

Construction and Demolition Waste: challenges and opportunities in a circular economy

January 2020



European Environment Agency
European Topic Centre on Waste and
Materials in a Green Economy



Authors:

Margareta Wahlström (VTT), Jef Bergmans (VITO), Tuuli Teittinen (VTT), John Bachér (VTT), Anse Smeets (VITO), Anne Paduart (VITO)

ETC/WMGE consortium partners: Flemish Institute for Technological Research (VITO), CENIA, Collaborating Centre on Sustainable Consumption and Production (CSCP), Research Institute on Sustainable Economic Growth of National Research Council (IRCrES), The Public Waste Agency of Flanders (OVAM), Sustainability, Environmental Economics and Dynamic Studies (SEEDS), VTT Technical Research Centre of Finland, Banson Communications Ireland (BCI), The Wuppertal Institute for Climate, Environment, Energy (WI), Slovak Environment Agency (SEA)

Cover photo © Jef Bergmans

Layout: Evelien Dils

Legal notice

The contents of this publication do not necessarily reflect the official opinions of the European Commission or other institutions of the European Union. Neither the European Environment Agency, the European Topic Centre on Waste and Materials in a Green Economy nor any person or company acting on behalf of the Agency or the Topic Centre is responsible for the use that may be made of the information contained in this report.

Copyright notice

© European Topic Centre Waste and Materials in a Green Economy (2020)

Reproduction is authorized provided the source is acknowledged.

More information on the European Union is available on the Internet (<http://europa.eu>).

European Topic Centre on Waste and Materials

in a Green Economy

Boeretang 200

BE-2400 Mol

Tel.: +14 33 59 83

Web: wmge.eionet.europa.eu

Email: etcwmge@vito.be

Contents

Acknowledgements	1
Executive summary	2
Key findings	2
1 Introduction and objectives	5
1.1. Background and objectives	5
1.2. Methodology	5
2 Policy background	8
3 Current status of the management of construction and demolition waste	10
3.1. Generated amounts	10
3.2. Treatment.....	11
3.3. Backfilling.....	13
4 Circular economy action affecting the generation and recycling of construction and demolition waste	15
4.1. Circular economy action in the built environment	15
4.2. Selection of action for better construction and demolition waste management.....	17
5 Effect of the selected action on prevention and recycling of construction and demolition waste	18
5.1. Concept 1. High-grade products with high recycled content.....	18
5.1.1 Description of concept	18
5.1.2 Drivers and barriers – boundary conditions.....	19
5.1.3 Case study.....	20
5.1.4 Conclusions.....	21
5.2. Concept 2: Design phase: design for disassembly.....	21
5.2.1 Description of concept	21
5.2.2 Drivers and barriers – boundary conditions).....	22
5.2.3 Case study.....	23
5.2.4 Conclusions.....	25
5.3. Concept 3: Construction phase: materials passports.....	26
5.3.1 Description of concept	26
5.3.2 Drivers and barriers – boundary conditions.....	26
5.3.3 Case studies.....	27
5.3.4 Conclusions.....	28
5.4. Concept 4: Extension of service life of constructions	28
5.4.1 Description of concept	28
5.4.2 Drivers and barriers – boundary conditions.....	29
5.4.3 Case study.....	29
5.4.4 Conclusions.....	30
5.5. Concept 5: Selective demolition to enable reuse and high-quality waste for recycling.....	31

5.5.1	Description of concept	31
5.5.2	Drivers and barriers – boundary conditions.....	32
5.5.3	Case studies.....	33
5.5.4	Conclusions.....	34
5.6.	Key elements to achieve circular scenarios in construction	35
6	Future development of construction and demolition management	38
7	Climate benefits.....	42
8	Policy options for facilitating the interplay between circular economy implementation and construction and demolition waste management.....	45
8.1.	Summary of the circular economy actions leading to better C&DW management.....	45
8.2.	Options for better construction and demolition waste management.....	45
9	References.....	48
10	List of abbreviations	54

Acknowledgements

The report has been produced within the task on Construction and demolition waste – state of play of the 2019 ETC/WMGE work programme. Ioannis Bakas (EEA) was the project leader and Margareta Wahlström (ETC/WMGE) the task leader.

The authors of the report are: Margareta Wahlström (VTT), Jef Bergmans (VITO), Tuuli Teittinen (VTT), Anse Smeets (VITO), Anne Paduart (VITO).

Ioannis Bakas (EEA) and Simone Manfredi (JRC) contributed to the report's design and production. Bart Ullstein (BCI) provided editorial support. John Bachér contributed to the final version of the report.

Executive summary

About 374 million tonnes of construction and demolition waste (C&DW) were generated in 2016 (Eurostat, 2019a) making it the largest waste stream in the EU by weight. Construction and demolition is defined as a priority area in the EU according to the Circular Economy Action Plan (EC 2015) for closing the loop, while the revised Waste Framework Directive (WFD 2008/98/EC, amended 2018/851) sets a mandatory target for its recovery of 70 per cent by 2020. Despite high recovery rates, however, C&DW is often downcycled. This report includes a short review of the current status in C&DW management in the EU as a background.

The recent Circular Economy Package, launched by the European Commission (EC 2018a), is unfolding, placing a new perspective on waste management policy making, namely that of the transition to a circular economy. This report explores how circular economy-inspired action in the built environment can directly contribute to increasing the prevention, reuse and recycling of C&DW.

In a circular economy, raw materials are not taken out of their cycles, but remain in the economy for as long as possible through their efficient and smart use. Their value is preserved by optimising reuse or high-grade recycling. In the built environment, this means buildings and construction elements being designed to be easily adaptable and/or dismantlable with hardly any being demolished. Building materials or building elements should be quickly and efficiently recovered, resulting in high-quality materials remaining in a closed loop. Furthermore, it is important to broaden the scope of action which can influence waste management to cover other stages of the lifecycle of buildings and other structures. Circular economy inspired action made in the early stages of a building's lifecycle may affect the management of the building's waste in a profound way.

The starting point for this study was to identify potential circular economy action during the whole lifecycle of construction products from design to end of life. A set of criteria for assessing the effect of selected circular economy action on the C&DW management at the EU level was developed. In addition to these criteria, the action were chosen in such a way that each takes effect at a different circular economy phase of the built environment. The following five are described:

- **material production phase:** new high-grade products with high recycled content;
- **design phase:** design for disassembly;
- **construction phase:** materials passports;
- **use phase:** lifetime extension of existing structures;
- **end-of-life phase:** selective demolition.

In reality, all cases and action are connected and benefits cannot solely be assigned to a particular stage of the value chain.

Key findings

Currently, many bottlenecks, often linked with past or current building practices, hamper the transition to a circular economy in the built environment. To make an economy truly circular, it is necessary to take additional measures by focusing on the whole lifecycle of construction products in a way that preserves resources and closes the loop.

The cases and examples analysed in this report show the potential that increased circularity considerations during a building's lifecycle have on the fulfilment of waste policy objectives. Often the benefits are highly case specific due to additional processing needs, such as energy, or environmental impacts from required maintenance and rehabilitation. The total environmental impact of these circular economy solutions depends on the whole, or multiple, lifecycles of structures, which can be decades.

All the cases presented lead to improved C&DW management in the long term. The introduction of reuse solutions, the reduction of material consumption and use of lower-carbon alternatives, especially in the

design and construction phases, will provide significant environmental benefits – waste prevention and less waste generated. Furthermore, in recycling concepts, the partial substitution of cement with other raw materials may in future lead to significant CO₂ savings.

Some common barriers were identified in all cases reviewed, primarily economic but also quality issues and delays in disseminating measurable results. Manufacturing processes using waste as input material will only work when production costs are lower than the cost of using virgin materials and market uptake can be assured. In the future, a shortage in primary resources may change these market conditions in regions with limited mineral resources. Policy measures may have a strong influence on these market conditions through for example taxes on virgin materials. Examples of other policy measures are green public procurement, taxes on landfilling, end-of-waste (EoW) criteria and extended product responsibility (EPR). However, EPR may not be appropriate for products that remain in a building over its lifetime.

Besides the economic factors, the quality of building products and materials is crucial for the uptake of circular economy solutions. Lack of available documented information regarding the origins of waste and data on the composition of historical construction products can create doubts about their quality. The use of traceability systems for recyclables and reusable products is mentioned in several cases as crucial for creating confidence among stakeholders in the value chain. In several cases also the importance of building information modeling (BIM) was brought up as a tool for material inventories and traceability as it carries information on construction products during their whole lifecycle up to the deconstruction stage. Passports for building materials can also be created to include information for maintenance, reuse and recycling. Traceability systems, BIM and materials passports can all support pre-demolition audits for identifying reusable and recyclable construction products. Policies can promote these system and technologies, certainly in construction works issued by the government, through for example green public procurement.

The delay, often of several decades, in measurable circular economy gains in the construction sector may discourage stakeholders from taking action on new material or product management solutions. A successful implementation of circular economy concepts requires support from all stakeholders in the value chain. Furthermore, it is challenging for manufacturers to retain responsibility for products that will remain in place for very many years. In future, voluntary schemes for sustainable buildings will probably influence the uptake of new approaches and designs with effects on the amount waste generated and also waste management.

Standardisation plays an important role in the assessment of performance of secondary materials in products replacing virgin ones and also in the design of construction products. Standardisation is often the base for certificates which are used in trade and business. Some standards include overspecification to secure performance, but this can lead to the increased use of raw materials. When standards are revised, attention could be paid to the evaluation of whether experience in construction performance and the introduction of tools to track material quality, including non-destructive testing methods, could support changes in material requirements.

Some of the barriers that are described in this report can be solved by integrating circular concepts over entire lifecycles. The examples provided are highly connected and benefits cannot solely be assigned to a specific stage of the value chain. Selective demolition, for example, enables high-grade recycling while design for disassembly supports lifetime extension (modular constructions are often easier to renovate), selective demolition and the high-grade recovery of materials.

Several examples in this document clearly indicate that a transition to a circular economy not only decreases material consumption and waste production, but can also lower greenhouse gas emissions. Climate action in the built environment is often strongly focused on the minimisation of greenhouse gas emissions during a buildings' lifetime. When this is implemented without taking the circular economy principles into account, it can have adverse effects on other lifecycle stages.

1 Introduction and objectives

1.1. Background and objectives

Construction and demolition waste (C&DW) is the largest waste stream in the EU by weight, of which the mineral content forming the biggest fraction (Eurostat, 2019a). Construction and demolition is defined as a priority area in the EU according to the Circular Economy Action Plan (EC 2015) for closing the loop, while the revised Waste Framework Directive (WFD 2008/98/EC, amended 2018/851) sets a mandatory target for its recovery of 70 per cent by 2020. The recycling potential of C&DW, although high in quantitative terms, is still under-exploited. The mineral fraction of C&DW, for example, is currently mainly being used in road foundations or backfilled. The recovery performances, although high, differ significantly between EU Member States, varying in 2016 between 54 and 100 per cent (Eurostat, 2019b)). However, data on C&DW are currently not sufficiently robust; for instance, Member States have differing understanding and accounting systems for recovery operations of backfilling according to a European Commission study on C&DW management (Bio by Deloitte, 2017).

Although a 70 per cent recovery target for C&DW has been present in EU legislation since 2008, recent policy developments, such as the launch of the Circular Economy Action Plan (CEAP) in 2015, shed a new light in the way waste management is viewed.

This report aims to explore and consolidate the links between improved management of C&DW objectives and the principles of the transition to a circular economy. The recent Circular Economy Package, launched by the European Commission (EC 2018a), is unfolding, placing a new perspective on waste management policy making, namely that of the transition to a circular economy. Although waste management's role in achieving a circular economy is known, information and proof is lacking as to whether the adoption of circular economy thinking has an effect on waste management. The key question that arises is **how specific circular economy action can help reach C&DW management objectives**.

The circular economy aims to foster an economy that retains as much of the value of materials as possible, for as long as possible (EEA, 2016). This means that the quantity of recycling or reuse is no longer the only objective: the type of recycling and the avoidance of downcycling is crucial. To transition to a circular economy, action that goes beyond waste management and improved recycling is necessary, as all products' lifecycle stages need to be involved.

The policy objectives for C&DW management, as these appear in EU legislation are:

- the prevention of C&DW generation – prevention is at the top of the waste hierarchy as described in the EU's Waste Framework Directive (WFD);
- the reduction of hazardous substances in C&DW – this stems from the definition of waste prevention in Article 3 of the WFD;
- the recovery of at least 70 per cent of C&DW generated by 2020 – this also appears in the WFD;
- the reduction of greenhouse gas emissions from the management of C&DW – a broad environmental policy objective.

Additionally, the Circular Economy Package emphasises the importance of retaining the value of materials; in recycling, this means high-quality recycling.

1.2. Methodology

To explore the links between the implementation of circular economy-inspired actions and waste management of C&DW, in this report, a methodology was developed with the aim of identifying relevant circular economy action and showcasing examples that have contributed to the fulfilment of waste policy objectives. A stepwise approach was followed.

1. Describe the current situation in the management of C&DW in Europe.
2. Identify circular economy action relevant to C&DW management and identify criteria for the selection of a set of circular economy actions that would have an effect on C&DW management in the EU.
3. Analyse five circular economy actions in terms of their results in preventing waste production and increasing the recycling of C&DW and support this selection with evidence from the literature and examples of good practice.
4. Quantify, as far as possible, the potential effect of the selected action on better C&DW management – for example, environmental benefits related to fewer emissions and better material efficiency through the use of high-grade products.
5. Describe the future of C&DW management due to the transition to a more circular economy.
6. Describe and quantify the climate benefits of improved C&DW management due to the transition to a circular economy.
7. Outline policy options for implementing circular economy principles for a better C&DW management.

The geographical scope of this report covers all member countries belonging to the European Economic Area and the report attempts to present an aggregated European perspective.

For an analysis of the current management situation, data on C&DW generation and treatment in recent years reported to Eurostat were used as well as from the European Commission's reviews and reports on the implementation of EU waste rules (EC, 2018a, EC 2018b, Bio by Deloitte, 2017) as the main source of information.

The information on the European Commission's webpage on policies and strategies related to circular economy objectives and targets, and especially action relevant to C&DW management, provided the background in the development of the selection criteria for the cases to be analysed in this report. Potential action for better waste management at different lifecycle stages in the construction value chain was reviewed from literature.

Data mapping from literature on examples of technological solutions linked to the cases was carried out to compile concrete information on benefits and boundaries in the case studies. The main source was results from recent EU funded projects on C&DW management. Results from the following projects provided illustrative information for the selected cases:

- Horizon2020 project: Holistic innovative solutions for an efficient recycling and recovery of valuable raw materials from complex construction and demolition waste (HISER), 2015–2019 (www.hiser.eu).
- Horizon2020 project: Buildings as material banks (BAMB), 2015–2020 (<https://www.bamb2020.eu/>).
- 7th Framework Programme for Research and Technological Development (FP7) project: Innovative strategies for high-grade material recovery from construction and demolition waste (IRCOW).
- FP7 project: Advanced technologies for the production of cement and clean aggregates from construction and demolition waste (C2CA).
- SPIRE project: REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction (Re4) (<http://www.re4.eu/>).
- Horizon2020 project: Cost effective recycling of C&DW in high added value energy efficient prefabricated concrete components for massive retrofitting of our built environment (VEEP) (<http://www.veep-project.eu/>).

For reviewing future developments and climate benefits, reports and documents reflecting future visions and trends in the built environment were mapped. The following reports were especially useful as inputs for this study:

- Enkvist & Klevnäs, 2018, The circular economy – a powerful force for climate mitigation.
- Circle Economy, 2019, The circularity gap report 2019.
- Arup, 2016, The circular economy in the built environment.
- Deloitte Sustainability, 2016, Circular economy potential for climate change mitigation.

2 Policy background

The European Commission’s 2018 Circular Economy Package (EC, 2018a) is an overarching policy that also covers waste legislation. It is therefore not possible to distinguish between policies related only to waste legislation or circular economy concepts.

The revised WFD (WFD 2008/98/EC, amended 2018/851) defines the waste hierarchy in waste management, setting waste prevention as the highest priority (Figure 2.1). It sets clear targets for the reduction of waste and requirements for waste management and recycling, including quantitative recovery targets for C&DW, to be achieved by 2020. The Directive also introduces the end-of-waste concept and defines criteria to establish when a waste ceases to be a one and becomes a secondary product or material. According to the WFD, “Member States shall take measures to promote selective demolition in order to enable removal and safe handling of hazardous substances and facilitate reuse and high-quality recycling by selective removal of materials, and to ensure the establishment of sorting systems for C&DW at least for wood, mineral fractions (concrete, bricks, tiles and ceramics, stones), metal, glass, plastic and plaster”. Furthermore, it suggests that, by 31 December 2024, the Commission should consider setting preparing-for-reuse and recycling targets for C&DW and its material-specific fractions.

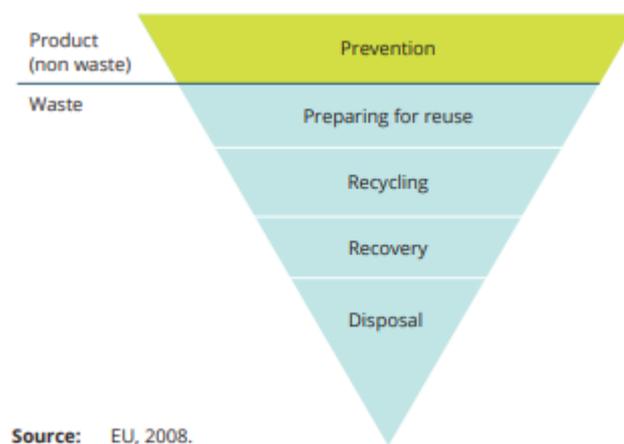


Figure 2.1. The waste hierarchy according to Waste Framework Directive.

In the revised WFD, Member States are encouraged to take appropriate measures to implement, among other things, the “production and marketing of products that are suitable for multiple use, that are technically durable and that are, after having become waste, suitable for proper and safe recovery and environmentally compatible disposal”, which stresses the importance of the design and production phases for waste management. Several examples of economic and other measures to provide incentives for the application of the waste hierarchy are listed in Annex IV.

Construction and demolition is mentioned as a priority area in the 2015 Circular Economy Action Plan (EC, 2015) and lists three actions related to C&DW required for the achievement of a circular economy. The following guidance or framework documents have been developed as a response to these actions (EC, 2019a) (Table 2.1):

- Waste Management Protocol: this aims to ensure recovery of valuable resources and adequate waste management in the construction and demolition sector.
- Waste Audit Guideline: pre-demolition guidelines to boost high-value recycling as well as voluntary recycling protocols aimed at improving quality and building confidence.
- EU Level(s) – European reporting framework for sustainable buildings: this aims to facilitate the assessment of the environmental performance of buildings.

Table 2.1. Action mentioned in Circular Economy Action Plan.

Action	Details
EU Construction and Demolition Waste Management Protocol (EC, 2016)	Any demolition, renovation or construction project needs to be well planned and managed to reduce environmental and health impacts while providing important cost benefits. The Protocol lists following actions to increase confidence in the C&D waste management process and the trust in the quality of C&D recycled materials: a) Improved waste identification, source separation and collection; b) Improved waste logistics; c) Improved waste processing; d) Quality management; e) Appropriate policy and framework conditions.
EU Waste Audit Guideline (EC, 2018c)	The Guideline describes the waste audit process and elements to be included in it. The waste audit, to be organised by the owner of a building or infrastructure, should results in an inventory of materials and components arising from (future) demolition, deconstruction or refurbishment projects, and provide options for their management and recovery.
Building sustainability performance – Level(s), (EC 2019b)	A tool for designing and constructing sustainable buildings. It is a voluntary reporting framework to improve the sustainability of buildings; it includes indicators reducing environmental impacts and for creating healthier and more comfortable spaces for occupants.

In 2019, an implementation report on revised waste legislation supporting a circular economy was published on the European Commission’s website. The document, Sustainable Products in a Circular Economy – Towards an EU Product Policy Framework contributing to the Circular Economy (EC 2019c), describes EU policies on products that influence the transition to a circular economy in selected priority areas, including construction. The document highlights that circularity and sustainability need to be assessed over the whole lifecycle of a building to optimise reductions of carbon emissions and material flows. Potential circularity in the construction sector is also discussed.

Work on a EU strategy for non-toxic environment mentioned in the 7th Environment Action Plan (7EAP) is continuing and publication has been postponed to 2020. The 7EAP mandated the European Commission to develop "a Union strategy for a non-toxic environment that is conducive to innovation and the development of sustainable substitutes including non-chemical solutions" by 2018. Identifying hazardous materials is of great importance in pre-demolition inventorying so that they can be removed from waste streams prior to recycling.

The UN 2030 Agenda for Sustainable Development also addresses resource efficiency. The Agenda defines 17 Sustainable Development Goals (SDGs) and 169 targets, which address the three pillars of sustainable development: economic, social and environmental. Particularly relevant goals for a circular economy/resource efficiency are:

- SDG 8.4: Improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead; and
- SDG 12.2: By 2030, achieve the sustainable management and efficient use of natural resources.

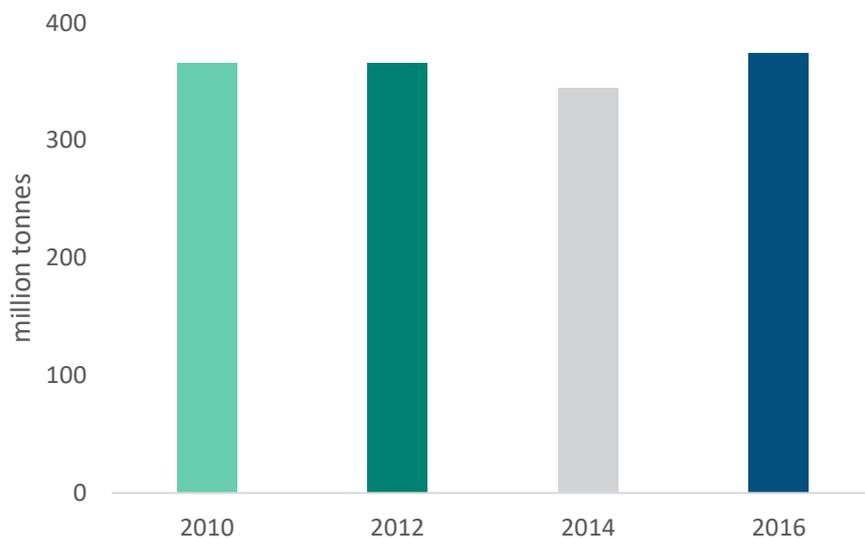
3 Current status of the management of construction and demolition waste

This section describes the implementation of Directives linked to C&DW, and waste policy objectives and targets as identified in Chapter 2.

The revised WFD requires the EU Member States to take the necessary measures to achieve the re-use, recycling and other material recovery, including backfilling, of a minimum of 70 per cent by weight of non-hazardous C&DW by 2020. The recovery rate to be used in verification of compliance is calculated based on the rules given in Annex III of Decision 2011/753/EU (EC 2011). In the calculation of the recovery rate, specific waste categories from the European List of Waste and equivalent Eurostat waste categories are included. It is notable that soil (waste code 17 05 04) is not taken into account in the calculations. Since Eurostat data on treatment does not provide information on the origin of wastes, with exception of mineral waste from construction and demolition, only the recovery rate for mineral waste can be calculated. This means that recycling rates are overestimated as a higher amount of the mineral fraction is recovered even if the rate is near actual for Member States in which mineral waste constitutes the major fraction.

3.1. Generated amounts

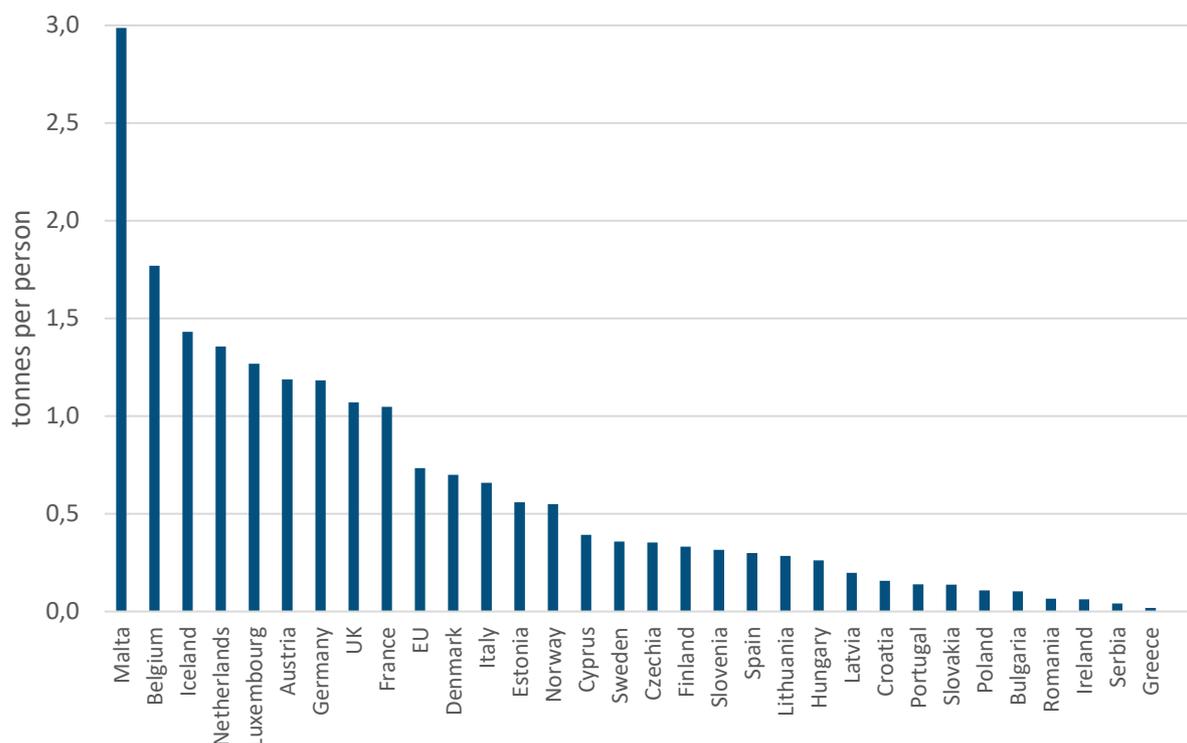
According to Eurostat data, in 2016, the EU generated around 374 million tonnes of C&DW (Eurostat 2019a) (Figure 3.1). The amount of C&DW generated is calculated as the sum of waste categories *W061 ferrous metal wastes*, *W062 non-ferrous metal wastes*, *W063 mixed ferrous and non-ferrous metal-wastes*, *W071 glass wastes*, *W074 plastic wastes*, *W075 wood wastes*, and total of waste category *W121 mineral waste from construction and demolition*, all generated by the Statistical classification of economic activities in the European Community (NACE) Rev. 2 Section F (construction sector). The mineral fraction forms the majority of C&DW. The amount of generated in different European countries is presented in Figure 3.2.



Source: Eurostat (2019a)

Figure 3.1. Generation of construction and demolition waste, EU, 2010–2016, million tonnes.

The generation of C&DW in the EU has remained relatively constant since 2010; nonetheless, it is one of the largest waste streams. Figure 3.2 shows that the differences in generation between countries is significant.



Source: Eurostat (2019a)

Figure 3.2. Generation of construction and demolition waste, EEA, 2016, tonnes per person.

Bio by Deloitte (2017) analysed the reliability of CD&W statistics in *Resource Efficient Use of Mixed Wastes - Improving management of construction and demolition waste*. The study gives the C&DW data in Europe a quality score of 2.3 out of 5, with a range from 1.5 to 4.3. According to the study, Austria, Czechia, Denmark, Germany, Netherlands, Poland, Portugal, Slovakia and Slovenia have good quality of C&DW data, whereas the Bulgaria, Cyprus, Finland, Greece, Ireland, Latvia, Malta, Romania and Sweden have poor quality data. There are, however, uncertainties related to the C&DW data in the best performing countries. For example, according to the Danish Environmental Protection Agency (2015) there is high uncertainty about the amount of concrete waste generated in Denmark because the registered quantities are much smaller than the actual amounts of concrete waste. In general, for most countries, improvements in the quality C&DW data are needed.

Poor data quality is often related to deficiencies in the data collection methodology. As countries can decide on their data collection methods, many different methodologies lie behind Eurostat data. For example, under coverage, double counting and misclassifications are typical problems that weaken the data quality. The misclassification of soil waste is one of the most important issues as some countries, such as Lithuania and Finland wrongly include excavated soils in national estimated amounts of C&DW. This leads to significant overestimations of non-hazardous mineral waste from construction and demolition (W121) and risks of overestimation of the recovery rate (Deloitte, 2017). The poor quality of C&DW data makes analysing C&DW generation and management challenging and hinders comparison of data between countries.

3.2. Treatment

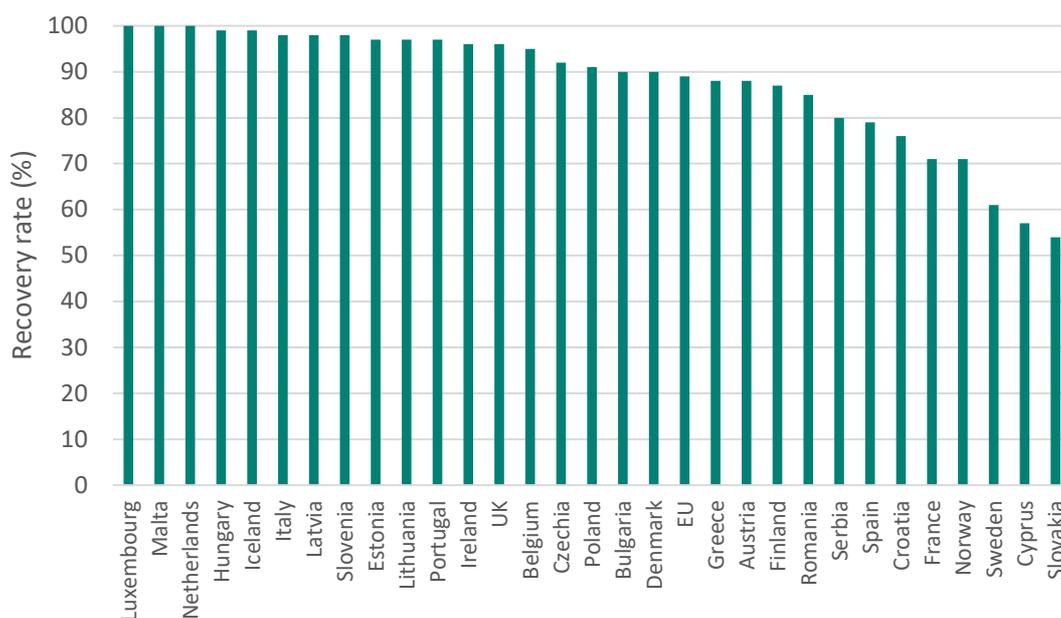
According to Eurostat, the average recovery rate of C&DW in EU was 89 per cent in 2016, the same as in 2014, the previous data collection year (Eurostat 2019b). Eurostat defines the recovery rate as the amount of C&DW that is prepared for reuse, recycled or subject to material recovery, including backfilling, divided by the C&DW treated. Figure 3.3 describes the recovery rate of non-hazardous mineral waste from construction and demolition (EWC-Stat 12.1) in different countries in 2016. It should be noted that this

C&DW treatment data is only based on mineral C&DW (W121 code), whereas data on the generation of C&DW includes other waste codes, because no data are available on the treatment of other C&DW in Eurostat. Furthermore, Eurostat data on the treatment of C&DW does not include data on reuse of construction materials or components.

The recovery rate of non-hazardous mineral waste from construction and demolition is generally high in EU countries. Most countries already meet the WFD target of, by 2020, preparing for reuse, recycling or other material recovery, including backfilling operations, 70 per cent by weight of non-hazardous C&DW, with Luxembourg, Malta and the Netherlands reporting 100 per cent recovery rates in 2016. However, there are some uncertainties surrounding reporting of C&DW treatment by EU Member States (EC 2018b).

Recycling C&DW often means using materials from demolished buildings and other structures being used in civil engineering projects, for example as base material in road building. As, however, there is also internal recycling in civil engineering the sector can become saturated with recycled aggregate. On the other hand, the building sector hardly uses any secondary materials – in the Netherlands, secondary materials only represent 3–4 per cent of all materials used in buildings. Therefore, despite high recycling rates, the recycling of C&DW is largely downcycling.

In low-grade applications, when no alternative secondary materials are available, the use of materials from C&DW is not necessarily undesirable. However, it is likely that the market of these more low-grade applications will decrease as, for example the EU’s 2050 zero land take objective could decrease the market for road building materials. As a result, the market for recycled C&DW materials needs to be able to react to adapt by developing its use in higher-grade applications through, for example, innovation.



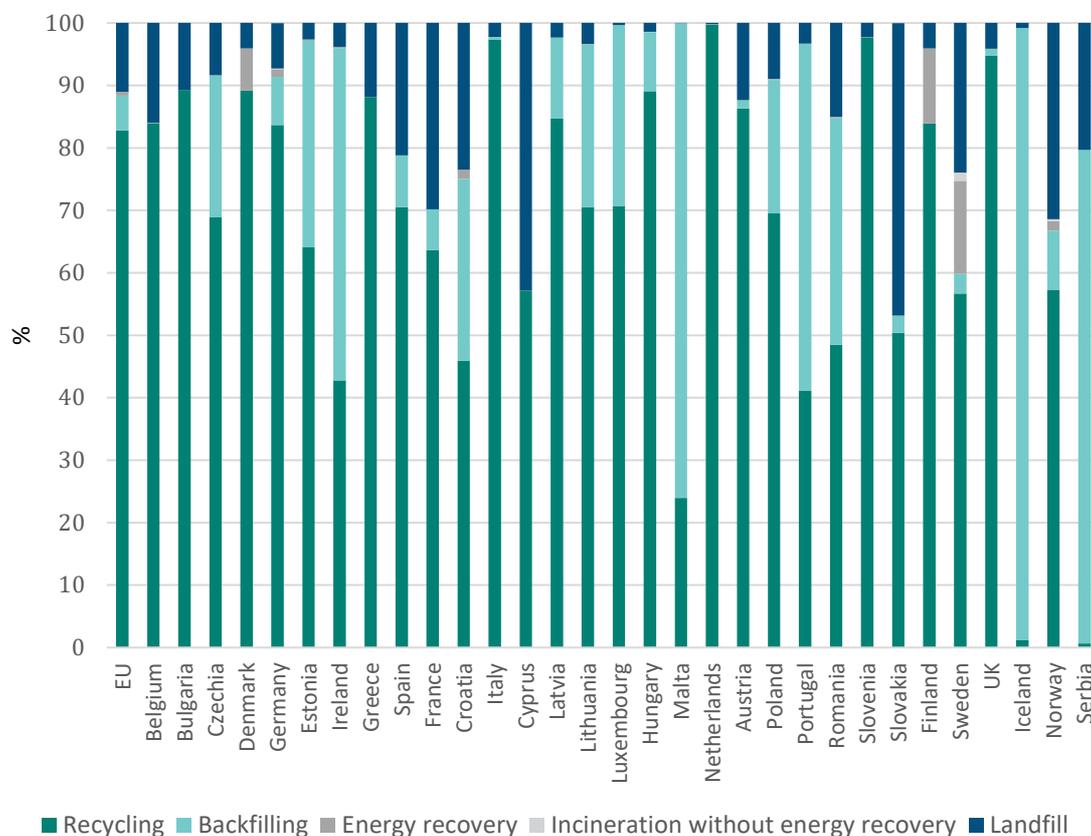
Source: Eurostat, EWC-Stat 12.1 (2019b)

Figure 3.3. Recovery rate of non-hazardous mineral construction and demolition waste, EEA, 2016, per cent.

The waste hierarchy ranks waste management options according to their sustainability. The top priority is on waste prevention, followed by recycling, energy recovery and finally disposal, for example by landfilling. Figure 3.4 shows the percentages of different treatment methods – recycling, backfilling, energy recovery, incineration without energy recovery, landfilling – of C&DW mineral waste in 2016.

National EoW criteria for C&DW mainly concern the use of mineral waste from construction as aggregate (Bio by Deloitte, 2017). The EoW concept lowers the administrative work in handling permits for the use of C&DW and may increase the trust in the quality of recycled materials. However, only Austria, Belgium,

France, the Netherlands and the UK have developed such national criteria though they are in preparation in some other countries. As there are only limited data on the influence of the criteria on recycling rates and it has not been possible to analyse whether recycling rates have increased because of the regulations. Four of the five countries with EoW criteria, France being the exception, already have recycling rates above the EU's 70 per cent target.



Source: Eurostat (2019c)

Figure 3.4. Treatment of mineral waste from construction and demolition, EEA, 2016, per cent.

3.3. Backfilling

Backfilling is not defined in the EU's 2008 WFD even though it is included in the target for reuse and recycling of C&DW. However, the Commission Decision 2011/753/EU establishing rules and calculation methods for verifying compliance with the WFD target backfilling as "a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials". In the revised WFD (2018/851) the definition of backfilling is tightened as "waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purposes". This new definition may in the future limit the amount of material reported as being backfilled (e.g. the materials that are currently used as filling materials in road edges, parking lots, noise barriers, are not always environmentally safe or stable).

Backfilling is classified as recovery under the WFD, but the definition of recycling excludes its use for backfilling operations. Backfilling can be considered as low-quality recovery, nonetheless because backfilling C&DW maintains the use of its original materials and obviates the need for additional natural resources. According to WFD Article 37(2), EU Member States should report the amount of waste used for backfilling and other material recovery operations separately from the amount of waste prepared for reuse or recycled.

The proportion of backfilling appears to be small in most countries with the exception of Iceland, Ireland, Malta, Portugal and Serbia, where more than 50 per cent of mineral C&DW is backfilled. However, there are discrepancies in the reporting of backfilling to the European Commission. According to Deloitte (2017), although only 13 EU Member States supplied data on backfilling volumes, 13 of the remaining 15 countries that reported no C&DW backfilling actually have backfilling operations. For these countries, it is unclear whether the backfilled amounts are included in their recycling figures or not included at all.

4 Circular economy action affecting the generation and recycling of construction and demolition waste

4.1. Circular economy action in the built environment

In a circular economy, raw materials are not taken out of their cycles, they remain in the economy for as long as possible through efficient and smart use. Their value is also preserved by optimising their re-use or recycling. The circular economy therefore involves much more than just recycling; it requires the fundamental rethinking of value chains and business models, of product design and the overall economic systems in which they are applied to achieve the lowest environmental impact.

In the built environment, this would mean buildings and construction elements are designed to be easy to adapt, easy to dismantle and are hardly ever demolished. Building materials or building elements would be quickly and efficiently recovered, which again would result in high-quality materials being maximally recovered in a closed loop and almost no material would end up as waste. Hazardous materials such as asbestos and tar would be removed from the material cycle.

To achieve this, a new holistic approach involving all actors in the value chain is necessary this, with various sectors working together. From a C&DW management perspective, the circular economy may have profound effects on waste management and on the attainment of relevant waste targets and policy objectives. In a circular economy, C&DW management is not viewed as an isolated sector but through a systems perspective, in which the analysis of interventions takes all parts of the system into account. Furthermore, it is important to broaden the scope of action which can influence waste management to cover other stages of buildings' and other structures' lifecycles. Circular economy inspired action made in early stages of a building's lifecycle may affect the management of the building's waste in a profound way. For instance, circular economy action in the production or design phase of a structure can have a strong impact on the recovery potential of material streams from its construction. The selection of durable and high-quality building materials would increase a building's life span and contribute to waste prevention. Overall, circular economy thinking views waste management systems as the result of decisions a taken in earlier stages in its lifecycle.

Currently, many bottlenecks hamper the transition to a circular economy in the built environment. These are often linked with past or current building practices. To make an economy truly circular, it is necessary to take additional measures by focusing on the whole lifecycle of construction products in a way that preserves resources and closes the loop. Typical examples of key action in applying circular economy principles across a building's lifecycle split, into different phases, have been collated by Adams *et al.* (2017) from literature and the following list was further elaborated with a focus on waste. Actions must be taken at every stage of the built environment:

1. **Material production phase** (Thelen *et al.*, 2018; Rizos *et al.*, 2017; Pomponi and Moncaster 2016)
 - the building materials are renewable;
 - the production processes have low environmental impacts;
 - the materials have a high recycled content – since the construction industry uses large volumes of materials, this recycled content can also originate through industrial symbiosis, in which the waste or by-products from one industry become the inputs for another;
 - the materials are highly durability and therefore have a long lifetime;
 - the building materials are not hazardous.

These approaches can strengthen one another. For instance, the use of granulated blast furnace slag or coal combustion fly ash as a supplementary cementitious material significantly lowers the environmental impact of cement production.

2. **Design phase** (Horizon2020 BAMB-project; Enkvist & Klevnäs, 2018, 2018; Webster 2013)

- Better design is key to facilitating recycling and helping to make buildings and construction products easier to repair or more durable, thus saving precious resources. Circular design weighs resource use against the needs and functionality of a building and considers deconstruction scenarios. The Level(s) (EC 2019b) framework supports efforts to optimise building design and their operation and minimises gaps between design and actual performance.
- Possible action includes:
 - modular and easy-to-disassemble buildings;
 - durable, flexible, upgradable, repairable and adaptable structures prolonging their lifetime;
 - reduce the amount of materials used by avoiding over specification and using higher-strength materials;
 - integrate nature-based infrastructure (such as green roofs).

3. **Construction phase** (EC, 2019b; Ellen MacArthur Foundation and Arup, 2019; Enkvist & Klevnäs, 2018)

- avoid material surpluses by using tailor-made construction materials;
- create a material passport during construction;
- additive manufacturing (such as 3D printing of concrete);
- selective sorting of construction waste;
- give away unwanted or surplus stock from the construction;
- building information management (BIM) helps create and maintain value through the entire lifecycle of a building and its parts (UK BIM Task Group, 2013).

4. **Use phase** (Ellen MacArthur Foundation, 2019; Thelen *et al.*, 2018)

- update building information models and its material passport during use;
- performance-based contracts for the built environment;
- extended producer responsibility, for example, for carpets (Hilton, 2018);
- increase use intensity of buildings through, for example, flexible functionality for different users at different times of the day, sharing work or living spaces;
- lifetime extension through the advanced rehabilitation – repairing and strengthening – and retrofitting of structures;
- maintenance of buildings and infrastructure.

5. **End of life phase**

The material streams that currently arise from renovation and demolition work are an inheritance from the linear economy and are not always easy to disassemble and some, such as glued materials and spray insulation, do not allow for reuse or high-grade recycling. For these material streams, it is important to establish suitable demolition practices, processing methods and logistics to close material loops as much as possible. The EU Construction and Demolition Waste Management Protocol (EC, 2016) describes the action to be taken at the end-of-life stage.

- qualitative pre-demolition material auditing and waste management planning;
- decontamination of the built environment: removal and safe handling of hazardous materials;
- at source sorting of high-grade material fractions;
- monitoring demolition and renovation work to assure (trust in) material quality for recycling and reuse;
- selective demolition;
- preparing construction materials for reuse and recycling;
- increase traceability, quality assessment and certification of C&DW streams;
- improved sorting systems for materials that cannot be collected separately during demolition.

These strategies need to be facilitated by the right business models such as product-service combinations and policy support instruments. These policy instruments could include green public procurement instruments, standards for reused elements and/or ecolabels for construction products. Artificial

intelligence (AI) and digitalisation have the potential to make information available to support circular business models.

Pilot and demonstration projects help to put these developments into practice and introduce them to the market more quickly.

4.2. Selection of action for better construction and demolition waste management

The scope of this report does not allow for a comprehensive analysis of all identified circular economy action in terms of its potential to contribute to the waste policy objectives. Instead, it identifies some examples suitable for a deeper analysis that showcases the links between circular economy and waste management for the built environment.

Chapter 5 elaborates on these examples of circular economy action, which were selected using the following criteria:

- The action should fit the concept of a **circular economy**.
- The action should be relevant for the **C&DW policy objectives**, meaning that the selected action should contribute to **increasing material recovery rates** or **increasing waste prevention**. Action that mainly targets other objectives such as water or energy consumption during the use phase are excluded.
- The selected actions should have a **significant impact** in increasing recycling and/or prevention of C&DW.
- The selected action should have been **demonstrated** in an operational environment and be likely to be implemented in the short term. However, the effects might only be noted in long term.

In addition to these criteria, each action was chosen to takes effect at a different lifecycle phase:

- **Production phase:** New high-grade products with high recycled content
- **Design phase:** Design for disassembly
- **Construction phase:** Material passports
- **Use phase:** Lifetime extension of existing structures
- **End of life phase:** Selective demolition

5 Effect of the selected action on prevention and recycling of construction and demolition waste

In this chapter, the action for better waste management selected in Section 4.2 is discussed in more detail. As stated, the presentation is not exhaustive, the aim is primarily to illustrate potential benefits by introducing circular action at different stages of the value chain through concrete examples. The focus is not only on the quantity of recovery, but also the type of recovery and the avoidance of downcycling is crucial. All action is connected in the value chain and the benefits cannot solely be assigned to one specific stage.

5.1. Concept 1. High-grade products with high recycled content

5.1.1 Description of concept

High-grade products are defined here as materials or components used in structural elements of a building or infrastructure with high durability. This means products or components that withstand degradation during the prevailing use conditions, such as products with sufficient strength. The durability of components directly influence the end-product's lifetime. Use of waste in high-grade products means that waste retains its value and contributes to the supply of raw materials; recycling of materials with high embodied energy can result in significant CO₂ savings; and keeping waste in the material loop reduces the generation of waste for disposal.

Products manufactured from recyclables must perform as well as those made with virgin materials, or at least meet high-performance criteria. Usually, the mineral part of C&DW, when recycled, is used in rather low-grade construction materials such as non-structural concrete applications, including coarse aggregates for road bases, paving blocks and embankment fills. In these, the inherent value of C&DW is lost to a great extent as their potential structural properties are not utilised. By creating a route that leads to their uptake in high-grade products, the recycling system would make much greater use of the C&DW's inherent, thus maintaining its value. In this way, the use of C&DW in high-grade products would avoid downcycling and follow the spirit of a circular economy.

The focus of this chapter is concrete. High-grade concrete recycling is especially relevant as it accounts for 42 per cent of building materials used in construction (Enkvist & Klevnäs, 2018). The Waste and Resources Action Programme (WRAP, 2009) also lists other construction waste, including asphalt, chipboards and some plastics, which can be recycled but in many cases the waste volumes involved are relatively small; are country dependent, for example, wood; or are wastes from construction activities such as surplus materials.

In the production of concrete, fine and coarse aggregates, sand and gravel; cement, water and additives are mixed. Coarse aggregate obtained from demolition works can be used to (partially) replace natural aggregates in high-grade concrete applications. Recovery of a high-quality stony fraction for recycling sets requirements on all steps of the value chain starting from the planning of demolition activities so that, for example, hazardous materials are removed prior to demolition to increasing trust of end-users in the quality through a reliable tracing system. This requires tight quality control and new agreements between stakeholders in the value chain to guarantee high-quality feedstock from demolition activities. If the demolition process is not carefully planned and supervised, demolition waste streams of variable quality are generated. The purity of the stony fraction generated during demolition, and thus the selection of this process, is crucial for the use of recycled aggregate in high-grade concrete products. Figure 5.1 illustrates stakeholders involved in concrete recycling.



Source: Lofti (2016).

Figure 5.1. Stakeholders involved in recycling of concrete waste from demolition.

European standards, such as EN 206: Concrete – Specification, performance, production and conformity; and EN 12620: Aggregate for concrete allow the use of recycled materials in concrete. Their use in different applications is regulated by national standards. Up to 20 per cent substitution of virgin aggregates with concrete waste is not considered to lower the new concrete's properties or influence its workability, for example, in requiring more water in mixing. The use of more than 50 per cent of concrete waste triggers the need for further testing to prove acceptable properties and the concrete is usually only suitable for certain applications. The Dutch standards and guidelines, for example, allow up to 50 per cent by volume of the stony fraction of concrete aggregates for certain applications to be recycled, while in Belgium up to 20 per cent by volume of the coarse aggregate fraction is acceptable under certain conditions without additional testing or proofing. Standards also set limits for the content of bricks and tiles and impurities in recycled aggregate in concrete. Replacement rates that go further than the current standards are technically feasible if the right measures are taken – selective demolition, adapted milling processes, extra processing of the aggregates, and/or adapted water management in the mix formulations (Lofti *et al.*, 2017, Xuan *et al.*, 2017).

Advanced technologies for concrete recycling have been developed and demonstrated in several EU funded projects, such as C2CA; HISER; IRCOW; and VEEP, covering smart demolition to produce concrete waste with a low content of contaminants and impurities; new classification processes to obtain clean coarser aggregates; sensor sorting for the removal of impurities of >6 millimetres (mm) of, for example, wood, plastics, and gypsum from recycled aggregates; a green thermal treatment for concentrating and purifying cement; paste and laser-induced breakdown spectroscopy (LIBS) tools for verifying the quality of input materials for the concrete facilities. An example of a technology currently used for producing high-quality aggregates from concrete waste is presented in Section 5.1.3.

5.1.2 Drivers and barriers – boundary conditions

The main obstacle for recycling aggregates from concrete waste in new concrete is the low price of virgin materials and the processing costs of demolition waste to secure high-quality material for recycling. Other factors hampering recycling relate to variability in the quality of demolition waste, especially its purity if a tight quality control system is not applied. Concerns about the quality and potential presence of hazardous materials, such as asbestos, lead to a lack of confidence or trust in the recovered waste streams.

To make the recycled concrete aggregates competitive with virgin materials, it is crucial to increase the market value of recycled aggregate. In some Member States, including Belgium and the Netherlands, the use of concrete aggregate is made an economically attractive option through government measures including levies on virgin materials and taxes on landfilling waste. There is also a need for national recommendations for the use of concrete waste in certain applications. A prerequisite for the use of waste in products is also agreements and commitments between stakeholders in the value chain (Horizon2020 project HISER, 2014-2019) (SPIRE project RE4, 2016-2020).

In the future, sustainability aspects in the building sector may increase the recycling of concrete. Green materials with recycled content or environmental benefits are often given credits in voluntary environmental rating systems for new or existing buildings. Examples of developed protocols are Level(s) from the European Commission, Building Research Establishment Environmental Assessment Method (BREEAM) from the UK's BRE, and the US Green Building Council's Leadership in Energy and Environmental Design (LEED). The protocols can be used by investors, designers, general contractors and real estate operators for proving the sustainability of a building.

Identified drivers and barriers in the literature are collated in Table 5.1.

Table 5.1. Drivers and barriers for circular concrete recycling.

Aspect/characteristics	Drivers/benefits	Barriers/challenges
Legislation, standards	Standards allow use of recycled concrete. Landfill taxes. Taxes on virgin aggregate. Reduced value added tax (VAT) rate for some recycled products.	Lack of national instructions for recycling in new concrete in some countries. The standards usually only allow low replacement rates in low-grade concrete.
Market/economy	Green concrete deal, for example, in The Netherlands – commitments between different stakeholders in the value chain.	Transport distances for recyclables may be critical in Member States with high availability of raw materials near the end user.
Quality	Traceability systems.	Lack of documented information available regarding the origins of waste and also data on the composition of historical construction products. Variable quality of feedstock, risk of contamination – for example the presence of asbestos.
Technical	New technologies developed. BIM under development to cover recycling aspects.	Cement-coated recycled concrete aggregates have higher water sorption and may weaken new concrete if it is not treated properly.
Awareness, knowledge	Recognition of structures as future material banks. Voluntary schemes for sustainable buildings may influence the uptake of new approaches for better C&DW. Urban metabolism supporting circular economy solutions for closing the loops of urban flows in cities/regions and increasing their regenerative capacity.	Virgin material is considered to have a higher quality than recycled aggregates. There can be a lack of confidence in the quality/purity of recycled materials.

5.1.3 Case study

Advanced Dry Recovery

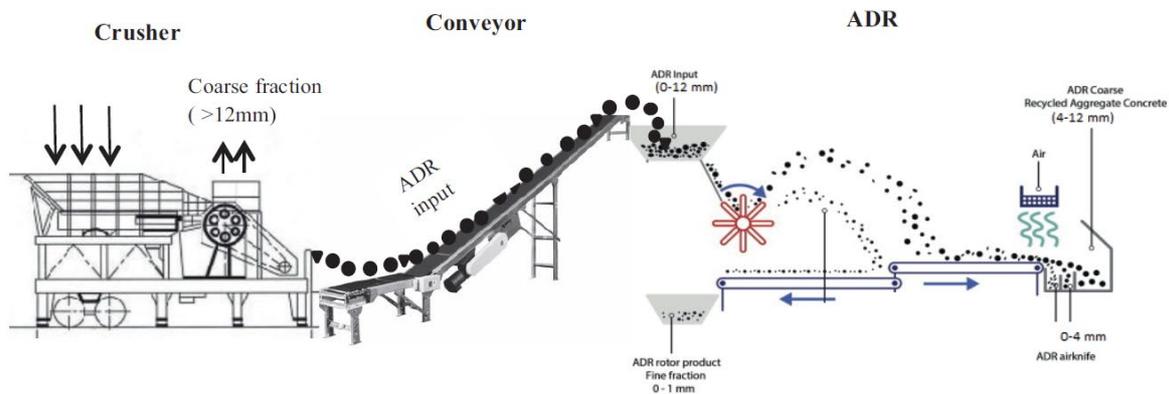
The separation of fine materials, those with a diameter of 0–1 mm, is crucial for enabling high-grade recycling from concrete waste in new concrete. Fines contain more cement/mortar paste which increases the water need during mixing and makes the 0–1 mm mixture sticky. Also the possible presence of sulphates and chlorides in the fines fraction makes production challenging. Cement adhered to surface of the coarse fraction also needs attention in the processing of concrete aggregate.

The advanced dry recovery (ADR) technology was developed and demonstrated by TU Delft for separation of mortar from concrete in the FP7 project C2CA and the H2020 project HISER (Gebremariam *et al.*, 2018). The ADR is a mechanical low-cost process and can be applied to moist materials, without prior drying or wet-screening.

The principle of the ADR process is illustrated in Figure 5.2. The feed is concrete waste from selective demolition which is crushed to a material with a diameter of less than 12 mm –autogenous milling is used to remove the loose mortar from the aggregate’s surface. First, kinetic energy is used to break the water bond that is formed by the surface moisture associated with the fine particles, after which first fines below 1 mm in diameter are removed and then the coarse aggregate, with a diameter of 4–12 mm, and a finer fraction with a diameter of 1–4 mm containing impurities such as wood, plastics, and foams is separated. The coarse aggregates, typically nearly 50 per cent by volume, recycled in concrete have shown comparable properties to natural aggregate in terms of workability and the compression strength.

Lifecycle analysis in which the ADR process was compared to the production of virgin aggregate showed environmental benefits in 12 product environmental footprint (PEF) categories of 15 evaluated. The

highest environmental benefit was achieved by on-site or nearby recycling. Local application for the recycled aggregates is therefore recommended.



Source: Gebremariam *et al.*, 2018

Figure 5.2. Working principle of advanced dry recovery.

5.1.4 Conclusions

The recycling of C&DW in high-grade products with high recycled content supports the circular economy principles by retaining the value of material in the loop and replacing virgin materials. In concrete, 20–30 per cent of virgin material can be substituted by waste material in several applications. Higher replacement, including multi-recycling cycles, in high-grade applications can be achieved if fines are separated from concrete waste. As the coarse fraction, with a diameter of more than 4 mm, makes almost half of concrete waste, ideally half of concrete waste could be recycled in high-grade applications.

The main barriers are reasonable processing costs and trust in quality, for which there is a need of traceability systems, which are lacking in many countries, for controlling the origin of waste streams.

Including a high content of recycled aggregate from C&DW in high-grade products does not have a significant benefit for CO₂ emissions due to the additional processing needs. The main environmental benefit relates to savings of natural resources.

5.2. Concept 2: Design phase: design for disassembly

5.2.1 Description of concept

The possibility of recycling and reusing building products in the future depends to a very high degree on how buildings are designed today. Design for disassembly, or deconstruction, (DfD) is a resource and waste-efficient design approach that takes the total lifecycle of products into consideration. The main concept is to design products that are easy to disassemble into their individual components, so that they all can be reused, reassembled, reconfigured or recycled, thus extending their useful life. Applied to the building sector, design for disassembly enables the reclamation of individual building components without damaging others and without a loss of quality or value. Buildings designed according to DfD principles can function as material banks in which building products are temporarily stocked and can then be reused in the future, as well as producing considerable resource savings and significantly reducing a building's total environmental lifecycle impacts related to the preservation of embodied energy, the reduction of carbon emissions and pollution (Debacker *et al.*, 2016). Alwood and Cullen (2012) describe the potential reduction of UK's CO₂ output by disassembling steel frames and reusing them rather than cutting them down and recycling the steel.

The ease of disassembly is affected by, amongst other factors, the building systems and technologies used – the quality of materials, reversible connection techniques, assembly sequences, accessibility, etc., and

also by the availability of background information in the future, the required time and competence for (dis)assembly (Kanters, 2018; Paduart, 2012).

Appropriate use of reversible technologies like bolts, nuts, clip systems, screws or even lime mortars instead of nails, glues, welded solutions or cement mortars is key to facilitating and increasing the future reuse of components. It is also needed to ensure that the quality of the chosen materials can withstand dismantling, transport and reuse stages over time.

The availability of relevant documentation and information about integrated building systems is also crucial to guide building workers through future disassembly. Ideally, materials passports of the building are integrated in a BIM model, making all information needed for deconstruction available at all times. Such passports can include all the detail of components' composition, their history and reuse potential (Mulhall *et al.*, 2019).

5.2.2 Drivers and barriers – boundary conditions

Although many authors, organisations and research institutes have published guides and tools addressing the principles of design for disassembly (Durmisevic *et al.*, 2019; Crowther, 2005), there are still few buildings that have been constructed according to them. A literature review of the drivers and barriers related to DfD reveals why.

Rather than technical barriers, most barriers are related to economic concerns related to the higher investment costs of DfD building products. There is a general perception that DfD requires higher investment. Although, indeed, some additional costs may occur related to, for example, the higher quality of materials for future reuse, DfD can in fact lower the overall lifecycle costs significantly since disassembly simplifies maintenance and adaptations processes that buildings typically have to face during their total lifetimes. There is a major opportunity for building applications with high maintenance and replacement rates such as shops, schools, care homes for the elderly and offices in terms of lowering periodic in-use costs. In addition, quality building components that can be easily dismantled can also be sold and reused, which implies a higher financial residual values and lower landfill taxes in the end of their lives. However, it is difficult to estimate the actual financial savings, as they will occur in the future and are highly context dependent. Clients may not see any benefits of a higher level of DfD design since many are typically developing new buildings to sell with short term investment benefits in mind.

Table 5.2. Drivers and barriers for design for disassembly.

Aspect/ characteristics	Drivers/benefits	Barriers/challenges
Policy	Lowering environmental and health pressures of the built environment. Eradicating C&DW and downcycling. Development of guidelines and assessment instruments to facilitate decision-making along the building value network.	Fragmented policy framework: from the EU to municipalities. Conflicting energy and environmental policy measures Lack of standardisation of qualitative data/information over the entire product/building value chain.
Market/ economy	Stimulation of circular economy initiatives and businesses. Decreased renovation, maintenance, replacement and end-of-life costs. Increasing life expectancy and real value of real estate, Increasing adaptability of space. Reusable building components have a higher financial value than their constituent materials.	Lack of standardisation of qualitative data/information over the entire product/building value chain. Linear construction industry models. Higher complexity of disassembly compared to demolition. Lack of certification and quality assurance for reclaimed products and recycled materials. Lack of a business model framework related to DfD building solutions.
Awareness, perception and knowledge		General perception that DfD solutions entail high financial costs.

Aspect/ characteristics	Drivers/benefits	Barriers/challenges
		Client's and architect's reluctance to second-hand materials. DfD is largely unknown to the general public. Lack of information/tools to implement DfD and reuse.
Design and technology	Development of applied socio-technical solutions for and with public and private stakeholders.	Certification of reused materials, for example, of fire resistance. Use of non-reversible connections, such as chemical bonds and plastic sealants, in today's construction methods.

Source: Rios *et al.* (2015); Densley Tingley (2013); Hechler *et al.* (2011) and Chini (2008)

5.2.3 Case study

While DfD strategies are not a common part of building practice, it has not always been so in the past. There are numerous historic examples of buildings that were designed for disassembly to allow materials, components or whole buildings to be reused or recycled in other economic circumstances (Crowther, 1999). For instance, in past times and places where there was a scarcity of suitable building timber, the reuse of timber beams was common practice.

Today, it is rare to find buildings that are entirely dismantlable, with exception of buildings that were specifically designed for temporary applications. In conventional construction, it is more usual to find buildings in which one of the main functional layers – structure, skin, and space infill – as defined by Brand (1994) is designed and constructed according to DfD principles. Two examples are discussed to illustrate how the DfD design of two of those main functional layers can be realised and what the main expected benefits are.

Design for disassembly infill solutions in the Circular Retrofit Lab

In the Circular Retrofit Lab (CRL), a pilot project within the Horizon2020 Buildings As Material Banks innovation project (H2020 BAMB-project), eight existing student housing modules at the Vrije Universiteit Brussel (Belgium) have been renovated according to DfD principles. Dismantlable solutions have been developed for the internal partitioning and the façade, with the main goal of turning student rooms into dissemination and office spaces that can later be transformed again into other functional spaces without requiring new resources or generating additional C&DW.

For the building partitioning, the approach was to analyse existing DfD wall solutions, determine their shortcomings and then develop new solutions jointly with industrial partners. The result was a set of adaptable and reusable wall partitioning that have diverging properties in terms of material use, connection techniques, number of elements, prefabrication, reuse potential and sub-layering. Then, instead of selecting one single optimised wall solution, a set of wall solutions was chosen that matches the different user flexibility needs in the building plan.

Three wall solutions used were:

- large prefabricated wood-frame units filled with mineral wool and covered with gypsum fibreboard panels (Figure 5.3 a);
- a structural steel kit of parts, consisting of 100 per cent reusable steel profiles and reversible connectors, covered with demountable plywood finishing (Figure 5.3 b);
- vertical wooden beams with tooth and groove, with horizontal steel connectors (Figure 5.3 c).

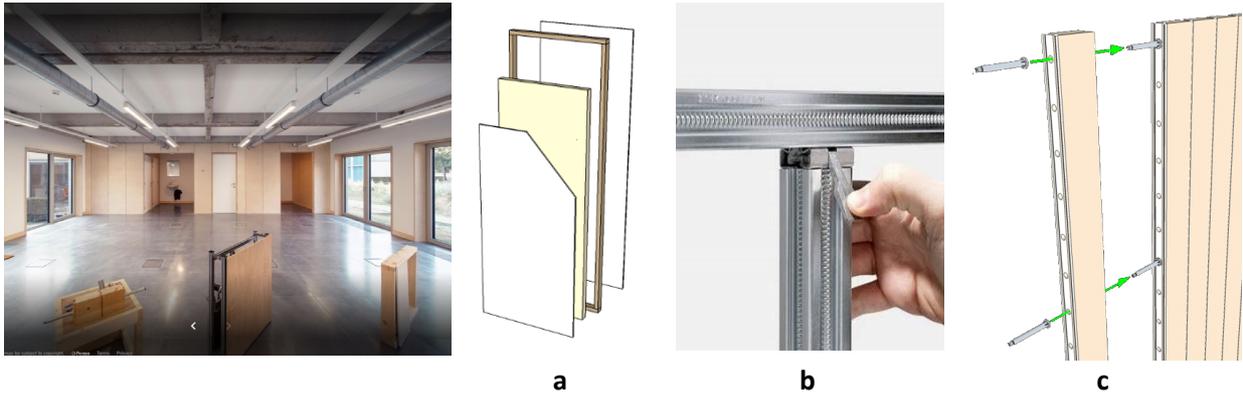


Figure 5.3. Demountable partitioning solutions integrated in the Circular Retrofit Lab, Belgium.

Although each of these solutions was designed according to DfD principles, the investment cost and initial environmental footprints were not necessarily as favourable, due to, for example, the building materials used, the assembly method and type of finish. As a result, life cycle analysis results were used in the decision-making process of where to implement which solution. The pilot project demonstrated the importance of assessing the lifecycle impacts of DfD building solutions including future scenario planning. The evaluation revealed that, rather than applying one single optimised DfD product, diverse implementation of DfD building products could result in larger environmental and financial gains in the long term.

Four wall turnover categories were first defined in relation to the estimated rate of change during the building's lifecycle. For instance, in the Circular Retrofit Lab, there are some walls which were likely to be changed regularly, such as temporary exhibitions walls. In contrast, there are others which were less likely to change during the building's lifetime, such as partition walls between living units. Together with the design team and the wall manufacturer, wall solutions were then linked to these categories, including design requirements such as the speed of assembly/disassembly, and acoustic and fire requirements. The reversible solutions were then compared to a baseline solution of drywalls, which are common in Belgium. The result of two scenarios with different turnover rates show that some reversible solutions, such as the reusable steel kit of parts, use larger material streams resulting in higher investment costs and higher initial environmental impacts. However, if regular transformations are likely, the disassembly and reuse potential of this solution results in important environmental lifecycle gains compared to the baseline. If lower rates of change or none were in the plan, results suggested the selection of alternative DfD solutions to minimising lifecycle impacts.

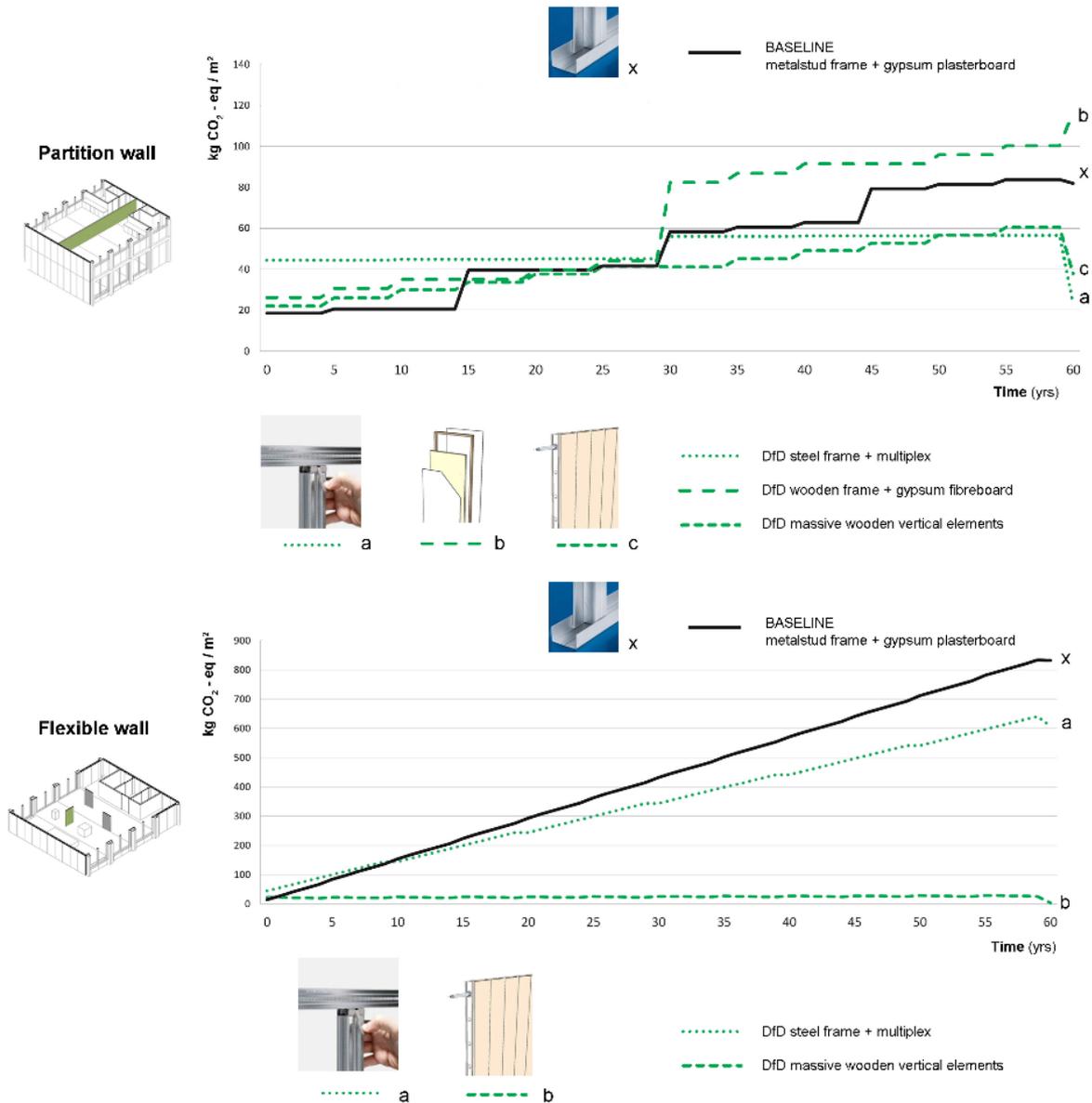


Figure 5.4. Lifecycle analysis results of different reversible wall solutions compared to a baseline of conventional drywall, considering a transformation process every 15 years (above) and each year (below).

5.2.4 Conclusions

Design of buildings and components that support future dismantling, selective sorting, reuse and remanufacturing can significantly lower the amount of C&DW. Currently, the high rate of heterogeneity of C&DW leads to large streams being downcycled. Design for disassembly not only lowers the amount of materials that are disposed of as waste at end of life, but also offers opportunities for design for recycling, so that building materials that cannot be reused can easily be deconstructed and sent for high-quality recycling.

Currently it is still exceptional to find many cases of DfD design. Most construction projects in which DfD is prominently present have been built as a result of interdisciplinary collaboration between a design team and research institutes, with financial support from industrial partners or (inter)national funding programmes (i.e. pilot projects), or as a result of the strong personal engagement of architects specialised in the circular economy. Design for disassembly is largely unknown to the general public – and there is little awareness of its advantages. To become a success, a large number of actors need to adopt this way of designing to create a larger market, effectively stimulating supply and demand.

It is expected that the EU initiatives including the EU Action Plan for the Circular Economy and the Roadmap to a Resource Efficient Europe will help promote building design approaches such as DfD that support the efficient use of resources and diminish waste production. However, to assess the potential lifecycle benefits and risks, DfD building design should always go together with a lifecycle assessment or a lifecycle cost assessment that takes the overall financial and environmental picture into account.

5.3. Concept 3: Construction phase: materials passports

5.3.1 Description of concept

To promote resource efficiency, minimise C&DW and realise the transition to a circular economy in the building sector, reliable and standardised information on the material composition of the building stock and related products is indispensable (Heinrich and Lang, 2019a). Materials passports – also referred to as building passports or circularity passports – can provide the necessary methodology and data structure for collecting, handling and providing this information. By cataloguing and disseminating the circularity and other characteristics of building materials, components and products, the passports contribute to bridging the existing information gap between relevant actors in the construction value chain and deliver them the needed data at the desired time (Heinrich and Lang, 2019b). Their aim is to maintain or even increase the value of materials, products and components over time, as well as facilitate reverse logistics and take back, and support reversible design action (BAMB, 2019).

Within the EU Horizon2020 Buildings as Material Banks (BAMB) project, which ended early 2019, materials passports are described as:

“(Digital) sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery, and reuse. They are an information and education tool that asks questions often not covered by other documents or certifications related to building products, especially in relation to the circularity of products. The materials passports do not itself assess the data output and are not an evaluator of data. Instead, they provide information that supports assessments and certifications by other parties and allows existing assessments and certifications to be entered into the passport as uploaded documents” (Mulhall et al., 2017).

Different materials passports might take into account different levels of abstraction, ranging from materials and components of products and systems making up a building, to the building stock for a certain region. For materials, passports can define their value for recovery, while for products and systems they can include design-for-disassembly aspects and specifics of a single product or system, for example, how products relate to a building – location, connections,, etc. – is essential to understanding their reuse potential (Luscuere, 2016)

Information requirements span the complete lifecycle of a building and the products and materials inside it. These include physical details, ranging from tensile strength for steel beams to ease of maintenance of flooring or doors; biological information on treatments or biodegradability; and chemical properties of materials used, together with process-related information on the design and production of building products, the building construction process, use phase aspects and dismantling approaches (Heinrich and Lang, 2019b).

5.3.2 Drivers and barriers – boundary conditions

Although materials passports could contribute considerably to a more circular building sector, some uncertainty remains around the concept, its benefits and costs, and the information required. Their added value needs to be sufficiently shown to all stakeholders involved (Debacker and Manshoven, 2016) and integration with existing frameworks such as BIM is indispensable to take the concept to scale. Otherwise the adoption of materials passports will be difficult and slow in the traditionally conservative construction industry.

Table 5.3. Drivers and barriers for materials passports.

Aspect/characteristics	Drivers/benefits	Barriers/challenges
Legislation and regulation	If set up correctly (see barriers section), materials passports have the potential to deliver relevant - circularity related information to the right value chain actor at the desired time, while meeting transparency expectations of users and data suppliers (H2020 BAMB-project).	Centralising all valuable information leads to legal questions of ownership and management of data, and protection of trade secrets (Debacker and Manshoven, 2016). While datasets such as materials passports offer a great deal of relevant information for circularity, liability issues, a lack of certification instruments, warranties, and guaranteed supply remain major barriers to recirculating materials and products. This is especially true for the heavily regulated building sector (Debacker and Manshoven, 2016).
Economics	Opportunity to retain or even increase the value of materials, products and components in buildings over time, and to enable circular product design and material recovery, eradicating C&DW and downcycling. This results in opportunities for cost reductions by managing resources rather than managing waste (Heinrich and Lang, 2019) Better access to information will prevent costly (de)construction errors and reduce building project timelines (Debacker and Manshoven, 2016).	Costs related to data gathering and maintenance.
Value chain actors	Materials passports allow for better communication and collaboration among actors along the construction value chain (Debacker and Manshoven, 2016).	High information need from various actors along the value chain (Heinrich and Lang, 2019b). This can prove challenging in building projects, which are often time constrained (Debacker and Manshoven, 2016).
Knowledge and data gathering	Traceability of materials and products along the construction value chain is key for implementation of circular economy principles. Materials passports can solve the issue of relevant material or product information being unknown or not communicated to the relevant stakeholder(s) at the right time (Heinrich and Lang, 2019b). It will also facilitate the selection of healthy, sustainable and circular building materials by developers, managers and renovators (Heinrich and Lang, 2019b). A multitude of initiatives around material-related data sources for the building sector already exist. The majority of them is limited to dedicated areas. They primarily focus on health, environmental or other aspects and are not aligned. Materials passports provide holistic information from different fields in a reliable, user-friendly data source for the circular built environment (Heinrich and Lang, 2019b).	Standardising methods of data collection for materials and products within buildings throughout a their lifecycle are needed (Heinrich and Lang, 2019b) Materials passports need to be compatible with existing standards, models and tools such as BIM. Some types of relevant information is currently still unknown, others are not publicly available due to intellectual protection by manufacturers (Heinrich and Lang, 2019b). Manufacturers and suppliers of (building) products, systems and services are reluctant to provide information that could undermine their commercial position (Debacker and Manshoven, 2016). Clear incentives for data supply are required.

5.3.3 Case studies

Circularity passports by EPEA GmbH

Circularity passports have been developed by EPEA GmbH in the light of the BAMB project. They consist of datasets containing the characteristics of materials in building products with the purpose of generating value by mapping their recovery, reuse and recycling potential at different levels and making them available to the right parties at the right time. Circularity passports can be requested and used by a wide range of stakeholders, ranging from product manufacturers, through building(system) owners and users

to dismantlers, urban miners and material suppliers. Different levels of information provide a safe way of sharing data across the entire construction value chain (EPEA, 2019). Over the duration of the BAMB project, more than 300 materials passports for various products, components or materials were developed.

Madaster

Where EPEA's circularity passports focus on building materials and products, Madaster takes the entire building perspective into account. Their materials passports give insights into the materials used in a building, their quantities, information on the quality of materials, their location, and their monetary and circular value. The Madaster platform is designed as a public, online library of materials in the built environment. It facilitates the registration, organisation, storage and exchange of data, while taking into privacy, security and continuity aspects into account. Madaster is an independent platform offering free access to private individuals, as well as companies, governments and scientific organisations (Madaster, 2019).

5.3.4 Conclusions

Materials passports are sets of data describing defined circularity-related characteristics of materials, products and systems in buildings. They have the potential to bridge the information gap between actors involved along the construction value chain and provide reliable and standardised information on the material composition of the building stock and material flows. In this way they preserve material and product value over the building's entire lifecycle, facilitating circular design, recovery and reuse practices and minimising waste. Some initiatives have already been launched, but in order to make the use of materials passports business-as-usual in the building sector their added value has to be proven towards potential users, data suppliers and other stakeholders. Additionally, integration with existing frameworks like BIM is key.

5.4. Concept 4: Extension of service life of constructions

5.4.1 Description of concept

Enkvist and Klevnäs (2018) list following key factors for promoting longer lifetimes of buildings:

- adapt and renovate buildings to avoid demolition;
- improve maintenance to extend the lifespan of key (structural) components;
- design and build upgradable, repairable and adaptable constructions.

According to Enkvist and Klevnäs (2018) the prolonged lifetime of the building has a significant impact on CO₂ emission (Chapter 7). It is estimated that the average lifetime can be lengthened from 64 years to 91 years by the year 2050 by use of circular models. This would mean around a 30 per cent lower need for new constructions in the long term. Prolonging of lifetime of construction products and buildings will result in generation of less waste, however, the use of machinery (energy), material needs and the generation of renovation waste will influence the overall environmental impact.

For new constructions, designing for longevity is the foundation for long-term durability. Durable materials and robust construction standards lower subsequent maintenance costs and increase the value of a building or structure. Designing for longer lifespans and continuous maintenance also lower the overall generation of waste during the lifetime of a structure. Furthermore, adaptability of buildings reduces the generation of waste by prolonging their lifetimes, for example, by enabling a switch from commercial to residential. Design for disassembly will allow for the easier replacement of specific elements while the off-site manufacturing of standardised components enables the use of higher quality-control standards and therefore minimises the risk of structural faults and reduces long-term maintenance requirements. (Zero Waste Scotland, 2019; Arup, 2016)

It is possible to extend the lifetime of existing buildings through the use of maintenance, upgrades and rehabilitation. Rehabilitation involves the retrofitting outdated buildings to meet current energy efficiency

regulations, construction guidelines and/or standards on comfort and usage. Different degrees of rehabilitation can be carried out, from the retention of all parts of a structure to the retention of (part of) the building’s envelope.

5.4.2 Drivers and barriers – boundary conditions

Drivers and barriers, particularly those related to renovation for improved energy efficiency in residential buildings, have been analysed in the literature (Figure 5.4). In residential buildings, potential cost savings related to energy efficiency and historical value are evaluated based on a lack of comfort in buildings planned under less strict standards, uncertainties related to potential material degradation and the need for special labour skills. Barriers and drivers are often related to socio-economic factors – the knowledge base in the decision-making process. Examples of typical barriers to the renovation of residential buildings are especially higher structural and comfort standards of new buildings, a lack of knowledge and trust in contractors.

Table 5.4. Drivers and barriers for extension of service life of constructions.

Aspect/characteristics	Drivers/benefits	Barriers/challenges
Construction practices	Modular and detachable constructions. The use of durable materials. Standardisation.	Use of inferior materials during construction. Energy inefficient buildings. Corrosion of steel rebars, degradation of structures. Higher structural and comfort standards. Energy-efficiency regulations.
Financial	Innovative financing. Lower taxation for maintenance costs and value-increasing investment in many EU Member States.	The need for longer term financing leads to more uncertainty. Lack of data makes it difficult to determine the residual value of a construction. High labour costs.
Architecture, urban planning	Artistic or historical value of existing constructions.	A change in architectural preferences – fashion. Redundancy of a building type. Urban planning setting new demands on building types.
Emerging technologies	The use of sensors for continuous performance monitoring. Long-term durability rehabilitation with ultra-high performance concrete.	
Others		Lack of knowledge among owners and contractors. Time delay in visible benefit of lifetime extension.

Source: Circle Economy, 2017; Palm, 2018; Klöckner, 2016; Häkkinen, 2012

5.4.3 Case study

Itard and Klunder’s (2007) comparison of the environmental effects of two housing blocks was conducted for four scenarios: ordinary building maintenance, consolidation – insulation measures, transformation – change of the floor plan to meet new needs, and rebuilding – the demolition of the old building and rebuilding/reconstruction with a new floor plan. One clear conclusion is drawn from this study: transformation, rather than demolition and rebuilding, is a much more environmentally efficient way to achieve the same result. However, transformation must be possible, which implies that the building must have a certain degree of flexibility from the design phase. An immediate advantage of transformation is that it minimises construction waste. The study, however, sets the following conditions:

- after transformation the operational energy use is equal to or less than originally;
- the quantity of materials used in transformation is less than for a new construction;

- the building method used in both is identical – new constructions often offer more possibilities for using environmentally friendly methods than renovations.

Ferreira *et al.* (2015) describe the refurbishment project of a residential 17th century palace. The structural walls were reinforced with 8 centimetres of shotcrete and the structural walls' foundations were widened using reinforced concrete. The vertical and horizontal elements were reinforced using reinforced concrete and steel elements in the stairway enclosure. This refurbishment was compared with a hypothetical demolition and the building of an identical new construction. The study showed that in this case the refurbishment was more environmentally sustainable than building a new equivalent. The most important environmental savings were in waste generation, -542 per cent, and eutrophication potential, -266 per cent. The construction of a new building was, however, found to be financially more competitive, largely due to essential seismic strengthening requiring large amounts of structural steel.

Too often new structures have very limited lifespans or rehabilitation fail, leading to repairs the repairs (Denarić and Brühwiler, 2006). Ultra-high performance fibre reinforced concrete (UHPFRC) is suitable for supporting reinforced concrete structures in critical zones subjected to an aggressive environment or mechanical stresses. Habert *et al.* (2013) evaluated the lifecycle impact of bridge rehabilitations with different types of UHPFRC and compared them to more standard solutions, both on the basis of a bridge rehabilitation in Slovenia. The UHPFRCs are characterised by a low water/binder ratio, a high powder content and optimised fibrous reinforcement, with low permeability and outstanding durability and mechanical properties. The upper surface of the bridge was covered with a continuous UHPFRC overlay with no dry joints in order to protect the full upper face of the bridge deck, footpath and external faces of the curbs. The construction process is both quick and highly durable. The waterproofing capabilities of UHPFRC obviate the need to apply a waterproofing membrane and the asphalt could be applied to the pavement after only seven days after the moist curing of the UHPFRC. The lifecycle analysis shows that rehabilitations with UHPFRC have a lower impact than traditional methods if the higher durability – a longer service life with no need for multiple interventions – of the UHPFRC is taken into account.

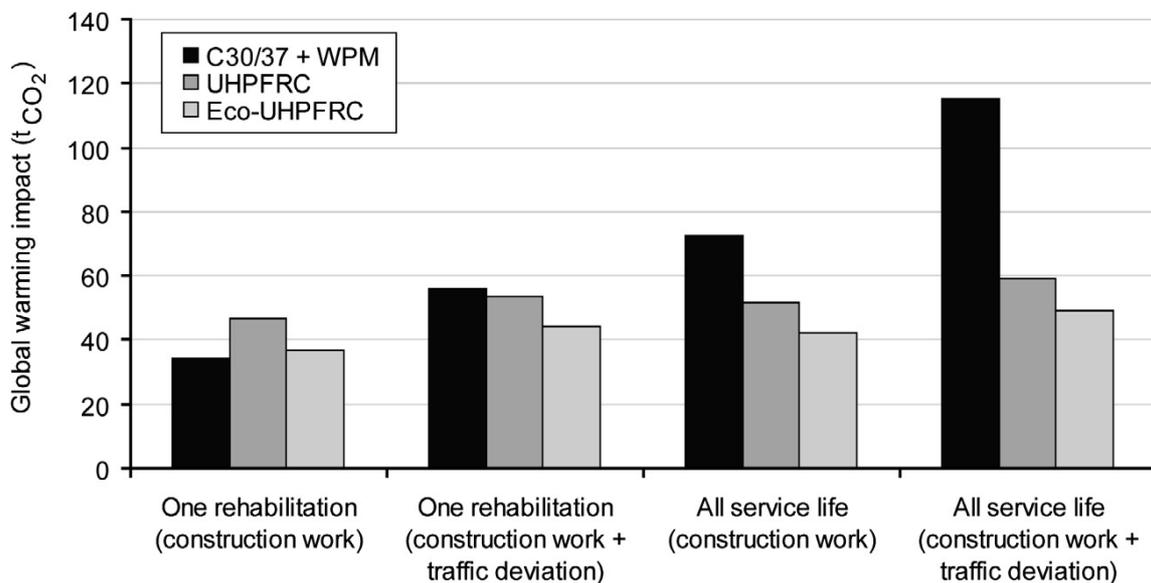


Figure 5.5. Global warming potential induced by different solutions for a bridge rehabilitation depending on which hypothesis is considered (Habert *et al.*, 2013). Comparison is made between one rehabilitation with no further maintenance and regular rehabilitation and 60 years of service life. For each hypothesis, two evaluation solutions are considered: the construction work only and the impact construction work plus traffic deviation.

5.4.4 Conclusions

Maintaining and extending the lifetime of buildings and other structures through the use of smart maintenance, repairs and renovation saves the use of new construction materials. The total environmental impact of extending lifetimes depends on the performance of the rehabilitated structure and the duration

of the extended lifetime. The extension of the service life of a building only has a positive impact if the environmental load generated by the maintenance and rehabilitation activities, and the use of resources such as water and energy during the structure's remaining lifetime is less than the load generated by demolition, new construction and resources used in the new construction.

In a circular economy, a new lifecycle phase/use can increase the feasibility of lifetime extension. For instance, building rehabilitation is more economically feasible if a building is designed in such a way that it becomes easily upgradable, adaptable and/or transformable.

The most significant barriers to extending the lifetime of buildings are related to the low value of the existing structure due to the use of inferior materials, changes in city planning, lack of comfort according to current living standards, higher standards such as for energy efficiency, and also out-of-fashion design.

Enkvist and Klevnäs (2018) state that extending lifetimes has a significant influence on CO₂ savings (Chapter 7).

5.5. Concept 5: Selective demolition to enable reuse and high-quality waste for recycling

5.5.1 Description of concept

The overall aim of selective demolition, based on information from the pre-demolition audit, is to recover high-quality (pure) material fractions for recycling or reuse. The purpose of such an audit is to identify hazardous materials that have to be removed prior to demolition and assess the recycling potential. The selective demolition is followed by the processing of the material fractions to ensure high-quality recovery. Selective demolition does not reduce the total amount of waste generated but enables the recovery of fractions for high-quality recycling.

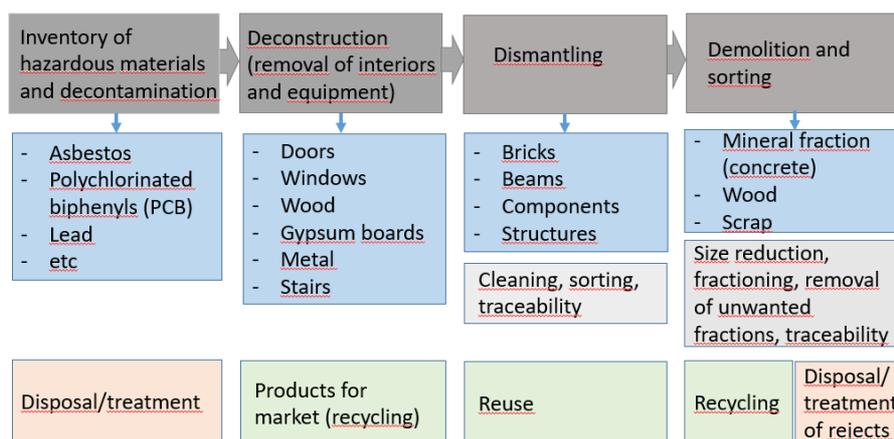
Selective demolition is closely linked to waste sorting requirements. In for example Belgium, Denmark, Finland and Sweden there are legal requirements for sorting different waste fractions. This means that the waste has to be separated at the demolition site, although in all four countries there is a possibility of allowing mixed construction waste to be sorted at special facility.

Table 5.5. Legal requirements or recommendations for material-specific separation of C&D waste in Nordic countries.

	Denmark	Finland	Sweden
Brick/tiles	X	X	X
Concrete	X	X	X
Glass	X	X	
Gypsum	X	X	X
Insulation	x (stone wool)		X
Mixed stony fraction	X		
Mixed concrete and asphalt	X		
Paper	X	X	X
Cardboard	X		
Plastics	X	X	X
Polyvinyl chloride (PVC)	X	X	
Scrap metal	X	X	X
Stone materials, e.g. granite	X		
Tiles and ceramics	X		X
Wood	X	X	X

Source: Wahlström *et al.* (2019)

Figure 5.6 illustrates the phases in the C&DW selective demolition process. It is clear that efficient deconstruction and dismantling depends strongly on the structure's design.



Source: Lauritzen 2018, revised.

Figure 5.6. Phases in a selective demolition process.

5.5.2 Drivers and barriers – boundary conditions

There are various boundary conditions, often case specific, affecting selective demolition. Economic factors are the most important, both promoting and hampering the use of selective demolition. Selective demolition results in materials with a higher value. For example, instead of a mixed stony fraction, a pure high-grade concrete fraction can be recovered. Furthermore, the amount of rejects for landfilling can be minimised. On the other hand, a more selective demolition process is more expensive; it is more labour intensive and more time consuming. The selectivity of the demolition process is determined by this economic trade-off. Policy action can shift this economic trade-off, for example through taxes or legal boundaries such as landfill bans (Horizon2020 project HISER, 2014-2019) (Bio by Deloitte, 2017).

Other common factors affecting selective demolition are time availability; space, especially in an urban environment; structural safety in the dismantling or the safety of the demolition work. Examples of factors listed in literature are shown in Table 5.6. In future, complex construction products or structures will make selective demolition more difficult or impossible – sandwich constructions with integrated insulation materials are almost impossible to separate into different material categories. On the other hand, in future buildings might be constructed to be easy to disassemble (Section 5.2).

Table 5.6. Drivers and barriers for selective demolition.

Aspect/characteristics	Drivers/benefits	Barriers/challenges
Legislation	Selective demolition is mandatory in many member states. Mandatory decontamination of the construction – removal of hazardous materials.	No demand for selective demolition in some EU Member States. Safety requirements in selective demolition are more demanding.
Market/economics	Higher value for pure C&DW fractions. Treatment costs are lower following selective demolition. Creation of more jobs. If a market for material recovery can be identified and connected prior to demolition, environmental success can accompany financial success.	Selective demolition prolongs demolition time and requires more labour.
Quality	Use of efficient selective dismantling enables the separation of unwanted fractions from recyclable C&DW and improves quality.	Potential presence of hazardous materials. Lack of traceability – limited information on the origin and quality of waste materials.
Local conditions		Low cost of landfill and virgin materials. Neighbourhood – creation of noise pollution and dust, lack of space.

Aspect/characteristics	Drivers/benefits	Barriers/challenges
Typology	Access to BIM data in new buildings. Design for disassembly.	Complex buildings increase costs for selective demolition and material separation. Some construction materials, sandwich elements, are not possible to separate economically. Old buildings are not designed to be deconstructed – from building to components – or disassembled – from components to materials – easily.
Technological development	New techniques for material recognition. Use of robots for demolition work. New recycling technologies for high-grade material fractions.	Material identification not yet available in older buildings.
Actors	Education on the circular economy at different levels in universities.	Several stakeholders involved in the value chain; challenge with communication.

5.5.3 Case studies

Some examples of benefits from selective demolition are presented below. In the selected cases, the recovered materials were used to substitute products or virgin materials in construction products.

Reuse of bricks

Reuse of old bricks in facades of buildings rather than new ones creates an architectural value and has raised interest in Denmark. Bricks are carefully dismantled from old buildings, sorted and cleaned – the mortar is removed. The dismantling and the cleaning processes are labour intensive and increase the cost of the bricks compared to new ones. Technically the renovated bricks fulfil the requirements for reuse and are marketed and patented by Gamle Mursten. With the support of the Danish Environmental Protection Agency, a circular economy concept for marketing reusable bricks has been developed (Danish EPA, 2018).

In Denmark a market has been created for old brick with a potential for 30 million bricks per year, which corresponds to about 10 per cent of total brick production. However, there are challenges: often, for example, there may only be only small batches of bricks available from a building being demolished, there may be significant variation in the bricks' technical quality, or a need for better cooperation between demolition contractors/dismantlers and recyclers.

The environmental impacts related to the reuse of bricks and the recycling of crushed bricks were compared in a lifecycle analysis. The results indicate that reuse clearly contributes to reduced impacts, from both an environmental and economic point of view. Both energy and virgin material use are avoided when bricks are reused.

The reuse of bricks saves significant amounts of CO₂, the estimated savings in greenhouse gas emissions is on average about 0.5 kg CO₂-eq per brick (EACI, 2014).

Reclaimed bricks are also common in other countries. In Belgium, for example, mostly fired full face ones that were bricked with a lime base or other soft mortar, generally used before the 1950s, are reused because they can be cleaned easily and have a high value. Reclaimed bricks are most often used for aesthetic reasons and are usually not a part of the load-bearing structure.

Tracimat – traceability system for waste recycling

The Tracimat traceability system was developed in Flanders, Belgium and covers the following elements:

- pre-demolition inventory;
- monitoring and supervision of flows;

- certification system for the construction and demolition material from selective demolition to be accepted as "low environmental risk material".

The purpose of Tracimat is to act as a traceability system providing quality assurance for the selective demolition process and the waste streams produced. Tracimat certification means that the demolition waste has been selectively collected and gone through a tracing system, thereby assuring the processing company of the quality of the recycled demolition waste – guarantee its origin/source and quality as free of contaminants.

Tracimat currently focuses on decontamination, the removal of hazardous materials, as a pure stony non-contaminated waste stream fraction with a low environmental risk clearly has greater upcycling potential. The certificate enhances trust in the quality of the material, resulting in an improved and more widespread market for the recycled products.

The Flemish environmental authorities require crushing companies to distinguish between materials with a low and a high environmental risk at the time of acceptance, with latter materials requiring more stringent processing and quality assessment. This risk profile depends on the prior demolition process. If the C&DW is accompanied by a Tracimat certificate, the processor can accept and process the demolition waste as low environmental risk material.

An important part of the Tracimat traceability system is the training of auditors.

The Tracimat system was compared to a business-as-usual practice in the EU HISER project. The conclusions were following: a Tracimat supported case leads to a significant decrease of 7–14 per cent in the potential impact in some environmental categories. The impact in the environmental categories were; acidification, 14 per cent; terrestrial eutrophication, 10 per cent; marine eutrophication, 7 per cent; and photochemical ozone depletion, 7per cent; all based on product environmental footprint calculations (H2020 HISER project, 2015–2019).

5.5.4 Conclusions

Selective demolition does not necessarily lead to increased recycling levels, but it is a prerequisite for the recovery of high-quality fractions from constructions and their subsequent high-grade recycling, thereby avoiding downcycling. The environmental savings in the use of selective demolition are highly case-dependent, for example, on the recovery potential of fractions. The CO₂ savings are influenced by the need for processing and machinery, and the distances to recycling facilities.

The benefit from a sustainable use of natural resources is not fully addressed in lifecycle analyses. The current impact assessment on resource depletion is based on extraction and consumption of scarce elements and use of fossil energy. The current indicator on abiotic depletion potential (ADP) in lifecycle analyses, according to EN 15804¹, focuses on fossil fuel use or extraction of scarce elements, but does not adequately take account of the saving of other natural resources.

The biggest barriers to selective demolition relate to the economics – the value of the separated fractions and near-by needs, including distance to recycling plants for separated or sorted materials, and the extra time needed for selective demolition. Also, a lack of clarity about the quality of the separated fractions hamper selective demolition and influence the value. Additionally, the risk for damage during dismantling lowers product value.

In future, buildings could be constructed to be easy disassemble. However, the current use of complex products, where several materials are integrated to provide energy efficiency, may hamper the use of selective demolition.

¹ EN 15805: Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products

Furthermore, the supplementary use of BIM tools to provide information on available materials flows provides possibilities for optimising environmental and economic benefits.

5.6. Key elements to achieve circular scenarios in construction

The examples of circular economy action analysed in the previous sections show the potential that increased circularity considerations during a building’s life cycle have on the fulfilment of waste policy objectives. Apart from increasing levels of recycling and waste prevention, the examples are in line with the full definition of circular economy as they also upgrade recycling by preserving value in the waste resources. In some cases, the environmental benefits, such as savings in CO₂ emissions, are very case specific, sometimes due to potentially high processing needs in the recovery of waste materials or, in others, to maintenance and rehabilitation activities having environmental impacts. Furthermore, the total environmental impacts of these circular economy solutions depend on the whole or multiple lifecycles of buildings, which can be several decades.

The analysis identified the main barriers that hinder the full-scale implementation of these actions (Table 5.7). A careful look reveals that the analysed actions share some common barriers that are deemed as the most important if the circularity potential of the construction sector is to be harnessed. The main barriers are economic, concern quality control, and the delay in seeing measurable results from the implementation of circular economy concepts at different lifecycle stages. Poor or inadequate quality, as well as continuity of supply, are challenges that influence the use of recovered materials in new products. Furthermore, the lack of standards, experience and guidance for ensuring the quality of reusable products hampers reuse. There are also various challenges related to the potential content of hazardous substances, contaminants which are banned today but were acceptable in the past when the products were originally manufactured, that risk being spread in the recycling process. Furthermore, challenges in data transfer along the value chain lower trust in the quality of recycled/reclaimed materials and products. And for some materials, technological innovations, as well as new business models, are required for more high-grade recycling.

Some of the barriers to certain concepts can be solved by other described concepts. Selective demolition, for example, enables high-grade recycling while design for disassembly supports lifetime extension (modular constructions are often easier to renovate), selective demolition and the high-grade recovery of materials. Furthermore, materials passports and systems focused on selective demolition, such as Tracimat, improve the traceability of materials, an important challenge for high-grade recycling. These examples are all connected and benefits cannot solely be assigned to a specific stage of the value chain.

Table 5.7. Challenges in implementation of circular principles in the management of construction and demolition waste.

Challenge	Specification	Example of construction waste	Examples of potential solutions for removing of barriers
Quality of waste	Heterogeneity (complex materials), too high content of impurities. Hazardous substances Lack of traceability. Material degradation during use.	Multicomponent products – sandwich constructions.	Less complex products. Pre-demolition audits with follow-up checks on the removal of contaminants prior to demolition. Introduction of sensors in products for securing traceability. Development of tools for detecting product degradation/ageing.
Technological challenge	Processing needs for new rejects. Complex products may require multiple processing steps before recycling, increasing total cost.	Prefabricated elements, fine fractions in concrete waste (cement), plastic waste, insulation waste.	New technological development/new business models. Design for disassembly.

Challenge	Specification	Example of construction waste	Examples of potential solutions for removing of barriers
Economics	Low price of virgin materials. Increase of cost due to more work intensive, higher energy needs. Lack of new business models – sharing of apparatus, facilities, etc.	Concrete waste, wood waste.	Governmental measures – landfill bans, taxes, green public procurement supporting recycling. Sharing of process equipment.
Traceability	Lack of standards and tools. Quality systems for complex materials.	Concrete waste, reusable components/structures.	Standardisation and commitments between stakeholders.
Responsibilities	Role of different actors not clear. Extended product responsibility not applicable for construction products with long lifespan.	Products containing parts from several manufacturers.	Role of building owner in construction phase.
Technical requirements	Potential overspecification of virgin materials, standards not suitable for recyclables.	Metal/wooden/concrete structural elements.	Development of new standards.
Legal issues	Difficulties for CE-marking (scope of harmonised product standards not covering waste related materials) Systems for implementation of EoW concept lacking in many EU Member States.	Metal/wooden/concrete structural elements.	Standardisation.
Environmental aspects	Emissions from several processes can increase impacts. Lack of assessment tools for estimation of material or landfill savings during whole lifetime – focus mainly on greenhouse gas emissions. Environmental impacts often case specific – local conditions, availability of alternative materials, transport. Risks for hazardous substances.	All waste types.	Develop further life cycle analysis indicators for the saving of natural resources – not only focus on greenhouse gases. Promotion of local solutions where materials are not transported.

All the cases presented in this report lead to improved C&DW management in the long term. The introduction of reuse solutions in the design and construction phases that support the prolongation of the lifespan of buildings/components will provide significant environmental benefits in waste management – preventing waste and lowering the amount waste generated. Only part of the suggested circular economy action, however, will improve the C&DW management in the short term. Selective demolition, for example, has an immediate effect on the production of pure fractions for reuse and recycling; prolongation of the lifespan of building products and buildings themselves prevents waste in the short term; and the use of a high content of recyclables in high-grade products avoids downcycling. Other concepts, such as design for disassembly, mainly have an effect during the renovation or demolition of an existing built. The delay, often of several decades, in obtaining measurable circular economy gains in the construction sector may discourage stakeholders from taking action on new material or product management solutions. However, governmental measures can ensure that action that brings long-term environmental benefits is supported economically.

In all cases, the economics of the solutions are the overriding consideration in their uptake. The market acceptance of products produced using waste as an input material will only be assured when production costs are lower than for virgin materials. The case studies also indicate that transport distances for

recyclables may be critical, especially for high-volume wastes, such as mineral wool, in Member States in which raw materials are readily available near the end user.

Besides the economic factors, the quality of building products and materials is crucial for the uptake of circular economy solutions. Lack of available documented information on the origins of waste and data on the composition of old construction products can create doubts about quality.

Standardisation plays an important role in the assessment of the performance of secondary materials in products replacing virgin materials and also in the design of construction products. In the Netherlands, for example, in some applications it is already common practice to use concrete waste in new concrete. Standardisation is often the basis for certification used in trade and business. The challenge in some cases is the scope of the standards and the requirement for CE-marking of construction products covered by harmonised standards.

Several of the cases presented are from projects financed by EU. These are important for understanding how the circular solutions work beyond a development phase and which factors are critical for upscaling, including information on actual costs. Furthermore, real results from such cases create confidence among stakeholders on new approaches to C&DW management.

6 Future development of construction and demolition management

In this sector, the effects on C&DW management from introducing circular economy action in the built environment are discussed. Currently, the application of circular economy thinking in construction focuses mainly on waste recycling and on minimisation in the construction phase.

In Chapters 4 and 5 some of the examples of better management of demolition waste will not show results in the short term due to the long lifespans of buildings. Circular economy action related to the material production, design and, to a lesser extent, the use phases mainly influences waste generation during construction, renovation or demolition. Buildings now coming to the end of lifetimes were not planned for circularity which limits the options for circular economy action in reuse and recycling. There is also a lack of sufficient background information about materials, potential hazardous substances, etc. in older buildings, which hampers the implementation of circular economy action for waste streams.

In the future, voluntary schemes for sustainable buildings, such as EU Level(s) (EC 2019b), BREEAM and LEED, will probably influence the uptake of new approaches and designs, with effects on both waste generation and management. According to Adams (2017), the client has a crucial role for the uptake of circular economy principles in the construction sector, since they set targets for sustainability. For successful implementation, however, support from all stakeholders in the value chain is needed for the waste management concepts.

A report by Arup (2016) includes a vision on circular approaches at the built environment level, rather than the individual component or building scale that offers the opportunity of increasing efficiencies and reducing costs and environmental impacts. Several examples of circular models to change the ecosystem and value chain for the design, construction, operation, renewal and repurposing of buildings are presented. These require designers and investors to take a longer time perspective, including the whole lifecycle of buildings. Furthermore, they also require cooperation between stakeholders and the exchange of information on characteristics of structures, components and materials.

Ecosystems: new business models will lead to performance-based contracts; services will be leased instead of purchased; buildings will be designed for a whole lifecycle, optimising all phases of construction. This holistic approach will support the optimisation of maintenance, disassembly, reuse of components or structures. The phases in the construction value chain will be integrated with other industrial sources, such as regional solutions. The sharing of facilities and equipment will be more common. As an example, Enkvist and Klevnäs (2018) estimate that currently only some 60 per cent of European office space is in use even during working hours, which gives opportunities for sharing. Facilities can be repurposed, leading to less need for new buildings. Equipment for maintenance, deconstruction or processing can also be jointly managed, providing more management options. All of these can lead to less waste by keeping buildings in use for longer or enabling more advanced management of C&DW, such as the use of more advanced sorting systems of waste treatment.

Design: both structures and components will be designed to accommodate future needs. Constructions will be planned to be reused, retrofitted, remodeled, expanded and dissembled according to actual need. The share of reusables will also increase in future. All this will lead to less waste generation.

Sourcing – extraction of materials for buildings: buildings are future materials banks. This means that the buildings will be designed for modularity and adaptability. Important will be the use of durable, reusable parts. These actions will prolong the lifespan of buildings and other structures. Furthermore, materials with a high recyclable content should be preferred if possible (WRAP 2009). These actions will retain the value of material and delay the generation of waste. The use of buildings as sources of material, especially of reuseable building products, requires the implementation of a system of building materials passports (Chapter 5).

The recycling of C&DW for use in new high-grade products calls for the development of new, innovative technologies, especially for construction products with a high carbon footprint. As buildings account for two-thirds of cement use and because of the high carbon footprint linked to its production and use, there is a need for increased cement recycling, the reuse of elements of structural concrete or the replacement of cement with other materials to reduce the overall carbon footprint of buildings. How circular economy action can have a positive effect on the carbon footprint is discussed in Chapter 7.

Construction: the focus will be on flexibility in the manufacture of construction products. Off-site manufacture and prefabrication of structures will optimise material use, leading to the use of fewer materials and less waste. Enkvist and Klevnäs (2018) point out the need to avoid over-specification and mentions as an example that currently an excess of 50 per cent of steel is used to achieve the desired structural properties of steel constructions. However, it should be noted that the over-specification is closely linked with the safety targets of construction and lowering the safety requirements may lead to failure or accidents. Digitalization and 3D printing are examples of tools for the optimisation of material use. Design for disassembly will significantly improve the amounts of materials retrieved for potential reuse/recycling during the demolition process (Brand, 1994).

Operation of buildings and the renewal of building materials: maintenance can prolong the lifespan of buildings and products. The use of sensors in construction materials, for example, can help avoid degradation of building products and the planning of renovations and thus prolong the lifespan of buildings. The concept of leasing rather than buying components and structures will promote improved performance and circular thinking.

Disassembly: The use of standard modules will make constructions mobile and flexible and thus promote reuse and prolong the lifetime of products. The use of standard dimensions will help transport of structures and components. Building information modelling will be used for data tracking, including information on disassembling structures and components.

Enkvist and Klevnäs (2018) describes the importance of digitalisation and robotisation in the future. Digitalisation in the construction sector gives opportunities to increase productivity through, for example, 3D printing; helps in data management, especially in the tracing of materials; provides tools for data sharing; and also provides possibilities for the optimisation of maintenance. Furthermore, construction robotics will help by performing some tasks faster and more accurately, and also may increase the work safety in, for example, demolition work.

Box 6.1 Digitalisation to support the transition to circular economy

Digitalisation can reduce costs at all stages of the construction value chain. It can be used to:

- track complex supply chains and manage material flows – material/product traceability, use of BIM and data storage from the use of sensors;
- design new products (3D) minimising material use, increasing productivity;
- optimise sharing business models;
- automate materials handling and maintenance in construction – for example, use of radio-frequency identification (RFID) tags and sensors in material detection and handling, and robot sorting of waste.

The use of BIM provides new possibilities for the future, raising efficiency in construction processes, especially material handling and waste management. It is defined by the United States National Institute for Building Sciences as “a digital representation of physical and functional characteristics of a facility. BIM is used to store building drawings in digital models. These BIM models are based on entities which include both (3D) geometrical and semantical information like materials, manufactures’ detail, construction details, etc. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition”.

Some advantages of BIM are:

- improved visualisation;
- improved productivity because of easy retrieval of information;
- increased coordination of construction documents;
- embedding and linking of vital information such as vendors for specific materials, location of details and quantities required for estimating and tendering;
- increased speed of delivery; and
- reduced costs.

Reference: Handbook for the introduction of Building Information Modelling by the European Public Sector Strategic action for construction sector performance: driving value, innovation and growth. <http://www.eubim.eu/handbook/>

Enkvist and Klevnäs (2018) present city planning as a tool for future circular economy concepts in the built environment. The role of the public sector is both as a customer of building and infrastructure projects, and a principal actor through its influence on city planning. At the city level, the ambition for sustainable urban development sets priorities for both buildings with longer lifetimes, through greater durability and adaptability, and managing material flows. The concept of an urban metabolism in which material flows are efficiently used within a city or region, might particularly receive more attention in future (Box 6.2)

Box 6.2 Urban metabolism

Urban metabolism or cityloops is a concept in which material flows circulate within a region or a city. Its aim is to optimise urban flows and stocks of waste material and close the loop for the resources used without increasing the environmental burden or causing losses of natural resources. For development of an urban metabolism, knowledge about processes, flows and stocks within the society is required. Typically, a material flow analysis (MFA) model is developed supporting the design of solutions. This allows an assessment of the change in flows and stocks, as well as in product quality, recycling rates, resource conservation and environmental protection.

In densely populated areas with a limited need of new infrastructure and difficult access to high-quality natural raw materials, for example, the processing and upgrading of the mineral fraction and other industrial waste streams can be a future sustainable solution. However, in countries in which virgin materials are available cheaply, the uptake of waste materials in high-grade products will probably remain low. Demonstration cases are needed to convince all stakeholders.

Examples of recent EU projects focussing particularly on construction and demolition waste include:

- “CityLoops brings together six ambitious European cities – Apeldoorn, Bodø, Mikkelí, Porto, Roskilde/Høje-Taastrup, and Seville – to demonstrate a series of innovative tools and urban planning approaches, aimed at closing the loops of urban material flows and increasing their regenerative capacity. Demonstration action will be implemented in relation to construction/demolition waste, including soil, and organic waste. During the inception phase, a circular city scan methodology and indicators will be developed and implemented in each city, by adapting current MFA and urban metabolism methods to include context-specific data and challenges, to adjust planned demonstration actions, provide an evaluation framework for the measures and monitor their progress towards a circular economy. A series of further innovative decision support tools will be developed (such as City Lab, a GIS based city planning tool, and a pre-demolition resource-mapping tool) for specific demonstration actions.” (<https://cordis.europa.eu/project/rcn/223258/factsheet/en>)
- “CIRCuiT will demonstrate three innovative solutions in the four cities (Copenhagen, Hamburg, Helsinki region (City of Vantaa) and Greater London): dismantle buildings to reuse materials; transformation and refurbishment; and design for disassembly and flexible construction. CIRCuiT will develop urban planning instruments to support cities in implementing circular construction solutions and initiate changes at system level; implement a Circularity Hub, a data platform to evaluate progress of circular economy and regenerative capacity; and set up a knowledge sharing structure, the CIRCuiT Academy, to promote upscaling of solutions.” (<https://cordis.europa.eu/project/rcn/223267/factsheet/en>)

Currently, changes in the built environment are often focused on energy efficiency. If the material impact of these changes is not taken into account, circular economy action in the future might be severely hampered by, for example, different materials glued to each other or non-dismountable composites from materials that require different recycling routes. New information on risks for human health and environment on use of specific materials could also change recycling options in the future.

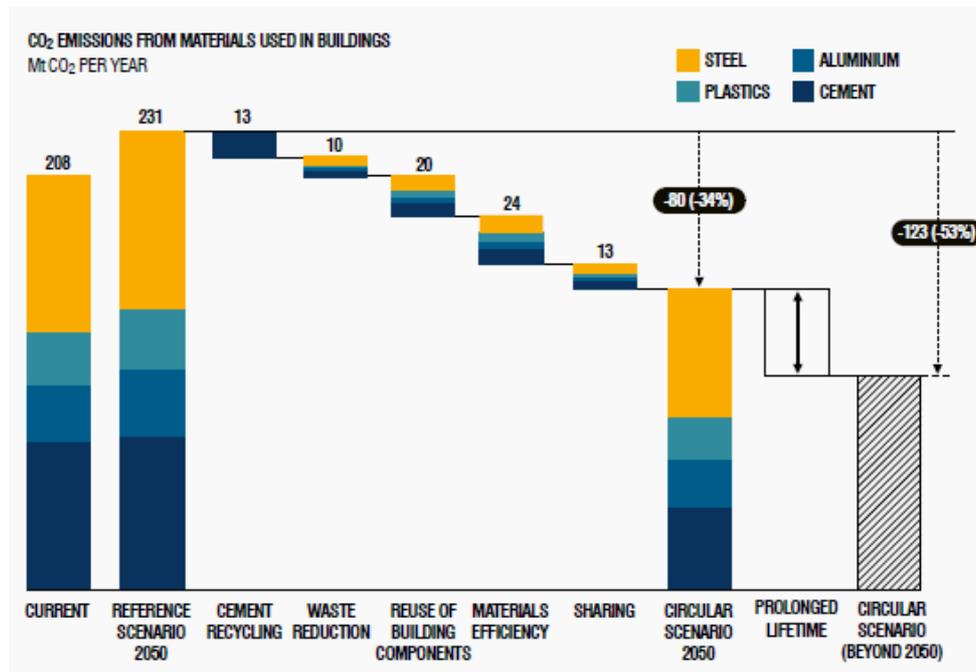
7 Climate benefits

In the construction sector, the climate challenge is primarily seen as an energy problem, solutions being sought in the light of the transition to renewable energy and the implementation of energy efficiency measures. This perspective must be supplemented by an underlying driver of high energy demand: high material consumption as a consequence of a linear economy. The *Circularity Gap Report* (Circle Economy 2019) calculates that 62 per cent of global greenhouse gas emissions, excluding those from land use, land-use change and forestry, are released during the extraction of materials, their processing and the manufacturing of goods. Construction and maintenance of the built environment consumes almost half of all materials entering the global economy and generates about 20 per cent of all greenhouse gas emissions. The report highlights five key circular strategies to be adapted in a circular built environment: maximising the use of products and extending their lifetimes; enhancing recycling; introducing circular design; reducing material consumption; and using lower-carbon alternatives. This chapter focuses on potential CO₂ savings from better C&DW management by introducing circular economy action.

In the assessment of the effect of a circular economy in the built environment, the net gain in CO₂ savings have been calculated based on lifecycle analysis principles, comparing its carbon footprint in a traditional linear economy to the alternative circular economy management solutions. The results are case specific and bound to the conditions in the selected waste management scenario. Comparison between different products with the same function is commonly utilised for reporting the environmental performance of construction materials.

In the construction sector, focus in impact analyses is on construction products and materials with so-called high embodied energy, the energy linked to the production of construction products and materials from raw materials. This includes the energy used in the extraction of materials, the manufacture of construction products, the construction phase itself and the end-of-life phase, demolition, but not energy used directly during the use phase. For comparison of the embodied energy of different materials, the impact needs to be evaluated based on construction works with the same function and performance, not simply by comparing embodied energy per weight. Carbon footprint correlates generally to the embodied energy of materials.

The CO₂ emissions embodied in construction materials make up 40–50 per cent of the total carbon footprint of an office building, primarily due to the production of the cement and steel required (RICS Research, 2010). By 2050, the materials used for construction will result in emissions of 250 million tonnes (Mt) of CO₂ in a baseline scenario in which they are made using today's production processes. Enkvist and Klevnäs (2018) state that, of these emissions, at least 80 Mt CO₂ per year could be saved by 2050 by demand-side measures (Figure 7.1). The same source also reports although steel represents about 2 per cent of total materials in buildings by weight, it represents for 25 per cent of the carbon footprint. Using secondary materials instead of virgin materials often requires less energy when considering energy associated with extraction. Reusing steel instead of having to mine ore and process it into steel can significantly reduce greenhouse gas emissions. Box 7.1 includes examples of CO₂ savings in multi-reuse scenarios for steel (Hradil *et al.*, 2014). A study by Deloitte (2016) shows similar results emphasising the importance of recycling and reuse.



Source: Enkvist & Klevnäs, 2018

Figure 7.1. A circular scenario reduces CO₂ emissions from building materials, million tonnes of CO₂ by 53 per cent.

The cement industry alone is responsible for approximately 8 per cent of current emissions globally (Olivier *et al.* 2016). This means there is a considerable potential in substituting cement as a raw material, replacing, for example. Portland cement clinker with supplementary cementitious materials, or, as a result of the use of new technologies, with non-clinker based cements. Scrivener *et al.* (2018) state that increasing the average level of Portland clinker substitution in cement to 40 per cent could avoid up to 400 Mt CO₂ emissions globally each year. Geopolymer or alkali-activated binders can have carbon footprints that are up to 90 per cent lower than Portland cement (Taylor 2013), but most conventional, high-quality supplementary cementitious materials such as blast furnace slags or combustion fly ash are currently fully used. If, we want to replace more Portland cement clinker, we will need alternative binders that to date have failed to significantly penetrate the market (Dewald & Achternbosch 2015), including waste glass, concrete fines and biomass incineration ash.

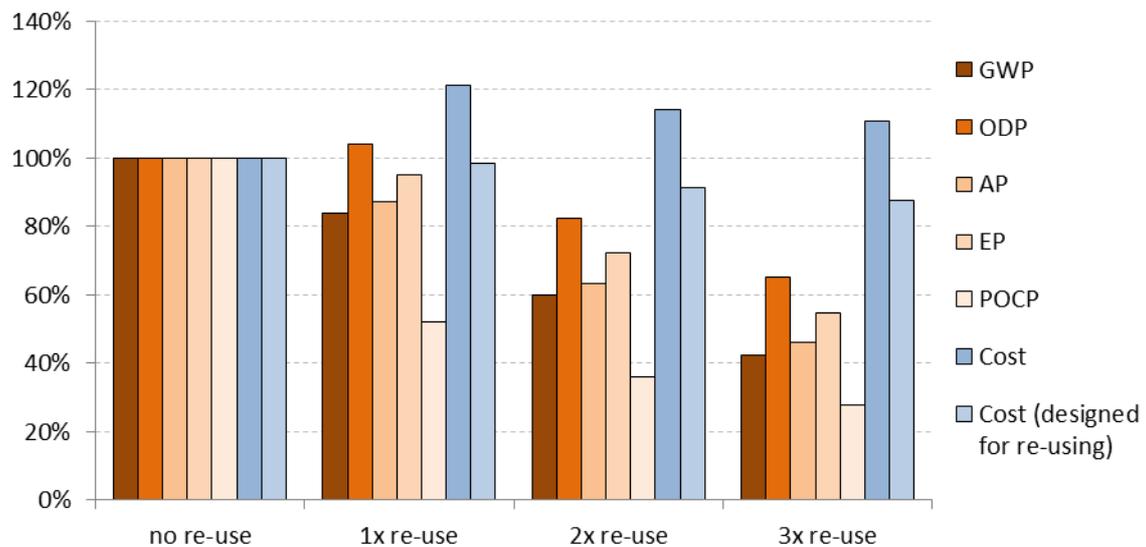
These examples clearly indicate that a transition to a circular economy could not only decrease material consumption and waste production, but also decrease greenhouse gas emissions. Climate action in the built environment is often strongly focused on the minimisation of greenhouse gas emissions during the lifetime of buildings. When such action is implemented without taking circular economy principles into account, it can have an adverse effect on the other lifecycle stages. The Horizon2020 HISER project includes a case study in which selective demolition was strongly hampered by the presence of thermal insulation materials that were difficult to remove separately – for example, suspended ceilings were filled with loose expanded polystyrene beads and spray-foam insulation was stuck to the walls and ceilings.

Box 7.1 The multi-reuse of building products

Case: Calculated environmental benefits from reusing a single steel element up to three times.

All lifecycle analysis/lifecycle costing illustrated the lifecycle environmental impact and costs of a hot-rolled steel beam with welded endplates and bolted connections that can be easily reused in a similar structure after dismantling from the original one. The results show a clear environmental benefit of reuse. The study anticipates reduced lifecycle costs by designing for deconstruction. (Hradil, 2014)

LCIA category	units	no re-use	1x re-use	2x re-use	3x re-use
Global warming potential (GWP100)	kg CO ₂ eq.	1075	901	642	454
Stratospheric ozone depletion (ODP10)	kg CFC11 eq. x 10 ⁻⁸	4.27	4.44	3.52	2.78
Acidification potential (AP generic)	kg SO ₂ eq.	3.33	2.90	2.11	1.53
Eutrophication potential (EP generic)	kg (PO ₄) ³⁻ eq.	0.293	0.278	0.212	0.160
Photochemical oxidation (POCP high NOx)	kg ethylene eq.	0.089	0.046	0.032	0.025
Cost	€	1149	1394	1312	1270
Cost (designed for re-use)	€	1149	1131	1048	1007



Source: Hradil, P. 2014. Barriers and opportunities of structural elements re-use. Research Report VTT-R-01364-14. VTT, Technical Research Centre of Finland, 2014

8 Policy options for facilitating the interplay between circular economy implementation and construction and demolition waste management

8.1. Summary of the circular economy actions leading to better C&DW management

Circular economy action for improved C&DW management can be introduced at many different levels – in buildings, at the component level or at the whole construction level. Currently, however, the application of circular economy concepts is currently often limited to waste minimisation and recycling.

All phases in the lifecycle of constructions are connected for the achievement of circular economy goals. Circular construction starts with the circular design of construction products, followed by a choice of sustainable non-hazardous materials, potentially including a high content of waste materials. For designing and manufacturing circular products, it is important that the architect knows how the demolition contractor works, the recycler must know about the technical requirements of the recovered products or materials for reuse and recycling. The recycling process needs to be adapted to provide suitable feedstock for recycling, potentially adding new process steps for material separation. The documentation and access of information on construction products and construction methods is especially important for the demolition and recycling companies.

Closing the material loops requires new business models and especially communication and commitments between all stakeholders over the entire life cycle.

Table 8.1. Examples of circular economy action for better construction and demolition management.

Lifecycle	Examples of circular economy action	Conditions (examples)
Design phase	Design for reuse, repurposing and recycling.	Less complex products – for example, dismountable products. Standards.
Material production phase	Material choices, use of a high content of recyclables.	Closing the loop with use of new technologies. Quality of separated waste fractions. Material documentation.
Construction phase	Lifetime optimisation for more circular products.	Lean manufacturing. Digitalisation, BIM, traceability, materials passports.
Use phase	Maintenance for extension of lifetime.	Planning of maintenance, use of sensors, etc. for optimising maintenance/renovation.
End-of-life phase	Separability of different materials with a low content of impurities, less complexity, technology development.	Importance on recovery of clean, pure fractions. Traceability – documentation.

8.2. Options for better construction and demolition waste management

The biggest barriers to circular economy concepts are economic, due to a lack of demand for recovered waste and poor quality due to impurities and the risk for contaminants. Policy measures may have a strong influence on these market conditions, for example, through taxes on virgin materials. Examples of other policy measures are the encouragement of green public procurement, taxes for landfilling, end-of-waste criteria and extended product responsibility (EPR), which has been introduced for many product areas. For construction products with short lifetimes, such as carpets, there are several successful examples of EPR schemes, including Tarkett's ReStart programme or Desso's Take Back Programma, but these may not be appropriate for products that remain *in situ* over a building's lifetime (Adams *et al.*, 2017).

The use of traceability systems for recyclables and reusable products is mentioned in several cases as a crucial tool for creating confidence among value-chain stakeholders. These traceability systems can be

built on information from a pre-demolition audit, such as Tracimat. In several cases the importance of BIM was also brought up as a tool for material inventories and traceability as BIM carries information about construction products during their entire lifecycle up to the deconstruction stage. Policy can promote these systems, certainly in government construction works contracted through, for example, green public procurement. Furthermore, materials passports containing details of the materials in building products enable their maintenance, recovery, reuse and recycling potential at different phases and can be made available to the key stakeholders at the right time. Circularity passports can be requested and used by a wide range of stakeholders, ranging from product manufacturers, through building owners and users to dismantlers, urban miners and materials suppliers.

Standardisation plays an important role in assessing the performance of secondary materials used rather than virgin ones in products and also in the design of construction products. For example, in the Netherlands it is already common practice to use concrete waste in certain applications of new concrete. Standardisation is often the basis for certificates used in trade and business. In some applications, however, standards include overspecification to ensure performance, and this leads to increased use of raw materials. The requirements related to different applications need to be checked, based on experience and availability of tools, such as non-destructive testing methods for checking on product properties including material degradation. However, it is important that safety targets of construction are not endangered.

The involvement and commitment of stakeholders throughout the value chain are important to align them to a common circularity objective, although the benefits of circular economy solutions are not shared equally in the value chain. The role of the client or end user of a construction is crucial for the uptake of circular economy principles in its construction by different stakeholders (Adams *et al.*, 2017) as the client sets the targets for sustainability. Other challenges include how to address the responsibility of a manufacturer for products that will only be demolished long into future and how the ownership of construction material is linked to responsibilities, questions the answers to which are not always clear.

Several of the cases presented in this report are from demonstration projects financed by the EU or national governments. These demonstration cases are important for spreading knowledge on how the circular solution work at scale and which factors are critical for upscaling, including information on actual costs. Furthermore, results of new approaches in C&DW management from demonstration cases create confidence among stakeholders.

In the short term, action promoting the extension of product lifetimes, selective demolition and reuse or high-grade recycling of construction products is identified as important for achieving better circular C&DW management as well as reducing CO₂ emissions. The implementation of action to improve reuse and recycling rates is influenced by governmental measures including taxes and bans.

In future, storing information about construction products and buildings will be crucial for circular C&DW management as it opens the possibility in data sharing thereby improving construction and demolition management along the whole value chain, from design to end of life. The design, manufacturing and construction of products which last for a long time and allow for easy maintenance set requirements for information documentation and sharing.

New business models are also needed. Today, a manufacturer or constructor does not bear the costs of C&DW management. Cooperation and commitment among all stakeholders will be crucial in future as without it and the availability of product data, extended producer responsibility for products designed to last for many years cannot work. Additionally, design directives need to be adapted.

Lastly, financial support for research on innovative circular technologies and solutions for material handling in construction and demolition sector provides a solid base to transition to circular economy in built environment.

9 References

- Adams, K., Osmani, M., Thorpe, A. and Gibbs, J., 2017, 'The role of the client to enable circular economy in the building sector.' HISER International Conference, 'Advances in recycling and management of construction and demolition waste'. Delft, June 21–22, 2017, Proceedings.
- Allwood, J. and Cullen, J., 2012, *Sustainable Materials with both eyes open*. UIT Cambridge Limited, Cambridge, UK.
- Arup, 2016, *The circular economy in the built environment*. Arup, London, UK. <https://www.arup.com/perspectives/publications/research/section/circular-economy-in-the-built-environment> [accessed 20 November 2019].
- BAMB, 2019, *Materials Passports*. Buildings as Materials Banks, Brussels, Belgium. <https://www.bamb2020.eu/topics/materials-passports/> [accessed 28 August 2019].
- Bio by Deloitte, 2017, *Resource Efficient Use of Mixed Wastes Improving management of construction and demolition waste*. Final report. European Union, Brussels, Belgium.
- Brand, S., 1994, *How buildings learn, what happens after they're built*. Viking Penguin, New York, US.
- Chini, A. R., 2008, 'Barriers to deconstruction and materials reuse' Proceedings of the World Sustainable Building Conference 2008, Melbourne, Australia, 21–25 September 2008.
- Circle Economy, 2017, *A future proof built environment, putting circular business models into practice*. Circle Economy and ABN AMRO, Amsterdam, Netherlands. <https://www.circle-economy.com/case/a-future-proof-built-environment/#.XcLLBTmZy2w> [accessed 20 November 2019].
- [Circle Economy, 2019, *The Circularity Gap Report 2019*. Circle Economy, Amsterdam, Netherlands. https://www.circularity-gap.world/](https://www.circularity-gap.world/) [accessed 20 November 2019].
- Crowther, P., 1999, 'Design for Disassembly', Conference Proceedings of the 8th International Conference on Durability of Building Materials and Components, 30 May–3 June 1999, Vancouver, Canada.
- [Danish EPA, 2015, 'Udredning af teknologiske muligheder for at genbruge og genanvende beton'. Miljøstyrelsen, Miljøprojekt nr. 1667.](#)
- Danish EPA, 2018, *Genbrug af mursten*. Miljøprojekt nr. 2002. <https://www2.mst.dk/Udgiv/publikationer/2018/04/978-87-93710-01-6.pdf> [accessed 20 November 2019].
- Debacker, W. and Manshoven, S., 2016, *Synthesis of the state-of-the-art: Key barriers and opportunities for Materials Passports and Reversible Building Design in the current system*. Report within the framework of H2020 BAMB project (grant agreement No-642384).
- Deloitte, 2016, *Sustainability circular economy potential for climate change mitigation*. Deloitte Conseil, Paris, France. <https://www2.deloitte.com/content/dam/Deloitte/fi/Documents/risk/Deloitte%20-%20Circular%20economy%20and%20Global%20Warming.pdf> [accessed 20 November 2019]
- Denarié, E. and Brühwiler, E., 2006, 'Structural rehabilitations with ultra-high performance fibre reinforced concretes (UHPRFC)'. *Restoration of Buildings and Monuments* 12, pp. 453-468.
- Densley Tingley, D., 2013, *Design for Deconstruction* (Doctoral dissertation). University of Sheffield, UK.
- Dewald U. and Achternbosch M., 2015. 'Why more sustainable cements failed so far?' *Environmental Innovation and Societal Transitions* 19, pp. 15–30.

Durmisevic, E., Beurskens, P., van de Boogaart, E., Balson, K. and Hobbs, G., 2019, 'Reversible Design Tool', Report D8 within the framework of H2020 BAMB project (grant agreement No-642384).

EACI, 2014, Project Information Sheet. Market uptake of an automated technology for reusing old bricks (REBRICK). http://www.gamlemursten.eu/files/9313/2671/0130/Project_information_sheet.pdf [accessed 20 November 2019].

EC, 2011, Decision 2011/753/EU (rules and calculation methods for verifying compliance with the target), European Commission, Brussels, Belgium.

EC, 2013, Consultation on the review of the Hazardous Properties. European Commission DG Environment, Brussels, Belgium. <http://ec.europa.eu/environment/waste/framework/list.htm> [accessed 20 November 2019].

EC, 2015, The European Economic and Social Committee and the Committee of the Regions — Closing the loop — An EU action plan for the Circular Economy (COM(2015) 614/2 of 2 December 2015), European Commission, Brussels, Belgium.

EC, 2016, EU Construction and Demolition Waste Management Protocol, European Commission, Brussels, Belgium. https://ec.europa.eu/growth/content/eu-construction-and-demolition-waste-protocol-0_en [accessed 20 November 2019].

EC, 2018a, 2018 Circular economy package – key documents, European Commission, Brussels, Belgium. <https://ec.europa.eu/environment/circular-economy/> [accessed 20 November 2019].

[EC, 2018b, Report from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions on the implementation of EU waste legislation, including the early warning report for Member States at risk of missing the 2020 preparation for reuse/recycling target on municipal waste. 24.9.2018 COM\(2018\) 656 final, European Commission, Brussels, Belgium. https://ec.europa.eu/environment/waste/pdf/waste_legislation_implementation_report.pdf \[accessed 20 November 2019\].](#)

EC, 2018c, *Guidelines for the waste audits before demolition and renovation works of buildings*, European Commission, Brussels, Belgium. <https://ec.europa.eu/docsroom/documents/31521> [accessed 20 November 2019].

EC, 2019a, Commission Staff Working Document accompanying the document Report from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the regions on the implementation of the Circular Economy Action Plan, European Commission, Brussels, Belgium.

EC, 2019b, Building sustainability performance - Level(s), European Commission, Brussels, Belgium. <https://ec.europa.eu/environment/eussd/buildings.htm> [accessed 20 November 2019].

EC, 2019c, *Sustainable Products in a Circular Economy - Towards an EU Product Policy Framework contributing to the Circular Economy*, European Commission, Brussels, Belgium. http://ec.europa.eu/environment/circular-economy/pdf/sustainable_products_circular_economy.pdf [accessed 20 November 2019].

EEA, 2016, *Circular economy in Europe - Developing the knowledge base*, EEA Report No 2/2016. European Environment Agency, Copenhagen, Denmark. <https://www.eea.europa.eu/publications/circular-economy-in-europe> [accessed 20 November 2019].

Ellen MacArthur Foundation, 2015, *Towards a circular economy: business rationale for an accelerated transition*, Ellen MacArthur Foundation, London, UK.

https://www.ellenmacarthurfoundation.org/assets/downloads/publications/TCE_Ellen-MacArthur-Foundation_26-Nov-2015.pdf [accessed 20 November 2019].

Ellen MacArthur Foundation, 2019, *Completing the picture: how the circular economy tackles climate change*, Ellen MacArthur Foundation, London, UK. <https://www.ellenmacarthurfoundation.org/publications/completing-the-picture-climate-change> [accessed 20 November 2019].

Ellen MacArthur Foundation and Arup, 2019. *Making buildings with new techniques that eliminate waste and support material cycles*. Ellen MacArthur Foundation and Arup, London, UK.

Enkvist, P.-A. and Klevnäs, P. (eds.), 2018, *The circular economy – a powerful force for climate mitigation*. Material Economics, Stockholm, Sweden. <https://media.sitra.fi/2018/06/12132041/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf> [accessed 21 November 2019].

EPEA, 2019, *Circularity Passports*. EPEA GmbH, Hamburg, Germany. <http://www.epea.nl/circularity-passports/> [accessed 20 November 2019].

European Parliament and European Council, 2018, Directive (EU) 2018/851 of 30 May 2018 amending Directive 2008/98/EC on waste. Brussels, Belgium.

Eurostat, 2019a, *Generation of waste by waste category, hazardousness and NACE Rev. 2 activity [env_wasgen]* [accessed 2 July 2019]. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en

Eurostat, 2019b, *Recovery rate of construction and demolition waste [CEI_WM040]* [accessed 2 July 2019]. <https://data.europa.eu/euodp/en/data/dataset/uCZdo4Z1o5qcLlbdtkbHQ>

Eurostat, 2019c, *Treatment of waste by waste category, hazardousness and waste management operations [env_wastrt]* [accessed 2 July 2019]. <https://data.europa.eu/euodp/en/data/dataset/8bxb7vuNmKpY3c2MnoElw>

Eurostat, 2019d, *Gross value added and income by A*10 industry breakdowns [nama_10_a10]* [accessed 2 July 2019]. https://ec.europa.eu/eurostat/web/products-datasets/product?code=nama_10_a10

Ferreira, J., Duarte Pinheiro, M. and de Brito, J., 2015, Economic and environmental savings of structural buildings refurbishment with demolition and reconstruction - A Portuguese benchmarking. *Journal of Building Engineering* 3, 114-126.

FP7 project C2CA: Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste, <http://www.c2ca.eu/> [accessed 29 November 2019].

FP7 project IRCOW, 2011-2014, Innovative Strategies for High-Grade Material Recovery from Construction and Demolition Waste. <https://cordis.europa.eu/project/rcn/97292/reporting/en> [accessed 29 November 2019].

Gebremariam, A.T., Di Maio, F. and Lotfi, S., 2018, 'Advancements in recycling of end-of-life concrete', *CPI Concrete Plant International* – 3/2018.

Habert, G., Denarié, E., Sajna, A. and Rossi, P., 2013, 'Lowering the global warming impact of bridge rehabilitations by using Ultra High Performance Fibre Reinforced Concretes', *Cement & Concrete Composites* 38, pp. 1-11.

Hechler, O., Popovic Larsen, O. and Nielsen, S., 2011, 'Design for Deconstruction. Summary Report of the Cooperative Activities of the COST Action C25' in Bragança, L., Koukkari, H., Landolfo, R., Ungureanu, V.,

Vesikari, E. and Hechler, O. (eds.), *Sustainability of Constructions - Integrated Approach to Life-time Structural Engineering* Volume 2, pp 339–354. CRC Press, London, UK.

Heinrich, M. A. and Lang, W., 2019a, 'Capture and Control of Material Flows and Stocks in Urban Residential Buildings'. IOP Conf. Ser. *Earth Environ. Sci.*, vol. 225, p. 012001.

Heinrich, M. A. and Lang, W., 2019b, *Materials Passports - Best Practice*. Technische Universität München in association with BAMB, Brussels, Belgium.

Hilton, M., 2018, *Policy Toolkit for Carpet Circularity in EU Member States*. Changing Markets, Eunomia Research & Consulting Ltd., Bristol, UK.

Hradil, P., Talja, A., Wahlström, M., Huuhka, S., Lahdensivu, J. and Pikkuvirta, J., 2014, *Re-use of structural elements; Environmentally efficient recovery of building components*. VTT Technical Research Centre of Finland, Helsinki, Finland.

H2020 project HISER, 2015–2019, 'Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste'. Halbo Industry Service, Kazincbarcika, Hungary. www.hiser.eu [accessed 20 November 2019].

H2020 project BAMB, 2015-2020, 'Buildings as material banks', Buildings as Material Banks. <https://www.bamb2020.eu/> [accessed 21 November 2019].

H2020 project VEEP, 2016-2020, 'Cost effective recycling of C&DW in high added value energy efficient prefabricated concrete components for massive retrofitting of our built environment'. <http://www.veep-project.eu/> [accessed 20 November 2019]

Häkkinen, T. (ed.), 2012, *Sustainable refurbishment of exterior walls and building facades*. VTT Technology 30. [VTT Technical Research Centre of Finland](http://www.vtt.fi), Helsinki, Finland.

ISO 14067, 2018, *Greenhouse Gases - Carbon Footprint of Products - Requirements and Guidelines for Quantification*. International Organization for Standardization, Geneva, Switzerland.

Itard, J. and Klunder, G., 2007, 'Comparing environmental impacts of renovated housing stock with new construction'. *Building Research & Information* 35, pp. 252-267.

Kanters, J., 2018, 'Design for Deconstruction in the Design Process: State of the Art'. *Buildings* 2018, 8(11), p. 150. <https://doi.org/10.3390/buildings8110150> [accessed 21 November 2019].

Klößner, C.A., 2016, 'Specific Barriers and Drivers in Different Stages of Decision-Making about Energy Efficiency Upgrades in Private Homes'. *Front. Psychol.*, 08 September 2016

Lauritzen, E.K., 2018, *Selektiv nedrivning - Hvad har vi af erfaringer, som vi kan bygge på?*. Presentation at DAKOFA Møde i netværk for bygge- og anlægsaffald 4. december 2018. <https://dakofa.dk/kort/netvaerk-for-bygge-og-anlaegsaffald-15/>

Lotfi, S., 2016, 'C2CA Concrete Recycling Process: From Development to Demonstration'. <https://doi.org/10.4233/uuid:70505a1f-c0d7-47c7-ab62-8d487761c021> [accessed 21 November 2019].

Lotfi, S. Rem, P., Deja, J. and Mroz, R., 2017, 'An experimental study on the relation between input variables and output quality of a new concrete recycling process'. *Construction and Building Materials* 137, pp. 128–140.

Luscuere, L., 2016, 'Materials Passports: Providing Insights in the Circularity of Materials, Products and Systems', presented at the Sustainable Innovation 2016. Circular Economy Innovation & Design, Epsom, UK, 2016.

Madaster, 2019, 'Vision, mission, aims'. Madaster. <https://www.madaster.com/en/about-us/vision-mission-aims> [accessed: 28 August 2019].

[Mulhall, D., Luscuere, L., Zanatta, R., Boström, J. and Elström, L., 2019, *Operational Material Passports*, D7 Report within the framework of H2020 BAMB project \(grant agreement No-642384\).](#)

[Mulhall, D., Hansen, K., Luscuere, L., Zanatta, R., Willems, R., Boström, J. and Elfström, L., 2017, 'Framework for Materials Passports'. Extract from an internal BAMB Report. EPEA Nederland and SundaHus, in association with BAMB. <https://www.bamb2020.eu/wp-content/uploads/2018/01/Framework-for-Materials-Passports-for-the-webb.pdf> \[accessed 21 November 2019\].](#)

[Olivier, J., Janssens-Maenhout G., Muntean M. and Peters J., 2016, Trends in global CO₂ emissions: 2016 Report. PBL Netherlands Environmental Assessment Agency.](#)

[Paduart, A., 2012, 'Re-design for Change: A 4 Dimensional renovation approach towards a dynamic and sustainable building stock', Doctoral dissertation. Vrije Universiteit Brussel, Brussels, Belgium.](#)

[Palm, J., 2018, 'Understanding barriers to energy-efficiency renovations of multifamily dwellings'. *Energy Efficiency* \(2018\) 11, pp. 53–65.](#)

[RICS Research, 2010, *Redefining Zero: Carbon profiling as a solution to whole life carbon emission measurement in buildings*. RICS, London, UK.](#)

[Rios, F.C., Chong, W.K. and Grau, D., 2015, 'Design for Disassembly and Deconstruction – Challenges and Opportunities'. *Procedia Eng.* 2015, 118, pp. 1296–1304.](#)

[Rizos V., Tuokko K. and Behrens A., 2017, *The Circular Economy, A review of definitions, processes and impacts*. CEPS Research Report. CEPS, Brussels, Belgium.](#)

[Schut, E., Crielaard, M. and Mesman, M., 2015, *Circular economy in the Dutch construction sector. A perspective for the market and government*. RIVM report number 2016-0024. The Netherlands National Institute for Public Health and the Environment, Bilthoven, Netherlands.](#)

[Scrivener K.L., Vanderley M.J. and Gartner E.M., 2018, 'Eco-efficient cements: Potential economically viable solutions for a low-CO₂ cement-based materials industry'. *Cement and Concrete Research* 114, pp. 2–26.](#)

[SPIRE project Re4, 2016-2020, REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction. <http://www.re4.eu/> \[accessed 21 November 2019\].](#)

Taylor G.M., 2013, Novel cements: low energy, low carbon cements. MPA Cement Fact Sheet 12.

Thelen, D., van Acoleyen, M., Huurman, ., van Brunschot, C., Edgerton, B. and Kubbing, B., 2018, *Scaling the circular built environment, pathways for business and government*. World Business Council for Sustainable Development, Geneva, Switzerland and Circle Economy, Amsterdam, Netherlands.

Webster C., 2013, *The art of design for disassembly*. Ellen MacArthur Foundation, London, UK.

[Wahlström, M., zu Castell-Rüdenhausen, M., Hradil P, Hauge Smith, K., Oberender, A., Ahlm, M., Götbring, J., and Bjerre Hansen, J., 2019, 'Improving quality of construction & demolition waste – Requirements for pre-demolition audit'. *TemaNord* 2019:508](#)

WRAP, 2009, *Delivering higher recycled content in construction projects*. Waste and Resources Action Programme, Banbury, UK.

<http://www.wrap.org.uk/sites/files/wrap/Delivering%20higher%20recycled%20content%20in%20construction%20projects.pdf> [accessed 21 November 2019].

Xuan, D., Zhan, B. and Poon, C.S., 2017, 'Assessment of mechanical properties of concrete incorporating carbonated recycled concrete aggregates'. *Cement and Concrete Composites* 65, pp. 67–74.

Zero Waste Scotland, 2019, *Designing Out Construction Waste. A guide for project design teams*. Zero Waste Scotland, Stirling, Scotland.
https://www.resourceefficientscotland.com/sites/default/files/Designing%20Out%20Construction%20Waste%20Guide_0.pdf [Assessed 6 November 2019].

10 List of abbreviations

ADP	Abiotic depletion potential
ADR	Advanced Dry Recovery
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
C&DW	Construction and Demolition Waste
CE	Circular Economy
CEAP	Circular Economy Action Plan
DfD	Design for deconstruction or disassembly
EoW	End-of-waste
EPR	Extended product responsibility
LEED	Leadership in Energy and Environmental Design
LIBS	Laser-induced breakdown spectroscopy
PEF	Product environmental footprint
PCB	Polychlorinated biphenyls
RFID	Radio-frequency identification
PVC	Polyvinyl chloride
SGDs	Sustainable Development Goals
UHPFRC	Ultra-high performance fibre reinforced concrete
VAT	Value added tax
WFD	Waste Framework Directive
7EAP	7th Environment Action Plan

European Topic Centre on Waste and Materials
in a Green Economy
Boeretang 200
BE-2400 Mol
Tel.: +14 33 59 83
Web: wmge.eionet.europa.eu
Email: etcwmge@vito.be

The European Topic Centre on Waste and Materials
in a Green Economy (ETC/WMGE) is a consortium
of European institutes under contract of the
European Environment Agency.

