of conformity and recycled content [61]
- EN 15342:2008 Plastics - Recycled Plastics - Characterization of polystyrene (PS) recyclates [62]
- EN 15344:2021 Plastics - Recycled plastics - Characterisation of Polyethylene (PE) recyclates [63]

The innovativeness enabling the recycling or reuse of secondary materials is another challenge from the viewpoint of technical requirements. Examples of such solutions are described in the following chapter ***(chapter 5)***.

5. Reuse of construction, renovation and demolition (CRD) waste - case study

This Chapter presents the possibilities of reusing or recycling selected post-demolition building materials. Moreover, each item mentions the related limitations.

5.1. Structural timber

Structural timber is used in construction and structures for frames, scaffolding, beams, posts, load-bearing walls and other structural items.

Waste structural and demolition timber (e.g. used pallets, floor planks, doors or tables) is shredded by industrial machines. Shredded wood can be further processed chemically or mechanically to remove other contaminants and prepare for further processing. Raw materials made this way can be recycled and used to manufacture new wooden products, e.g., fibreboard or chipboard. Some wood is sent to cogeneration and power plants as biomass and further processed into briquettes or pellets (fuel). Some waste wood can be used to produce various composite materials, but much of the remaining wood is turned into compost. Timber also used to produce thermal insulation products for buildings, such as industrially produced wood wool (WW) [64] or wood fibre (WF) products [65]. Information on the requirements for wood-based panels using recycled content could be found on European Panel Federation page [66]. These are mainly requirements for the chemical composition of the waste wood.

One should remember that not all wood types are suitable for recycling. Structural timber can be contaminated, depending on its application and history of use. Structural timber is often painted or varnished to protect and maintain its aesthetic appearance. Moreover, as a natural material, wood is vulnerable to damage by insects, mould and dampness, so regular maintenance should protect it from hazards (e.g., impregnating agents). Such treatment often disqualifies the wood or reduces its reuse potential. Paints, varnishes and impregnates may contain chemical substances that are either toxic or hard to dispose of. Metal items, e.g. nails, screws and fittings embedded in structural wood, may cause contamination with heavy metals or other compounds. During the construction of buildings, timber is bonded with glues or sealants with other structural components. Some glue or sealant ingredients may contain chemicals detrimental to the environment.

Due to its nature, wood can be contaminated with such natural substances as resin, oils or other organic substances. Once exposed to humidity, wood can become the habitat of microorganisms and mould, affecting its durability and condition.

All the contaminants may pose a challenge for wood recycling. Before taking any recycling measures, the contaminants shall be carefully examined and their type evaluated to select the proper wood processing and cleaning methods. If possible, the substances should be removed to ensure better wood processing. Effective recycling of wood infected with pests or too damaged can be hard or even impossible.

5.2. Steel, reinforcement steel, reinforced concrete composites

Steel means an iron alloy with a small amount of carbon (typically from 0.02% to 2.1%) and other alloy additives subjected to plastic treatment. Reinforcement steel stands for bars or wires made of steel of very high tensile strength. Reinforcement concrete composites, also known as ferroconcrete, are common in construction where strength and durability are required. They consist of two main components: concrete and reinforcement steel. Combining two materials makes the best of their synergic characteristics to achieve strength, load-bearing capacity and durability higher than for each material individually.

Steel scrap is a secondary material acquired through steel and metal recycling. Although the term "scrap" might suggest that the product is waste, in fact, it is a valuable raw material used for steel production. It consists of waste metal that is collected, processed or transformed (smelted) into new products or raw materials. Scrap metal includes structural components from demolition and mechanically damaged steel structures corroded or unsuitable for further safe use. Steel scrap is important from an environmental and economic point of view because its recycling helps reduce the demand for primary metal production and mining, resulting in lower consumption of energy and natural resources [67].

Recycling steel scrap involves melting it in industrial furnaces, followed by casting into moulds to create new steel products. Steel production covers various methods and processes to transform iron- and carbon-based raw materials into products with specific mechanical and chemical characteristics.

In a traditional blast furnace process, iron ores and coke (iron-based raw materials) are placed in a huge furnace. A high temperature and reduction process help separate iron from other ingredients. The pig iron produced this way is then processed to make steel. In the BOF (Basic Oxygen Furnace) process, ferrous raw materials and alloy additives are subject to an oxygen reaction in a converter, leading to the removal of excess carbon and other contaminants. The blast furnace-basic oxygen furnace (BF-BOF) route can use up to 30% of recycled steel.

The charge in electric arc furnaces (EAF) is heated with electric art, reaching the temperature of several thousand degrees Celsius, which enables the melting of steel raw materials or scrap. The electric arc furnace (EAF) steel production method can use only recycled steel. Electricity-based steel production uses electrical energy to melt charges of up to 100% of scrap metal to make new steel products [68].

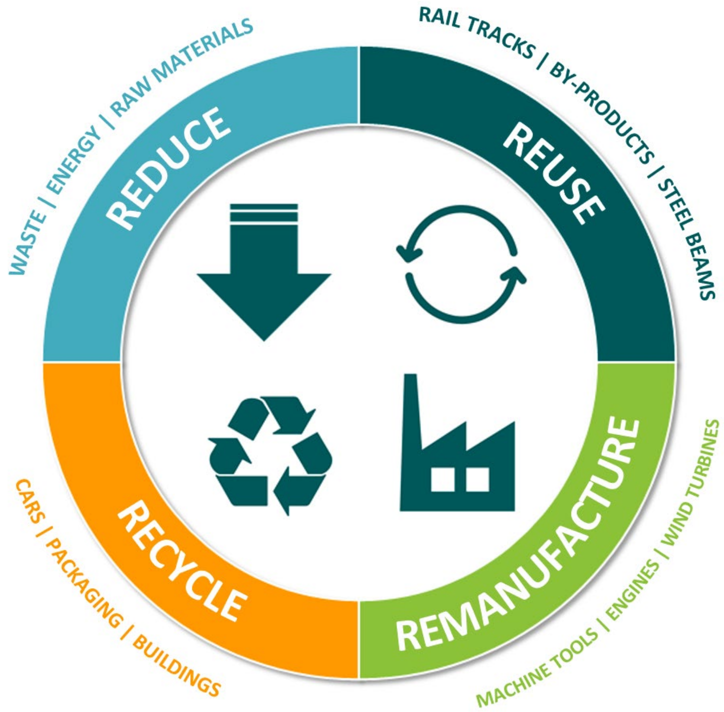
Quick tips

Steel is a material that perfectly matches sustainable construction assumptions. Generally, steel characteristics remain unchanged regardless of the number of recycling cycles [69].

Steel intended for recycling should be carefully selected, i.e., free from glass, plastic, paper and aluminium components. Owing to magnetic sorting, it is also relatively easy to recycle. A higher contamination rate of scrap metal negatively affects the metallurgical processes and hence generates more metallurgical waste, consequently increasing steel manufacturing costs. Regardless of the recovery rate, recycling steel items generates side products, e.g., mineral compounds such as steel-making gravel or foundry furnace gravel. The products can be used for road construction, enriching soil and producing industrial raw materials.

Steel structures are more environmentally friendly than reinforced concrete structures. The recovery percentage of steel scrap (non-ferrous metal scrap) is relatively high because steel is among the most commonly recycled materials globally. According to various sources and statistics [69], steel scrap recovery ranges from 70% to over 90% in some countries [70]. The reinforced concrete recovery rate can be lower than that of reinforced steel alone because concrete recycling requires more complex processes.

Fig. 7: Steel in circular economy (based on [71])



5.3. Glass

Structural glass means various types of glass designed and processed to fulfil specific construction, aesthetic and functional requirements. Sodium-lime-potassium-silicate glass types are most popular for structural glass. Flat glass such as float (sodium and lime), tempered, laminated, insulation, reflective and soundproofing glass is used in construction. Float glass is manufactured by melting silica, soda and lime. It is characterised by good transparency and a smooth surface. Its typical applications include windows, doors, facades, mirrors, etc.

Glass fibre production is an example of a special glass application. The fibres are manufactured by stretching or elongating molten glass to form fibres. Then, the fibres can be combined and fixed with resins to create an extremely durable and lightweight material with numerous applications. Glass fibres can be added to concrete to improve its tensile strength and cracking resistance; they can also be used in prefabricated construction items, e.g. partitions, flooring panels, stairs or facade components, or added to flooring concrete. Glass fibres are used for making composite reinforcing bars that are a green alternative to reinforcing steel bars.

Glass powder, also known as ground glass, is a ground powder obtained by fragmenting glass into fine particles. It is used as an addition to cement and concrete as a substitute for fine aggregate (dusty fraction) or as a binder ingredient, depending on the glass powder's reactivity. Such glass does not require colour segregation and most likely can be used even if slightly contaminated with mortar or concrete. The optimum added quantity of glass powder can be up to several dozen per cent of the cement mass - above the value, concrete characteristics gradually deteriorate versus the control concrete. The value varies depending on the waste and the degree of its shredding. Many studies describe glass application as fine aggregate for concrete. It should be emphasised that the attempts to use glass aggregate or glass powder in concrete or cement have recently gone beyond the laboratory stage.

Glass can be recycled with no quality loss, theoretically in 100%, provided that the material selection is stringent. Glass intended for recycling shall have a uniform composition and be free of contaminants like metals, plastics or wood. The contaminants can negatively affect the quality of the processed glass and be hard to remove. In practice, glass is often contaminated and separating its coats (in laminated glass or glass composites) tends to be uneconomical, so the actual recycling rates are low. Sometimes, whole glass panes can be reused, but typically glass cullet is acquired.

Unfortunately, even minor differences in the packaging and structural glass composition mean that the glass cannot be mixed as such a condition affects the strength and safety of end products. That is why glassworks manufacturing flat glass can use only the cullet from adequately sorted flat glass. The requirements for float glass are higher than those for packaging glass. Cullet from recycling, despite being purified, is not an ideal raw material, so its management poses most problems. Tests on glass containing 30% and 60% of recycled float glass cullet proved that it can be safely used for commercial glass melting [72].

Glass cullets can be used as raw materials for glass fibre production, including concrete reinforcement. Glass fibre applications include concrete scattered reinforcement or polymer and glass composites resistant to corrosion and chemicals.

In 2017, the leaders of the European glass industry developed the ECN-E-17-010 document [73] on the criteria for applying for end-of-waste status, e.g. for flat glass. It was discovered that the end-of-waste status of glass cullet from demolition would increase the recycling scale as it would not entail so many administrative formalities.

The total amount of glass waste from renovation and demolition of buildings in 2013 amounted to 1.5 million tons in the EU; 58% of it originated from the housing sector and 42% from services. These are only estimated data [72].

Quick tips

Currently, full glass recycling encounters a significant problem: effective selective demolition of buildings and adequate glass segregation/conditioning. Cullet from demolition of buildings is mixed with debris, PVC foil or metal chips and not all contaminants can be removed, even by specialised recycling companies. There are plenty of applications for high-quality cullet, and managing clean glass waste is not a problem.

Recycling laminated glass causes problems because it is more complex than single-layer glass recycling, as laminated glass consists of two or more glass layers bound with polymer foil. Such a structure makes the application of traditional glass recycling methods more difficult, involving melting and processing into new products. Still, some methods and technologies enable the recovery of laminated glass components and their use in industrial processes. Considering the increasing interest in sustainable management of raw materials, the emergence of new technologies and methods can be expected to facilitate more effective recycling of laminated glass.

Structural glass, due to its characteristics and nature, shall be segregated as early as possible during the building's renovation/demolition (before heavy-duty equipment enters the site) by removing and protecting the windows/railings/tiles. Glass shall be segregated according to colours and types or as transparent and tinted; coats, metals and foil layers should be removed at the initial stages of recycling, and then the glass is enriched. Glassworks use it as raw material, decorative material (crushed glass) and in the production of insulating materials (glass wool, fibreglass cloth).

5.4. Plastics

Polyvinyl chloride, used for cladding, flooring, window profiles, window shutters, pipes and cables, is the most popular type of plastic used in construction. Polystyrene (PS), typically in the form of expanded polystyrene (EPS) and extruded polystyrene (XPS), is another polymer popular in construction. Styrene is used for making XPS foam panels (commonly known as Styrofoam panels). Polyurethane (PU) makes a perfect insulating material due to its thermal insulation properties. Essentially, these materials are employed in construction as insulating panels on the outer walls, ceilings, floors on the ground and other partitions and as sandwich board core. Rigid insulation has become a notable construction material, using PU, polyisocyanurate (PIR, polyiso or ISO) and PS [74].

High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE) constitute a popular construction material, mainly in pipes [75]. Carpets are another major application area that uses polymeric synthetic fibres such as nylon, polypropylene (olefin), acrylic, and polyester.

Even though plastics are highly recyclable, in 2020, the share of plastics in recycled CRD waste amounted to only 5.1% globally [76]. There are two essential methods of plastics recycling: chemical and feedstock recycling, where XPS can be molten or dissolved, and the recovered polystyrene monomers can be reused to produce new polystyrene, typically by injection moulding [77]. The recycling process is selected based on the waste stream complexity and contamination rate [78]. Many manufacturers of XPS foam panels implement their various manufacturing methods based on recycled material, typically from own production waste. Many ISO and industry standards on plastic products are intrinsic to ensuring adequate quality of materials from plastics production.

Actually, primary plastics are preferred over plastics from CRD recycling because of the known amount of additives and high production performance; moreover, they are better value for money. Nevertheless, as described in many publications, an adequate and controlled content of recycled CRD in new products does not deteriorate their performance [81].

Cost-consuming solutions dominate the global technologies of XPS waste recycling. During thermal processing, XPS foam panels can be incinerated in dedicated facilities where waste is transformed into heat or electrical energy. This method can be used whenever other recycling methods are impossible or non-economical. Regardless of technology, the fact and method of segregating XPS and other plastics on the renovation or demolition site significantly improves recycling profitability.

Interestingly, the highest amounts of XPS waste are generated during thermal insulation improvement works. According to estimates, waste can constitute up to several per cent of the applied material for façade surfaces in buildings with many windows, balcony slabs and loggias [79].

The characteristics of XPS products containing recycled polystyrene should enable fulfilling all technical requirements resulting from the expected conditions of their use in buildings, especially within their strength, resistance to external factors and safe use. Taking the last aspect into account, special attention should be paid to flame retardants - antipyrenes - that inhibit combustion processes. Hexabromocyclododecane (HBCDD) is among the most common compounds. Considering the large scale of XPS consumption and the amount of waste generated at the construction, extension, refurbishment, and demolition stages, it is purposeful to develop a method to control residues of dangerous antipyrene used for manufacturing XPS construction products.

With regard to HBCDD toxicity, persistence and high bioaccumulation potential, the following shall be performed: an analysis of the XPS' chemical composition (raw materials, pigments, flame retardants, auxiliary agents), XPS assessment for the content and release of dangerous substances, XPS testing for flame retardant (hexabromocyclododecane (HBCDD) content and elemental analysis [79]".

5.5. Gypsum (gypsum boards)

Standard gypsum boards consist of the gypsum core and paper (cardboard) layers. A traditional gypsum board contains approximately 90-95% of gypsum. The rest belongs to modifiers and paper layers surrounding the gypsum core and adding to the board's stability and surface finish. The exact ratios may vary depending on the board manufacturer and type.

Gypsum boards are collected from their dismantling or removal sites, e.g. from renovated or demolished old buildings. Then, they are segregated to be separated from other materials, such as metal clamps or other components. The next step involves separating gypsum from paper layers. Recovered gypsum can be subject to processes restoring its raw material status. The gypsum can be reused to make new gypsum products such as gypsum boards or other construction products.

Gypsum powder, a secondary material from the recycling of gypsum boards, can theoretically be recycled many times, and its chemical composition is expected to remain the same as that of the original raw material. Gypsum powder is a crucial ingredient in producing various building materials, including gypsum cardboard, gypsum plaster, gypsum putty, etc. Combined with water, gypsum powder is subject to hydration, forming a solid mass, which makes it perfect for surface finishing and reinforcing. A low price of the primary raw material, which typically is waste from flue gas desulphurising in power plants/cogeneration plants, is the main problem when using gypsum waste. Shifting the energy generation to sources other than the combustion of fossil fuels shall reduce the amount of gypsum raw material, offering the opportunity to use recycled gypsum.

In many member states, waste is collected from demolition sites, and a full-value secondary material is supplied as gypsum powder directly to construction product manufacturers. An increasing number of studies are devoted to identifying how many recycling cycles can be performed to obtain mechanical characteristics no worse than those of products made from primary raw materials. Nonetheless, gypsum products are among a few construction product types that can be recycled many times.

Gypsum from waste gypsum boards can also be used in concrete or, more precisely, in cement production. Recycled gypsum can substitute natural gypsum to control cement binding time. Nowadays, natural gypsum is rarely used as a cement ingredient or in the production of building materials. Power plants and cogeneration plants, where gypsum is waste from wet desulphurisation of flue gases, are the primary sources of raw materials for gypsum products. A low price and better quality of gypsum raw materials from coal-fired power plants pose a problem for gypsum debris reuse. Using it as a full-value substitute for natural gypsum in cement production is the subject of many studies.

In accordance with the Directive of the European Parliament 2003/33/EC [80], waste containing gypsum should be stored in separated and adequately secured areas, as storage of gypsum waste together with municipal waste causes severe hazard to the natural environment. Gypsum in contact with water may trigger chemical processes that cause the acidification of soil, groundwater, and surface water, affecting the organisms in the ecosystem. Calcium sulphate can precipitate in water, forming gypsum deposits that block the flow of natural waters. Sulphur in gypsum contributes to the formation of toxic hydrogen sulphide.

5.6. Mineral waste (concrete, brick, cement, ceramic tiles)

Concrete is formed by mixing cement, fine and coarse aggregate, water, admixtures (if any), fibres and mineral additives, e.g. fly ash, granulated blast furnace slag and silica dust. Concrete is a set-ratio mixture that gains durability and strength after mixing and hardening, becoming suitable for various applications, including construction. Structural concrete in building structures is additionally reinforced (rebars, fibres, reinforcing mesh). Standard recycling of structural concrete covers crushing into smaller fragments, magnetic separation of the reinforcement (metal scrap) and sorting into the required fractions with screens.

Construction debris is formed due to renovation and construction works during the demolition and dismantling of buildings. If waste is selectively collected and processed on the demolition site, e.g. by mobile crushing stations, it can be reused as the foundation substructure for a new structure constructed thereof. This requires adequate demolition planning and organisation.

Quick tips

Aggregate from concrete recycling can be used for non-construction or auxiliary (substructure) concrete. Aggregate obtained this way can be used for pavements of roads, yards, driveways, and walkways; material for prefabricated items; sub-crust of hardened surfaces; or filling excavation sites.

Nevertheless, one should remember that about fifty million cubic metres of concrete mix globally is not embedded and returns to ready-mixed concrete production plants. The construction industry struggles with the problem of unused concrete manufactured for specific projects. This situation results from design modifications or implementation errors. Returning unused concrete mix to its manufacturer can be problematic because of costs, disposal management and harmful environmental impacts. Some ready-mixed concrete production facilities feature systems for partial recycling of concrete mixes. The systems help divide the concrete mix into aggregate and particle suspension in water. Coarse aggregate is almost fully recovered and reused in new concrete. The Assessment of mixing water's suitability for concrete, including the mixing water recovered from concrete industry processes, enables the use of suspensions generated as waste during concrete production [81]. Concrete mix manufacturing plants that do not have systems for recovering ingredients from non-cured mix, send the unused concrete to a local storage yard where it is periodically processed by crushing. The rubble formed this way is then added to concrete with low strength class for non-structural applications.

Non-homogenous composition, non-uniform dimensions, and poorer functional characteristics (mechanical and physical) of recycled aggregate compared to natural aggregate pose the main problem when using concrete debris for concrete production. In order to use recycled aggregates, some additional efforts might be required, including cleaning, crushing, washing, increasing cement content in the concrete mix, as well as valuable additives in the concrete formula [82], which in turn increases concrete manufacturing price. On the other hand, prices of natural aggregates are expected to rise as renewable natural resources exhaust and transport prices increase. Still, the prices of recycled aggregate are expected to go down with further advancement of recycling methods. Opportunities for reusing concrete rubble for concrete production are outlined in EN 206 [83] as a recommended maximum content instead of natural aggregates. The limit share of concrete rubble mainly depends on its quality, exposure classes and types of environmental aggression that the newly produced concrete will be exposed to. The Rilem group developed more detailed recommendations for selective demolition of concrete structures and the most effective methods of using rubble obtained this way to produce new concrete mix [84-85].

Brick is a masonry component made of clay-based raw materials by forming, drying and high-temperature burning. During burning, a chemical reaction occurs that hardens the brick and leaves it durable and robust. There are several types of brick, including clay, concrete (cement as the binder's main component + sand and aggregate), ceramic (clay and ceramic clay), and chamotte.

Brick debris, formed by crushing or refining used brick, can be used as recycled material in various construction and infrastructural applications.

Quick tips

Road construction (road substructures, walkways and pavements) is the main application area of brick debris (typically brick and concrete debris). Refined brick debris can be used as a substitute for some traditional aggregates in concrete mixes and mortars and as a drainage layer in gardens or other areas requiring effective water removal.

Opportunities for using brick debris in concrete mixtures are limited due to its absorbability and negative impact on most strength and durability characteristics. Brick content in concrete rubble used for concrete mix production is typically treated as contamination. Using brick debris from building demolition is most economical on the site, e.g., for soil reinforcement or embankment.

Brick rubble is used in road construction for ground forming and compacting (brick rubble with lime) for making preliminary substructures and hardening. Considering the fact that brick rubble is a brittle and highly absorbent material (porous and hence absorbing high quantities of water), brick rubble substructures are recommended for low-traffic roads, e.g. in rural areas, forests or as temporary roads in building sites, festivals and other events. In such cases, brick rubble is a cheap and functional construction material. It can be laid under bicycle lanes, walkways, car parks and playgrounds.

The acquisition method matters for brick rubble, as debris should be selectively collected and processed already on the demolition site. Traditional demolition methods are not possible in such cases, and they need to be replaced by gradual dismantling, with the materials divided into fractions. Careful dismantling of brick structures can help recover whole bricks. Building materials obtained this way can be reused in construction - after adequate cleaning - as decorative or structural items or partitions. Previously, bricks were cleaned only by manual hammering of their surfaces. Nowadays, automated cleaning has become popular, without any chemicals and based only on vibrations. Parts of façade face bricks, several centimetres thick, are used as tiles in modern interiors.

The presence of mortars and plasters on the brick surface constitutes the primary constraint for their reuse as wall elements. Leaving the lime and cement, cement-only, or gypsum layers deteriorates the appearance and durability of the new wall. Old mortar weakens the contact between bricks. It is porous and so accumulates harmful environmental pollutants and absorbs water unpredictably.

6. Summary and conclusions - prospects and directions for circular economy development in the construction industry

The main factors contributing to the low level of construction products processing after the end of their life include a lack of knowledge among demolition entities as to the economic benefits and fitness for recycling owing to the proper deconstruction method; low availability of contamination-free - and hence recyclable - building waste, and a lack of experience and processing technologies enabling the use of recycled building materials. Implementing effective recycling processes requires collaboration between producers, recyclers and regulatory bodies to ensure effective and profitable recycling processes. The Guidebook's authors perceive it as a great opportunity, which will require many endeavours and raising awareness of the target groups mentioned above. We hope the Guidebook will contribute to the outcome.

At the current stage of legislative work, there are no standard requirements for the reuse of construction products. Legislative works on reusing construction products from demolition or deconstruction would strengthen the circular economy practices. If legislation were to include the "reuse" characteristic, the conditions for the product recycling should be specified, along with the expected conditions of use to ensure its suitability for reuse and/or the methods of assessing its parameters after the end of life. One should remember that determining the product type, and hence its performance, in accordance with the CPR definition is a challenge for recovered items. That is why the change must start at the legislation development stage.

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8. List of figures

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