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Deconstruction in building construction - Current practice and potential for resource conservation

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Deconstruction in Building Construction – Current Practice and Potential for Resource Conservation

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ATV	General technical conditions of contract
BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development
BIM	Building Information Modeling
BMBF	Federal Ministry of Education and Research
BMI	Federal Ministry of the Interior, Building and Community
BNB	Evaluation system for sustainable building
BTU	Brandenburg University of Technology Cottbus - Senftenberg
DGNB	German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen e.V.)
DIN	German Institute for Standardisation
EnEV	Energy saving regulation
EPS	Expanded polystyrene
EU	European Union
GAEB	Joint Committee Electronics in Civil Engineering
HBCD	Hexabromocyclododecane
HOAI	Fee structure for architects and engineers
ifeu	Institute for Energy and Environmental Research Heidelberg GmbH
ICT	Information and communication technology
IT	Information technology

KEA	Cumulative energy demand
KIT	Karlsruhe Institute of Technology
KrWG	Closed Substance Cycle Waste Management Act
LAGA	Federal/State Working Group on Waste
LB	Power range
MGP	material building passport
PET	Polyethylene terephthalate
ProgRess	German Resource Efficiency Program
R	resource-conserving
RC	Recycling
FGD	Flue gas desulphurisation plant
RFID	radio frequency identification
STLB-Bau	Standard service book for the building industry
VDI	Association of German Engineers e.V.
VOB	Award and contract regulations for construction services
ETICS	External thermal insulation composite system
WU	impermeable to water

1 INTRODUCTION

Building construction - i.e. residential and non-residential buildings - is a very large, anthropogenic material store. In Germany, around 15 billion tonnes of building materials are tied up in this - in comparison, "only" 400 million tonnes of raw materials are used in capital and consumer goods, including all vehicles, machinery, household appliances and clothing.[1] The anthropogenic material store in building construction is constantly changing: Every year, more than 200 million tonnes of construction and demolition waste are generated from the construction industry.[2] This is more than half of the total amount of waste generated in Germany. The annual demolition volume for the buildings amounts to around 42 million tonnes.[3] It consists mainly of mineral materials, mainly concrete, bricks, sand-lime bricks and other mineral materials including floor coverings. Only a very small proportion of the recycled products made from them are used in building construction itself. Primary raw materials are mainly used there. The development of secondary raw materials for building construction thus offers great potential for conserving resources. Regional resource and landfill bottlenecks could also be mitigated with the best possible recycling of secondary raw materials.

Today's planning of new buildings lays the foundation for recycling-oriented demolition in the future. Demolition and deconstruction must be planned from the very beginning of a building's life cycle. Strategies for the high-quality recycling of buildings are both a recycling-friendly selection of building materials - ideally also the installation of secondary raw materials - and the consideration of a sorted recovery already in the planning of the construction. A reliable documentation of which materials are used where is absolutely necessary and could be created with the help of Building Information Modeling (BIM).

When demolishing existing buildings, the most important approach to conserving resources is "selective demolition", in which the waste fractions are collected by strict separation according to type. This makes a targeted recycling of the material flows and thus a high-quality recycling possible, in

[1] Cf. Federal Environment Agency (2017a), p. 32.
[2] Cf. Federal Statistical Office (2017), p. 57, lines 29 and 47.
[3] Cf. BBSR (2017), p. 22.

which the quality level of the secondary raw material ideally corresponds to that of the primary raw material and thus a use in the original purpose remains possible. Many components cannot be separated according to type on the demolition site because they are composite materials which cannot be separated cleanly even by subsequent preparation. In practice, however, there is often only partial selective deconstruction, which makes high-quality recycling more difficult. Alternatively, dismantling can be considered in which components are dismantled non-destructively and thus retained. The direct reuse of the components is in the foreground. However, it is still unusual to reuse components so that this great potential to conserve resources remains untapped.

The present brief analysis contains a brief description of the mass flows in building construction, a presentation of the (legal) framework conditions, a collection of the relevant terminology and an overview of the state-of-the-art in the demolition of buildings. The focus is on demonstrating the inherent potential to conserve resources. Measures are presented that can be implemented in planning and documentation in order to achieve the highest possible level of recycling at the end of a building's life. The potentials of selective dismantling and deconstruction and the preparation of secondary raw materials are also considered. Resource efficiency potentials are supplemented by current research projects and examples of good practice.

2 MASS FLOWS IN BUILDING CONSTRUCTION

Building constructions - residential and non-residential buildings - represent a very large, anthropogenic material store in Germany with more than 15 billion tonnes of built material. Building construction thus accounts for about 55 % of the man-made raw material stock in the construction industry.[4] In addition, there are more than 12 billion tonnes of building materials in civil engineering, which includes all structures for the transport networks, as well as supply and disposal networks for drinking water and sewerage. For comparison: The stock of raw materials tied up in consumer and capital goods - such as vehicles, industrial machinery, large household appliances, home electronics, ICT equipment, clothing - is only about 1.5 % of the raw materials used in construction, with a total of less than 400 million tonnes.[5]

According to the Federal Environment Agency, 90 % of the more than 15 billion tonnes of material in the residential and non-residential buildings were mineral materials, i.e. concrete and cement, stones and bricks. Almost 6 % are iron, structural steel and non-ferrous metals, 1.5 % petroleum-based plastics. All these building materials and their preliminary products are of natural origin and do not grow again - with the exception of wood, which accounts for 2 % of the anthropogenic material stock in building construction. Other substances, including Glass and ceramics, do not even reach 0.5 % by mass.[6]

The 2017 study "Material flows in building construction" published by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) provides a comprehensive analysis of the existing situation and material flows in building construction, including a breakdown by construction product groups for the year 2010.[7] The authors process the results of their material flow model with the statistics from production and waste management and the numbers of the associations in order to create a consistent model calculation and to explain deviations. However, there are some

[4] Cf. Federal Environment Agency (2017a), p. 32.
[5] Cf. Federal Environment Agency (2017a), p. 32.
[6] Cf. Federal Environment Agency (2017a).
[7] Cf. BBSR (2017).

limitations to all the values quoted in this study: For example, mineral products used in civil engineering work in direct connection with building construction on the property, i.e. outdoor facilities and pipeline and path construction, were also taken into account.[8] Building under 50 m^2 Base area was not taken into account.[9] The structure, breakdown and dimensions of data vary from source to source, so allocations to construction product groups are not always clear.[10] Despite these limitations, the study "Material flows in building construction" provides important clues for the situation in building construction. The material stock in building construction is shown in Figure 1.

[8] Cf. BBSR (2017), p. 29.
[9] Cf. BBSR (2017), p. 9.
[10] Cf. BBSR (2017), p. 20.

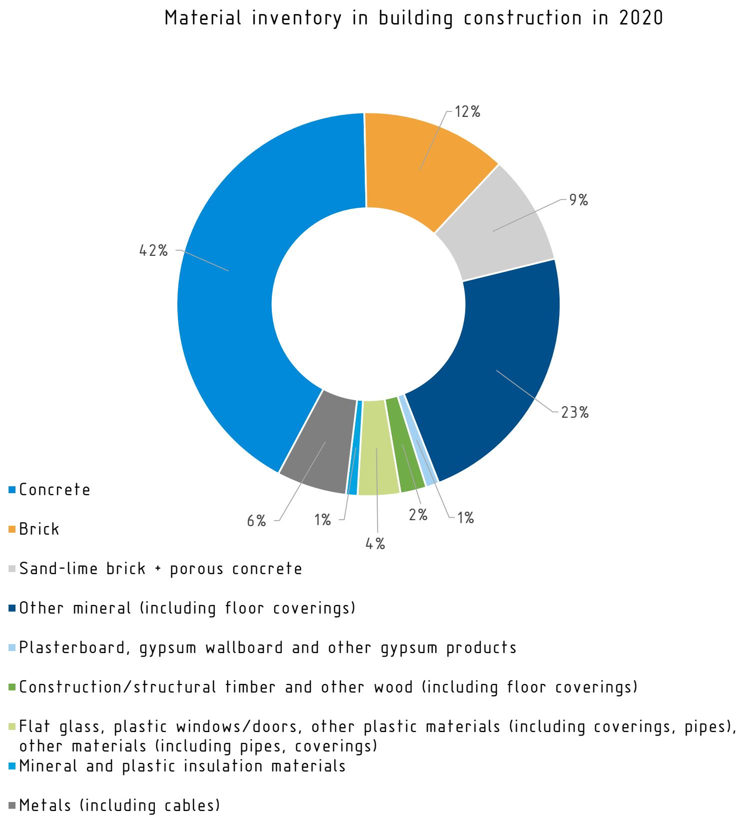

Figure 1: Material stock in building construction in 2010 for 16 material groups[11]

The mineral fractions concrete, brick, sand-lime bricks, porous concrete and "other minerals" are collectively referred to as "building rubble". "Other mineral" substances include mortar, plaster, ceramics, granite, marble, tiles, ceramics and sand. Wood, glass, plastics and metals are summarised[12] under

[11] According to BBSR (2017), p. 21.

[12] Cf. BBSR (2017), p. 18.

the so-called "building site waste". Added to this are "gypsum-based construction waste”.[13]

According to the stock, the waste in the construction industry in particular should now be considered for the material flows. In Germany, the 209 million tonnes of construction and demolition waste from the construction industry represented more than half of the total waste generated in Germany in 2015.[14] The magnitude of this value can be seen in comparison with the widely discussed plastic waste generated by consumers and industry in society: In Germany, this amounts to 5.92 million tonnes per year, not even 3 % of the waste generated in the construction industry.[15]

Since 1996, the "Kreislaufwirtschaft Bau"[16] initiative has presented the statistically recorded quantities of mineral construction waste in monitoring reports for the development over time. Between 1996 and 2016, an average of 55.5 million tonnes of building rubble were produced annually, with fluctuations between 50.8 million tonnes in 2004 and a maximum of 59.1 million tonnes in the last reporting year of 2016. Peaks of over 58 million tonnes were already reached in 1998 and 2008, see Figure 2.

[13] Cf. closed-loop construction industry (2018), p. 5.
[14] Cf. Federal Statistical Office (2017), p. 57, lines 29 and 47.
[15] Cf. Federal Environment Agency (2018).
[16] Kreislaufwirtschaft Bau (2019).

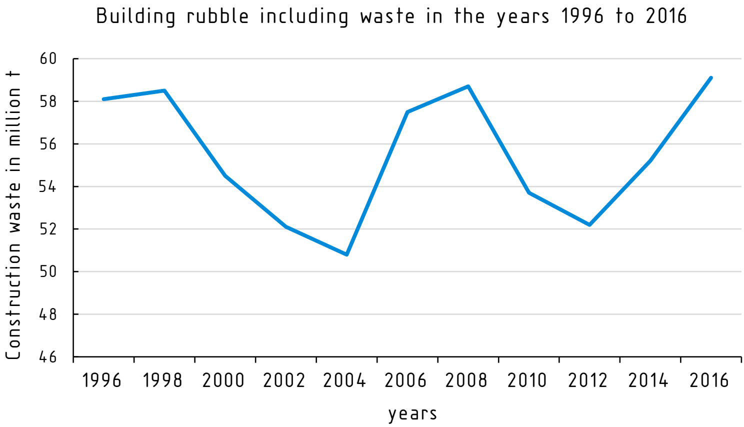

Figure 2: Time course of the accumulation of building rubble incl. gypsum-based building waste in the years 1996 to 2016[17]

The study "Material flows in building construction" published in 2017 presents figures for the input - i.e. the construction - and the output - i.e. the demolition - especially of buildings for the year 2010 with the restrictions mentioned above. These material flow quantities are broken down into 16 material groups for residential and non-residential buildings in Figure 3.

[17] Based on Kreislaufwirtschaft Bau (2018), p. 14, own presentation.

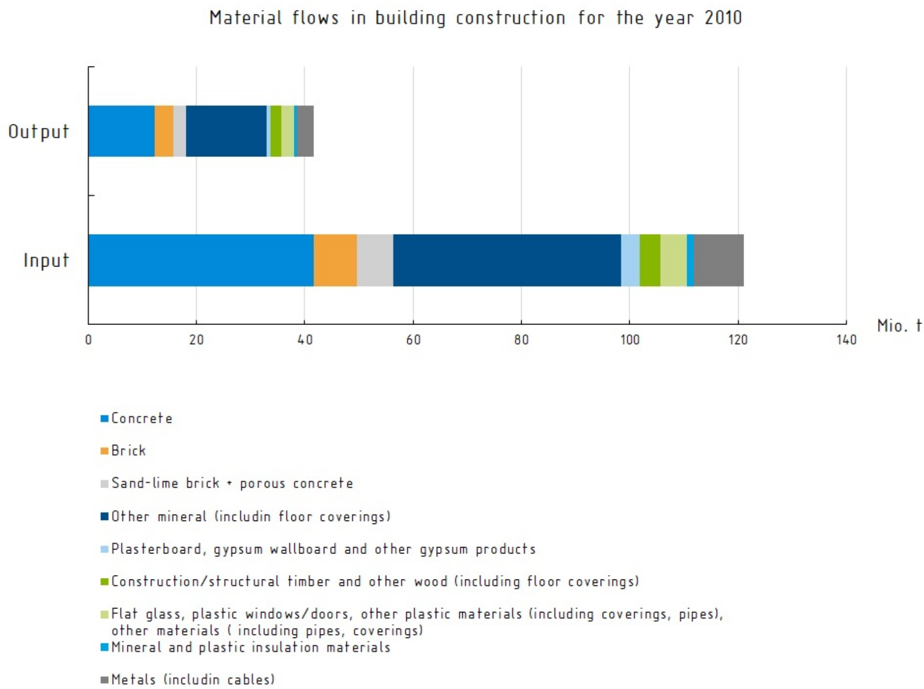

Figure 3: Material flows in building construction for 2010 for 16 material groups[18]

In 2010, construction products with a mass of around 121 million tonnes flowed into residential and non-residential construction, while the demolition volume (including conversions) was around 42 million tonnes.[19] Overall, the input in 2010 was approx. three times greater than the output that could be available for the production of secondary raw materials. It would therefore not be possible, in terms of quantity alone, to construct new buildings from secondary raw materials alone from demolished buildings.

Waste is generated not only during the removal of building structures, but also during new construction, above all due to excess ready-mix concrete, cuttings from building slabs and breakage. This so-called construction waste

[18] According to BBSR (2017), p. 23.
[19] Cf. BBSR (2017), p. 22.

is between 3 and 15 %, depending on the type of construction product, and is not considered in detail here.[20]

For the 2016 reporting year, the "Construction Closed Loop Waste Management" initiative states that around 59 million tonnes of building rubble were generated, i.e. mineral waste such as concrete, bricks, sand-lime bricks and ceramics. These include the masses from building construction and civil engineering, but without the road opening. Of these, 3.6 million tonnes (6.2 %) were disposed of in landfills. 9.4 million tonnes (16.1 %) were used in the backfilling of excavations and landfills. 45.5 million tonnes (77.7 %) - the largest share - was recycled. In the period under review, an additional 16 million tonnes of road construction were incurred, of which 15.2 million tonnes (95.4 %) were recycled. Only 0.8 million tonnes were equally recycled in landfill construction/filling and disposed of in landfills.[21]

In addition to the 45.5 million tonnes of recycled building rubble and the 15.2 million tonnes of road construction waste, 11.3 million tonnes of recycled aggregates from the preparation of the soil and stone fraction can be added. Together with a small amount of processed construction site waste (0.2 million tonnes), a total of 72.2 million tonnes of recycled building materials were produced in 2016.[22]

Of these, 15.2 million tonnes (21.0 %) were used as aggregates in asphalt and concrete production. This share corresponds to the quantity recycled during the period under consideration when preparing road construction material. It should be noted that only 0.6 million tonnes are used in the production of concrete. The proportion of RC aggregate in concrete, which is used as a secondary raw material especially in building construction, is thus less than 1 %.[23] The largest share of recycled building materials (57 million tonnes) is used in road construction (approx. two thirds) and earthworks (one third).[24]

[20] Cf. BBSR (2017), p. 20.
[21] Cf. closed-loop construction industry (2018), p. 7.
[22] Cf. closed-loop construction industry (2018), p. 10.
[23] Cf. BBSR (2017), p. 51.
[24] Cf. closed-loop construction industry (2018), p. 11.

In general, far more recycled aggregates from building construction could be used again in building construction. The use of recycled building materials mainly in road construction creates a great dependency, as the material-intensive construction of new roads will decrease, especially in structurally disadvantaged regions.[25] In road construction, high demands are placed on the aggregates used. The use of building rubble in road construction and earthworks is a further utilisation that involves a loss of quality in the materials used and does not contribute to a closed cycle of construction and deconstruction.[26] The quantities taken from the closed cycle for road construction - 38.1 million tonnes[27] in 2016 - will be replaced by natural raw materials with hydraulic binding agents and used to cover building construction requirements. Instead, these natural resources could flow directly into road construction and would not be lost as a natural resource. The installation in the road substructure would only be a local change of the deposit and not an actual consumption.[28]

There is still a high potential for the proportion of recycled building materials, especially in building construction as a whole, since the material flows from deconstruction are primarily used in civil engineering, as the above figures show. The study "Material flows in building construction" proves this on the basis of the - mostly extremely low to non-existent - proportion of secondary raw materials that originate from the recovery of formerly used building products in building construction. Recycled material from other sectors, such as container glass (bottles), which is used in the production of glass wool, is also permitted. The presented comparative calculation does not include by-products such as gypsum from flue gas desulphurisation plants, blast furnace slag or slag, since these by-products of industrial processes are not produced specifically for the construction industry, but are only used there. Even the return of production residues or waste is not taken into account.[29]

[25] Cf. Federal Environment Agency (2017b).
[26] Cf. Rosen, A. (2017), p. 54.
[27] Cf. closed-loop construction industry (2018), p. 11.
[28] Cf. Jehle, P. (2019).
[29] Cf. BBSR (2017), p. 50.

Table 1: Recycling percentages for use in building construction in the respective construction product segment for 2010 [in %][30]

Construction product	Recycling percentages (in %)
Concrete	0.4
Brick	0.0
Sand-lime brick	0.0
Cellular concrete block	0.0
Plasterboard/Gypsum wall-boards/ other gypsum products	0.0
Construction timber	0.0
Wood building boards	4.0
Flat glass	15.0
Plastic doors and windows	13.0
Mineral thermal insulation	27.0
Petroleum-based thermal insulations	10.0

For the gypsum fraction listed in the table, the situation has changed since 2010, after the Federal Environment Agency commissioned a research project to investigate processes for gypsum processing from construction and demolition waste, which should enable gypsum recycling in Germany on a commercial scale. Natural gypsum is only available to a limited extent and the so-called REA gypsum from flue gas desulphurisation plants of power plants will decrease in volume due to the decommissioning of fossil power plants.[31] In 2014, the first stationary preparation plant for the high-quality material recycling of gypsum-containing waste was commissioned in Germany.[32] Especially gypsum plasterboard as a building product is processed into secondary gypsum.[33]

[30] BBSR (2017), p. 51.

[31] Cf. Federal Environment Agency (2016).

[32] Cf. MUEG (2019).

[33] Cf. Müller, A. (2016a), p. 34 et seq.

3 FRAMEWORK CONDITIONS

The large mass flows in building construction outlined in Chapter 2 and the low proportion of recycled building materials used in building construction clearly demonstrate the great potential for conserving resources. This chapter provides information on resource efficiency and presents the legal framework conditions.

3.1 Resource efficiency

The "conservation of resources" mentioned in the title of this brief analysis essentially results from increased resource efficiency. Resource efficiency is defined according to the directive VDI 4800 Part 1, "Resource efficiency; methodical bases, principles, strategies"[34], as the quotient of the benefit of a product or a process and the use of natural resources. In order to increase this quotient and thus the resource efficiency, either the benefit is increased or/and the effort is reduced. The increase in benefit can be achieved, for example, by recycling - i.e. a product is recycled or reused - or by extending its useful life: thus the benefit of a building increases if it is not demolished, but instead renovated or modernised.

In order to reduce costs, the natural resources used, such as primary raw materials and energy, must be reduced, as must the use of land or ecosystem services. The latter describes the benefits that humans derive from ecosystems such as forests. The definition of resource efficiency does not take into account economic expenditure such as personnel and capital.[35] The resource efficiency measures considered in this brief analysis mainly aim at saving natural resources such as energy and raw materials.

The German Resource Efficiency Programme II (ProgRess II), which was adopted in March 2016, also calls for a strengthening of recycling in construction processes. An important element of ProgRess II is the promotion of selective demolition and deconstruction with preparation of construction

[34] VDI 4800 sheet 1:2016.
[35] Cf. Vogt, M. (2015), slide 2.

waste, ideally on site or near the construction site.[36] A change in the legal requirements could also make it possible to use mobile preparation plants outside the property in connection with individual demolition or deconstruction measures.[37]

3.2 Legal framework conditions

Construction Products Ordinance

The Construction Products Ordinance, which was introduced in 2013, requires in principle the high-quality recycling of buildings. It stipulates that buildings or their parts must be reused or recycled after demolition. For new buildings, environmentally compatible raw materials and secondary raw materials must be used. However, no requirements are defined for the qualities or quantities of recycling.[38] In addition, there are no clear requirements for the production of known construction products or the development of new ones with regard to their recyclability.

EU Waste Framework Directive 2008/98/EC

The EU Waste Framework Directive 2008/98/EC[39] stipulates, among other things, a recycling rate for construction and demolition waste of 70 % by 2020. It must therefore be possible to prepare this proportion for reuse, recycle it or recycle it in some other way. In Germany, the Waste Framework Directive has been implemented since 2012 in the Closed Substance Cycle Waste Management Act (KrWG) as the central federal law in German waste legislation.

Closed Substance Cycle Waste Management Act (KrWG)

The core of the Closed Substance Cycle Waste Management Act (KrWG) is the five-stage waste hierarchy, with a gradation from waste avoidance, reuse, recycling and other, also energetic recovery of waste. The last option is waste disposal.[40] The recovery operation which best ensures the protection of man

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36 Cf. BMUB (2016) Section 7.5.4.

37 Cf. Jehle, P. (2019).

38 Cf. Hillebrandt, A.; Riegler-Floors, P.; Rosen, A. and Seggewies, J. (2018), p. 16.

39 Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

40 Cf. BMU (2016).

and the environment throughout the life cycle of the waste must be carried out. In particular, the emissions to be expected, the conservation of resources, the energy - which must be used, but also that which can be recovered - and the accumulation of pollutants in the substance/material that has undergone a recycling method must be taken into account.[41] The five-step waste hierarchy is described in detail below:[42]

Stage 1 **Waste avoidance**: The useful life of the building is extended by appropriate planning, renovation and further use.

Stage 2 **Preparation for reuse**: A component or construction product is reused in its original purpose after testing, cleaning and/or repair.

Example: Masonry blocks after deconstruction and cleaning, concrete components after their removal.

Stage 3a Recycling through **further use**: A component or construction product is no longer used for its original purpose because the necessary quality can no longer be guaranteed.

Example: A window is further used in the garden house because the thermal insulation no longer meets today's requirements due to age.

Stage 3b Recycling through **recycling**: In the case of material recycling, the given quality level is maintained.

Example: Aluminium window frames can be melted down, window frames can be made from the secondary raw material again.

41 Cf. § 6 KrWG.
42 Cf. Hillebrandt, A.; Riegler-Floors, P.; Rosen, A. and Seggewies, J. (2018), p. 17.

Stage 3c Recycling through **further utilisation**: The material recycling takes place with a loss of quality.

Example: The recycled material of high-quality flat glass from windows can only be used for decorative profiled glass in façade construction.

Stage 4 **Other utilization/other use**: Use for backfilling or energetic (thermal) utilisation (combustion for heat generation).

Stage 5 **Disposal of** substances at a landfill.

In addition, **§ 5 of the Closed Substance Cycle Waste Management Act** stipulates that a substance or object is no longer waste after it has undergone a recycling method and is subsequently "normally used for certain purposes", "there is a market for it or a demand for it" and it fulfils the applicable technical requirements, legal provisions and standards in its respective intended use.[43]

The Closed Substance Cycle Waste Management Act is supplemented and completed by legal ordinances, such as the **Industrial Waste Ordinance**, the **Ordinance on** Waste Recovery and **Disposal, and the Landfill Ordinance**. The structural requirements for the use of mineral recycled building materials are[44] also regulated uniformly throughout Germany. Furthermore, the remaining regulatory competences under waste law are determined by the respective federal states, e.g. the **Brandenburg Waste and Soil Protection Act**[45], the[46]**Berlin Closed Substance Cycle Waste Management** Act, the **Bavarian Waste Management Act**[47] or the **NRW State Waste Act**[48]**.**

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[43] BfJ (no date).
[44] Cf. Kopp-Assenmacher, p. (2016), p. 8.
[45] BbgAbfBodG (2016).
[46] KrW-/AbfG Bln (1999).
[47] BayAbfG (2018).
[48] LAbfG (1988).

Industrial waste ordinance

The Industrial Waste Ordinance, which came into force in 2017, stipulates that specific waste must be separated and recycled for commercial municipal waste and construction and demolition waste. The following fractions are to be separated from construction and demolition waste:[49]

- Glass (waste code 17 02 02)
- Plastic (waste code 17 02 03)
- Metals, including alloys (waste codes 17 04 01 to 17 04 07 and 17 04 11)
- Wood (waste code 17 02 01)
- Insulation material (waste code 17 06 04)
- Bitumen mixtures (waste code 17 03 02)
- Gypsum-based building materials (waste code 17 08 02)
- Concrete (waste code 17 01 01)
- Brick (waste code 17 01 02)
- Tiles and ceramics (waste code 17 01 03)

Waste such as soil, stones and dredged material, which can be assigned to waste group 17 05 of the Waste Catalogue Ordinance (AVV), are excluded.[50]

Only if the separate collection of the respective waste fraction is economically unreasonable (e.g. due to high levels of pollution) or technically impossible (e.g. no space, reasons for deconstruction) does the above-mentioned obligations no longer apply.[51] As logistical tasks or challenges can usually

[49] § 8 paragraph 1 GewAbfV (2017).
[50] Cf. § 2 paragraph 1 GewAbfV (2017).
[51] Cf. § 8 paragraph 1 GewAbfV (2017).

be solved, these duties should only be waived in individual cases after careful examination.

Communication 20 of the Federal/State Working Group on Waste (LAGA), Replacement Building Materials Ordinance and Ordinance on Framework Conditions

Communication 20 of the Federal/State Working Group on Waste (LAGA) deals with the requirements for the recycling of mineral residual materials and wastes. This set of technical rules should lead[52] to a uniform evaluation of the environmental compatibility of recycled building materials in recovery projects in all federal states, but this has so far only been implemented in eleven out of 16 federal states.[53] In the medium term, the recycling of building materials and the requirements for the production and use of mineral substitute building materials are to be regulated uniformly throughout Germany by the planned **Replacement Building Materials Ordinance**. Like LAGA Communication 20, however, the Replacement Materials Ordinance will be oriented towards civil engineering and will not cover the use of RC building materials in building construction.[54]

The planned introduction of the Substitute Building Materials Ordinance is a consequence of the **Ordinance on** the Use of Building Materials adopted in May 2017. With the amendment of the **Federal Soil Protection and Contaminated Sites** Ordinance and the amendment of the **Landfill and Industrial Waste Ordinance**, the Ordinance is intended to harmonise the requirements for a closed-loop economy with stricter requirements for soil and groundwater protection.[55] This intensified soil and groundwater protection could lead to a material flow shift towards landfill.[56] However, landfill space is limited. Demand forecasts for individual federal states assume that existing, planned and approved landfills will be exhausted by 2030. An expansion is unlikely in Germany due to the high settlement density and low social acceptance, especially since landfills are usually served regionally within a

[52] Cf. Bertram, H.-U. (2003), p. 2.
[53] Cf. LAGA (no date).
[54] Cf. BMU (2017).
[55] Cf. BMUB (2016), Section 7.4.4.
[56] Cf. Dittrich, S. et al. (2016), p. 456.

radius of at most 50 km. As a consequence of the Ordinance, the demand for the disposal of construction waste at a landfill could therefore increase in the future, but also become considerably more expensive due to the limited landfill capacities.[57]

The future framework conditions, such as the Alternative Building Materials Ordinance and the other ordinances under the umbrella of the Ordinance on the Construction of Shells, can generally result in building rubble no longer being used in road and path construction or - in the case of fine-grained aggregates - being dumped at high cost. New recycling methods are therefore required.[58] This is reinforced by the European Economic and Social Committee's call for the circular economy package[59]to be abolished as a recycling option within the framework of European activities on the circular economy. Existing buildings should in principle be seen as a resource to be reused and recycled.[60]

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[57] Cf. Hillebrandt, A.; Riegler-Floors, P.; Rosen, A. and Seggewies, J. (2018), p. 124.
[58] Cf. Fraunhofer UMSICHT (2018a).
[59] Cf. EC (2018).
[60] Cf. Kopp-Assenmacher, p. (2016), p. 7.

4 DEMOLITION, SELECTIVE DISMANTLING AND DECONSTRUCTION

This chapter presents basic definitions in the field of building demolition and describes the state-of-the-art.

4.1 Definitions and terminology

Demolition procedure

In the VDI Directive 6210, "Demolition of structural and technical installations"[61], is defined in sheet 1: "**Demolition** is a planned division of a previous whole into two or more parts, using suitable procedures for the total or partial dismantling of structural or technical installations". In everyday language, deconstruction is often equated with demolition. In DIN 18007, deconstruction is a synonym for dismantling. Directive VDI 6210 goes further in the definition of **deconstruction** as a synonym for dismantling[62]. **Dismantling or deconstruction** is a special procedure of "non-destructive demolition of components by the loosening of connections and/or the creation of separating slots and/or the lifting of components to protect remaining structural components with the aim of reusing or further use of the dismantled components"[63]. In addition, the directive VDI 6202 also defines deconstruction in accordance with DIN 18007.[64] The dismantling or deconstruction of individual components serves in particular the purpose of minimising the release of pollutants during demolition or pollutant remediation.

In the Construction Recycling Directive, the term "deconstruction" is used as a general term and includes demolition. Deconstruction is understood as the sum of all partial services for the removal of structural installations and includes the partial services of clearing out, dismantling, gutting and demolition. Contrary to DIN 18007, the demolition is not a demolition procedure,

[61] VDI 6210 sheet 1:2016.
[62] Cf. DIN 18007:2000.
[63] VDI 6210 sheet 1:2016.
[64] Cf. VDI 6202 Sheet 1:2013.

but a partial performance of the demolition, related to the deconstruction of the structural elements of a structure.[65]

In linguistic usage, a distinction is also made between conventional and selective demolition. **Conventional demolition** is usually understood to mean smashing, pulverizing, cutting and blasting without any mandatory requirements with regard to a prior gutting and/or clearing out. The **selective demolition/deconstruction** is carried out after previous clearing, taking into account the requirements for the type-specific collection and disposal of the demolition material.[66]

Clearing out refers to the removal of furnishings and other non-fixed objects and materials.[67]

The term "**gutting**" refers to the removal of facilities and objects that do not influence the stability of the building construction, so that in the end the supporting structure, usually made of concrete and/or steel or even wood, remains.[68]

Recycling methods

For the recycling methods, the terminology of the Closed Substance Cycle Waste Management Act, which are explained in Chapter 3.2, are mainly used.

If the brief analysis only refers to **recovery**, it refers to stage 2 (preparation for reuse), stage 3 (further use, recycling, further utilisation) and stage 4 (other use/other utilisation).

In addition to the distinctions according to the waste hierarchy, the terms **mechanical recycling** and **raw material recycling** are used specifically for the recycling of mineral construction waste, building rubble. When materials are recycled, only the mechanical properties are changed. The chemical and

[65] Cf. BMI (2018), p. 19.
[66] Cf. BMI (2018), p. 13.
[67] Cf. Mettke, A. et al. (2018), p. 81.
[68] Cf. MLUL (2015), p. 48.

mineralogical composition remains the same. In the case of raw material recycling, a material-converting process takes place. New product properties are generated through targeted changes in the chemical or mineralogical composition.[69]

4.2 State-of-the-art

Conventional demolition in the sense of the construction-technical directive recycling hardly occurs any more today, since a gutting, clearing out and separation of demolition materials take place regularly. Last but not least, building materials containing pollutants must be removed before they are destroyed or blown up. With the introduction of the Closed Substance Cycle and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz) in 1996, and since 2012 only the Closed Substance Cycle and Waste Management Act (Kreislaufwirtschaftsgesetz), demolition materials are increasingly pre-sorted because, in addition to higher-value recycling, recycling costs fall significantly. A study at the Technical University of Darmstadt, for which 32 companies were surveyed, showed that pre-sorting of demolition materials did not take place in only 3 % of the cases investigated.[70] Irrespective of the different views on the use of the terms demolition and deconstruction, this publication focuses on qualified planning and structured implementation of the mandatory partial services required for the partial or complete removal of structural works.

Demolition or deconstruction is preceded by a planning phase in which a demolition and disposal concept is drawn up. An essential feature is the extraction of material fractions that are as separate as possible, with the lowest possible quantity of non-recyclable materials. In selective deconstruction, the procedure is either purely use-oriented and recovery-oriented or in reverse order to the original assembly sequence. With both procedures, polluted and contaminated components are always dismantled first in accessible areas after clearing out the trunk. At the end, impurities such as insulating materials, filling foams and treated wood are removed before the demolition of the structural elements in accordance with the Building Directive

[69] Cf. Müller, A. (2016a), p. 18.
[70] Cf. Motzko, C.; Klingenberger, J.; Wöltjen, J. and Löw, D. (2016), p. 27.

Recycling is started. Care must be taken to ensure that a suitable sorting depth is achieved from the outset. Thus, broken masonry must be divided into individual materials such as sand-lime bricks, bricks and cellular concrete. Mechanical pre-sorting can already take place at the point of demolition.[71]

In practice, separation by type is often not completely feasible (economically and technically) due to the properties of the building materials and components (hardly designed for recycling, often contaminated with pollutants) of the existing buildings. If this is the case, a partially selective deconstruction is accepted. For example, when demolishing an office building, the component layers of the gravel-covered flat roof cannot be separated according to type. In particular, bitumen waterproofing and bonded mineral wool or foam insulation materials cannot be separated. In addition, bitumen adhesives (impurities) and possibly tar-containing adhesives (pollutants) must be milled off the concrete surface when recycling as high-quality as possible.[72]

Dismantling

During dismantling, components of the shell construction are dismantled non-destructively by loosening and separating connections. Connections can be separated and exposed by (chiselling out), flame cutting, cutting-off, sawing or loosening. A special role is played here by securing the detached components against tipping over and falling down. With the help of a crane or a cable excavator, the components can be lifted and deposited one after the other. The dismantling enables the preservation of fully functional components and elements for reuse or further use at another location. Dismantling is associated with a higher expenditure of time and personnel and is therefore rarely carried out in practice.[73] In addition, there is hardly any market for the dismantled parts.

Costs

The demolition and deconstruction costs are strongly dependent on the chosen method and the degree of pre-sorting of the demolition materials. Today

[71] Cf. MLUL (2015), p. 48.
[72] Cf. Rosen, A. (2017), p. 54.
[73] Cf. Mettke, A. et al. (2018), p. 101.

it must be assumed that demolition and deconstruction work is always carried out in accordance with the statutory and legal requirements, i.e. according to the principle of waste minimisation. Data surveys and discussions with experts have shown that equipment and disposal costs usually account for approx. 40 % of the cost drivers each and directly influence the price.[74]

The deconstruction or complete deconstruction of entire components is often more expensive than a conventional demolition procedure due to the higher time and personnel expenditure. However, disposal costs can be significantly reduced by reusing complete components.[75] Complete dismantling or deconstruction of complete solid structures depends on the degree of prefabrication of the building structure and is still reserved for prefabricated buildings.

Preparation

The mechanical process technologies of shredding, classifying and sorting, which take place in mobile or stationary plants, form the basis for preparation the mineral construction waste, which dominates in terms of quantity, into recycled building materials. Crushing is carried out with jaw and impact crushers, for example. In the subsequent classification, the heap is fractionated. In single-stage classification in mobile plants, the grain sizes are limited. Three fractions are regularly produced: the fine-grained fraction 0/8, the target fraction 8/56 and the oversized >fraction 56 mm edge length. The oversized grain is returned to the crushing plant to be crushed. Depending on requirements, the upper and lower limits of the target fraction can be varied. By using several screens one after the other with different hole diameters / mesh widths, further fractions can be produced, for example with recycled aggregates of grain group 16/32, i.e. with diameters between 16 and 32 mm.[76] For this purpose, the aggregates are passed through two limiting screens, e.g. with hole widths of 32 mm at the top and 16 mm at the bottom.[77] In the third step, sorting, impurities such as foils, cardboard, insulating materials and plastics are removed. In the dry state, this is done by so-

[74] Cf. Motzko, C.; Klingenberger, J.; Wöltjen, J. and Löw, D. (2016), p. 210.
[75] Cf. Mettke, A. et al. (2018), p. 102.
[76] Cf. Müller, A. (2016a).
[77] Cf. concrete (2016).

called wind sifting, in which light impurities are blown away while the heavier ones remain on the conveyor belt. Wet sorting processes such as hydraulic belt separators, setting machines and washing drums separate light mineral building materials such as porous concrete and light gypsum building materials according to their density. Overband magnets remove metallic, magnetizable impurities. It is also sorted out by hand.[78]

For some years now, sensor-based sorting systems have been used in some industries to sort materials according to colour, shape and size. Camera systems record the material to be sorted, identify the individual substances and grains according to a given pattern and separate them by means of targeted use of sharp air currents. In contrast to the sorting of plastic waste or the selection of rock granulates by colour, the sensor-assisted process has not yet established itself in the sorting of demolition materials.

[78] Cf. Müller, A. (2016a).

5 POTENTIALS FOR RESOURCE CONSERVATION - RESEARCH PROJECTS AND EXAMPLES OF GOOD PRACTICE

There are usually many decades between the construction of a building and its demolition - in 2010 about half of the demolished buildings were 40 to 60 years old.[79] Therefore, this chapter first describes measures for recycling-friendly planning that can be implemented today and will have an impact in the distant future. Then the required documentation is considered so that the information of the building planning and construction is available at the end of the life cycle.

Subsequently, examples will be used to show how both selective demolition and dismantling of components from existing buildings can contribute to material flows that are as pure as possible. Finally, the question is how secondary raw materials can be processed and produced from these material flows, which in turn are used in building construction.

5.1 Building design

The design and planning phase significantly influences the entire subsequent life cycle and thus also the end of a building's life. With the help of integral building planning, both RC building materials can be taken into account and, at the end of life, high-quality recycling in building construction can be made possible. However, the long utilisation phase of buildings - usually considerably longer than that of capital goods such as machinery - brings with it challenges: Both the evaluation of materials/substances and the possibilities that exist in the future for materials and processes are unknown today. In 30 to 50 years, substances used today can be assessed differently, which could render their suitability for recycling and the appropriate deconstruction methods adopted today obsolete - as has happened with asbestos in the past.[80] The consideration and use of recyclable building materials, which are easy to separate at the end of their life cycle, support the removal of environmentally and health-endangering substances from the cycle. On the other hand, innovations can ensure that in the future it will be possible

[79] Cf. BBSR (2017), p. 16.
[80] Cf. Kaiser, O. S.; Krauss, O. (2015), p. 51.

to separate firmly bonded composites efficiently. By combining different high-performance materials, functional components can be designed with minimized material input, as is already being done, for example, with lightweight construction in building construction. For this purpose, however, detachable connections are already indispensable today for lightweight constructions, which will allow recycling in the future. The additional costs for the not yet established recycling-friendly design are currently not reflected in the current fee structure for architects and engineers (HOAI), so that this is not remunerated in the early planning phase.[81] If, in the future, the consideration of recycling capability with regard to sustainability and resource conservation is established in the planning, if knowledge about it is widespread and easily accessible, this challenge will be omitted.

In the evaluation systems of the Federal Ministry of Building (BMI) "Sustainable Building Evaluation System" (BNB) and the German Sustainable Building Council (DGNB), recycling-friendly design and construction are evaluated positively at several points. The BNB system considers, inter alia, the following measures:

- the reuse of components and the use of RC building materials,
- the ability of the building to be dismantled and recycled and
- the creation of a waste and recyclable material concept.[82]

The current evaluation version from 2017 of the DGNB also gives a positive rating to recycling-friendly planning, as bonuses are awarded for aspects of the "circular economy" that improve the certification result. Among other things, the criterion of ease of deconstruction and recycling favours components which are completely dispensed with, which are reused or which are or have been processed into a comparable product by means of mechanical recycling.[83]

81 Cf. Rosen, A. (2017), p. 57.
82 Cf. BMI (2015).
83 Cf. DGNB (2018).

In addition, education and training courses for understanding the content of buildings as raw material warehouses could further promote recycling-friendly planning and construction. The academic education in the field of construction in existing buildings and demolition/deconstruction has so far received too little attention. [84]

Extension of the utilisation phase

In the Closed Substance Cycle Waste Management Act, waste avoidance is given top priority in the hierarchy of waste management. This waste avoidance is feasible in the existing building stock by refurbishment, i.e. by dispensing with demolition and new construction. In the planning phase, the foundation can already be laid for a later renovation of a building, so that new usage scenarios become possible. This includes a generous room height and sufficiently dimensioned shafts so that new building services can be integrated retrospectively. Flexible room layouts are prepared with floor plans largely without load-bearing walls. Exchange processes can[85] also be optimised through clever planning by designing components that form a separate usage unit or other constructive units with easily detachable connections.[86] In addition, at component and building material level according to the motto: "As much as necessary, as little as possible".

The Gesellschaft für Immobilienwirtschaftliche Forschung e.V. also deals with the extension of the utilisation phase in a 2016 published guideline "Redevelopment - Leitfaden für den Umgang mit vorgenutzten Grundstücken und Gebäuden". It discusses the options for refurbishment, revitalisation and redevelopment.[87] The directive, published by the company itself, is to be published in the form of a guideline VDI 6209 by the end of 2019.

Recycling-friendly building material selection

Planning for recycling-friendly begins with the selection of building materials. The future recycling potential and the future recycling route of the build-

84 Cf. Rosen, A. (2017), p. 57.
85 Cf. Rosen, A. (2017), p. 58 et seq.
86 Cf. El khouli, p.; John, V.; Zeumer, M. and Hartmann, F. (2014), p. 67.
87 Cf. Gif, Gesellschaft für Immobilienwirtschaftliche Forschung e.V. (2016).

ing materials should be taken into account. Building materials with manufacturer take-back systems or leasing models have the advantage that they have existing recycling structures and remain specifically in their material cycle. This strategy, which is particularly widespread in the consumer industry, is difficult to implement because of the long service life of building materials, especially the raw construction materials used in the construction industry. An important prerequisite for high-quality recycling is that the materials are free of pollutants. The absence of pollutants must be defined in each individual case. If possible pollutants are bound permanently and safely during product manufacture and are not released again during processing or recycling, some experts believe that they should be declared to be free of pollutants.[88] For example, the natural clay contains heavy metals of geogenic origin, which are permanently immobilised during brick firing; the bricks and bricks are considered to be free of harmful substances. In contrast, when processing products containing asbestos, the initially fixed fibres are released again, which is associated with considerable health risks as a result of the fibre release even at low asbestos fibre contents.

In addition, a small variety of materials or even a homogeneous choice of materials for components reduces the effort required for separation during deconstruction. The homogeneous materials have the advantage that joint recycling is possible, for example a wooden supporting structure with soft wood fibre insulation without additives or an aluminium sheet façade on an aluminium substructure (see Figure 4). A homogeneous choice of materials for component layers is often difficult to implement when thermal insulation and impermeability to moisture are required at the same time. Non-separable composite materials should, however, be limited to exceptional cases or used only if an established recycling process exists.[89] The recently developed composite materials from insulating bricks illustrate such problems.

[88] Cf. Jehle, P. (2019).
[89] Cf. Rosen, A. (2017), pp. 53 - 59.

Figure 4: An aluminium cassette with clip connection on a bolted aluminium substructure as an example of a dismountable and recyclable facade[90]

Detachable constructions

In addition to material selection, a soluble joining of the materials is important for the later recyclability of the building materials. The connection techniques should be planned as clamp connections or loose supports instead of gluing - for example, a recyclable roof waterproofing membrane could be secured against wind by green roofing. The aim of all measures must be to ensure that different materials can be easily detached and dismantled according to type.[91] In the case of permanent connections such as gluing, welding, soldering and hot or cold riveting or joining in a composite by means of mortar, this is usually difficult to achieve. Detachable connections can be both friction-locked and positive-locked, such as snap-, twist-

[90] Photo: Roses, A. (2017), p. 56.

[91] Cf. Rosen, A. (2017), pp. 53 - 59.

and clamp-locks, screws and nails. Few and few different connections are generally advantageous.[92]

Modular construction offers a number of advantages in terms of dismantling. In this construction system, prefabricated modules are assembled according to a modular system. During dismantling, the outer shell and then the individual modules can be removed and transported away again. Due to the non-destructive dismantling, reuse and recycling are usually possible.[93] Reuse is dependent on wear and tear or ageing.

Mono-material construction

A completely different approach to avoiding component connections is the so-called mono-material construction method. Supporting structures and shell components consist of a large number of successive, specialized shells and layers. In contrast to the traditional construction method with load-bearing structures and shell components, which consist of a large number of successive, specialized shells and layers with and without bond, mono-material components have established themselves in recent years, especially in timber construction. If, instead, only a base material is used that can meet the functional building physics requirements, this makes it easier to separate the materials by type. An example of this is the wooden construction method, in which both disc and panel-like components are made of wood: Solid or glued wood as supporting elements, wood fibre insulating materials as filler and wood material boards or wood board formwork for the surfaces. The costly separation by type is not necessary for an energetic utilization of the wood building materials. However, if this down cycling is to be carried out after material recycling, a later separation according to type is also associated with increased effort and often uneconomical. In the case of sealing and ground-contacting building components, the mono-material construction method is easily possible through the use of waterproof concrete. Single-material solid construction methods made of clay, brick, porous and lightweight concrete can only be evaluated in this way with restrictions. They do not always meet all the requirements for load-bearing capacity, thermal or sound

92 Cf. El khouli, p.; John, V.; Zeumer, M. and Hartmann, F. (2014), p. 67.

93 Cf. Dutczak, M. (2013).

insulation or tightness. The structural and building physics requirements are often only fulfilled with additional functional layers made of other materials.

A further challenge is posed by the preparation and recycling routes. These should be examined on a case-by-case basis. Lightweight concrete, for example, still has to be dumped as mineral building rubble today, because the property-forming aggregate of expanded clay or glass gravel cannot be separated from the rest of the concrete and cement adheres to it. Even further utilisation as a base course in the subgrade is out of the question due to the low density and the lack of frost resistance and load-bearing capacity.[94] In the event of future reuse in lightweight concrete or during processing into RC bricks, immediate landfilling can be avoided.

Research project: "Future House B10"

The deconstruction and further use and recycling of the building was part of the concept of the research project "Zukunftshaus B10" from 2014, named after its location at Bruckmannweg 10 in Stuttgart. Since the house is designed as a temporary experiment, its life cycle lasts less than a decade. After use in the years 2015 to 2019, it will be dismantled. All materials in the prefabricated house can be separated according to type and recycled. In 2018 it had not yet been decided whether it would be recycled or rebuilt elsewhere.[95] From a research point of view, the end of life was only one aspect. B10" was designed primarily as a plus energy house with consistent IT networking, operation via smartphones and integration of an electrically powered car as an energy storage system.[96]

Research project "ReMoMaB – Recyclable modular solid construction" and follow-up project

In comparison to the research project "Future House B10", Prof. Wolfram Jäger from the Chair of Structural Design at the Technical University of Dresden pursued a consistent planning approach based on recycling throughout the entire life cycle of the "ReMoMaB" research project until 2016. The aim

[94] Cf. Hillebrandt, A.; Riegler-Floors, P.; Rosen, A. and Seggewies, J. (2018), p. 105.
[95] Cf. HfWU (2018).
[96] Cf. Abele, R. (2014).

of the "recyclable modular solid construction method" - according to Projektakronym - was to reuse the individual components by abandoning the usual "joining in a bond" on the construction site, i.e. the joining of various materials such as concrete, steel and plastics by liquid composites. In masonry, for example, flat bricks are manufactured with such precision that they can be joined dry, which enables problem-free deconstruction after the useful life. The building shell and interior fittings are designed as separate layers in order to ensure that the interior fittings can be replaced at any time during their useful life by means of point-shaped connections and simple manual joining and loosening. In order to avoid wet joints, compensate for tolerances and create a homogeneous surface, techniques such as screws, clips and Velcro connections were tested up to and including tensioning.[97] As a result, completely demountable solid constructions - the mortarless brickwork - could be produced with lime-sand brick plan elements joined without joints. The component masses could[98] also be reduced by using the preload. The entire structure can be erected quickly and disassembled by type at the end of its life cycle, whereby the materials are separated without additional energy input.[99]

[97] Cf. Sigmund, B. (2014).
[98] Cf. Sweden, D. (2015).
[99] Cf. TU Dresden (2016).

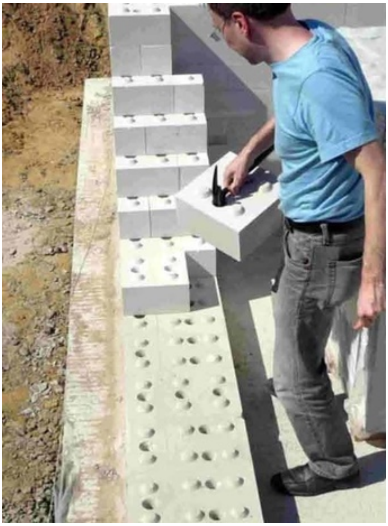

Figure 5: The mortarless masonry developed in the "ReMoMaB" research project[100]

As a follow-up project to "ReMoMaB", the construction research project "From theory to practice: development of an applicable dry construction method for use in the construction of demountable, energy-efficient show houses" will continue to work on the recyclable dry construction method from 2017 to 2019 (Figure 5). For this purpose, at least one model house will be built from the collected findings. As with "ReMoMaB", the design for the utilisation phase is based on zero energy. In order to close the life cycle, the model house is dismantled again and reused to demonstrate its dismantlability in practice.[101]

Research project: "Design2Eco"

Life cycle considerations should start early, i.e. already in the concept and planning phase. For office and administration buildings, the Chair for Energy Efficient and Sustainable Planning and Construction at the Technical University of Munich investigated in the "Design2Eco" project how lifecycle-based information on the economic and ecological qualities of the five buildings considered can serve as a basis for decisions on resource conservation. For

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100 Photo: Wolfram Jäger in Sigmund, B. (2014).

101 Cf. Fraunhofer IRB (2019a).

this purpose, detailed life cycle cost calculations and life cycle evaluations will be carried out and the resulting effective adjusting screws will be identified and made available to planners as recommendations for action. The final report of the project, which was completed in November 2018, is still pending. Nevertheless, it has already become clear that 22 % of the global warming potential can be saved by suitable components without additional costs over the life cycle of the design.[102]

Practical example: Active house settlement Winnenden

One example is the Aktivhaus settlement in Winnenden, a residential complex for 200 refugees. The entire settlement is based on a building system with modules in timber frame construction.[103] The wooden structure is insulated with a layer of fibreboard and covered with larch formwork. Composite materials were not used in order to make recycling through further use possible. Right from the start, the further use was also taken into consideration. Therefore, the individual modules are expandable and can be dismantled.[104]

Practical example: Bakery of the bakery Peter

Another practical example of a building construction that does not use composite materials and insoluble compounds and can be completely recycled at the end of its life is the bakery of the Peter bakery in Essen (Ruhr area), which opened in 2018 (Figure 6). The planners have taken the dismantling of the building into consideration and implemented it so consistently that it could also be dismantled and rebuilt elsewhere. For this purpose, gold certification was awarded by the German Sustainable Building Council (DGNB).[105]

The completely dismountable and recyclable bakery Peter in Essen[106]

102 Cf. future construction (2018).
103 Cf. BDA (2017).
104 Cf. fair weather, C. (2017).
105 Cf. Peter Backwaren (2018).
106 Photo: Peter Baked Goods (2018).

Figure 6: The completely dismountable and recyclable bakery Peter in Essen

Practical example: Administrative headquarters of the RAG Foundation and RAG AG in Essen

Essen is also home to a circular-flow building, the administrative headquarters of the RAG Foundation and RAG AG, on the site of the Zollverein World Cultural Heritage Site. The building completed in 2018 is a pilot project of the EU research project "Building as Material Banks" (BAMB). All materials are selected and dismantled[107] according to their recyclability, the building products are tested and certified for their recyclability, composite building materials and "sandwich materials" are not used.[108] In addition, all components are documented in a "Material Passport" so that they can later be used as a material depot.[109]

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107 Cf. construction network (2018).

108 Cf. Baunetz (2018), picture gallery, picture 21.

109 Cf. Kölbl Kruse (no date).

5.2 Documentation

In order to make a high-quality and efficient recycling process possible at the end of life, information relevant to recycling such as the building materials used and the building construction must be available. If this is not the case, the advantages of recycling-friendly design and construction are largely lost. This also applies to planned post-use concepts. Therefore, a systematic recording and documentation of essential building information and the updating and updating over the entire life cycle are necessary. Until now, detailed, material-related documentation was not usual. Key information includes a post-use concept, a dismantling plan, data on the weight and occurrence of building materials, recovery strategies, recycling potentials, etc.[110]

Demolition contractors often estimate the demolition costs from experience or orient themselves on the gross tonnage, since information on the materials used is not available or can hardly be recognised on site. This problem is solved by qualified demolition and deconstruction planning. A performance description according to ATV DIN 18459 of the VOB/C is always based on the building materials and materials used. The gross tonnage does not provide a suitable basis for calculation and invoicing. Moreover, at least the public clients are bound to the use of dynamic construction data, which contain performance texts prepared by GAEB[111]. In the service areas of STLB-Bau,[112] qualified text modules are provided for demolition in LB 084 "Demolition, deconstruction and pollutant clean-up work" and in LB 087 "Waste disposal, recycling and disposal", which also require intensive planning. If this information is available, a client can decide in favour of selective deconstruction on the basis of a reliable calculation, also for monetary reasons. At the moment, the demolition company decides on the demolition procedure on which the quality of the recycling depends, because according to the current legal

[110] Cf. Brenner, V. (2010), p. 67.

[111] GAEB, Joint Committee Electronics in Civil Engineering. The results of GAEB's work are published by DIN Deutsches Institut für Normung e.V. (German Institute for Standardization). They are prerequisites for the tendering, awarding and accounting of construction services (AVA).

[112] STLB-Bau, Standardleistungsbuch für das Bauwesen des Gemeinsamen Ausschusses Elektronik im Bauwesen, for tenders for federal building construction measures by decree already introduced as of 1998.

situation, the client is liable for the proper disposal, but he is not responsible for the quality of the recycling.[113] According to some experts, there is a lack of qualified planners across the board. Beyond this, no special requirements are placed on the executing companies in terms of trade licensing. The most far-reaching development is that in the amended state building regulations, the removal of construction works from the licensing obligation and, in part, from the notification obligation was released.[114]

Building Information Modeling (BIM)

Building Information Modeling (BIM) can be a tool for permanently documenting the building properties in a "digital twin". This method captures the data of a structure digitally and over the entire life cycle. The virtual, object-oriented and three-dimensional image of a building construction can bring together the previously separate planning and construction and is also useful during operation. The aim is to record all changes to the building and its equipment during its use and renovation. The use of materials can be traced and located, which makes both the renovation and the deconstruction plannable.[115] RFID chips (radio-frequency identification) built into the component can take over the local documentation of the installed materials and represent a digital link to the BIM-based central database. Reference is made here[116] to the corresponding research results of the Institute of Construction Management, Chair of Construction Process Engineering at the Technical University of Dresden.[117]

Research project: "BIMaterial"

It is obvious to generate a material building passport (MGP) from the BIM data in order to document the composition of the building rubble over the previous life cycle. The research project "BIMaterial" at the Vienna University of Technology pursues the approach of the building passport, in which the determination of mass and quantity, including the location of building

113 Cf. Hillebrandt, A.; Riegler-Floors, P.; Rosen, A. and Seggewies, J. (2018), p. 21 et seq.
114 Cf. Jehle, P. (2019).
115 Cf. BMWi (2018), p. 24 et seq.
116 Cf. Jehle, P.; Seyffert, S.; Wagner, S. (2011), p. 50.
117 Cf. Seyffert, p. (2011).

materials and materials as well as their accessibility and separability, are automatically generated.[118] The project was successfully completed with a proof of concept, so that a semi-automated creation of a material building passport with BIM as a tool seems feasible. In the future, the coupling of digital tools and databases will be made possible by an independent software product for the automated generation of building passports. In addition, a coupling to a geo-information system would enable the establishment of a comprehensive secondary raw material register.[119]

Research project: "Building Information Modeling (BIM) as a basis for dealing with digital information for the optimization of material cycles in the construction industry"

The use of BIM for deconstruction is also planned in Germany. In the research project "Building Information Modeling (BIM) as a basis for dealing with digital information for the optimisation of material cycles in the construction industry", it will be investigated[120] by mid-2019 how material cycles in the construction sector can be closed by providing concrete data on construction products that will later have to be dismantled and recycled. For this purpose, these construction product data are obtained from generally accessible databases or collected during construction, e.g. within the framework of quality assurance during construction or during dismantling or conversion measures, as well as determined in the inventory by inspection and sampling. Steel, construction metals, the mineral building materials concrete, masonry and plaster, dry building materials, adhesives, carpets and interior paints are considered. The new "RecycBIM" software developed in the project will be tested and validated on real construction sites for the construction products mentioned.[121]

Research project: "Sustainable plastics value chain" (KUBA)

Since information about the installed materials is usually missing for the building stock, it makes sense to gain knowledge about the current condition

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[118] Cf. IOER (2017).

[119] Cf. Kovacic, I. et al. (2018), pp. 10 - 12.

[120] Cf. DBU (2019).

[121] Cf. BIM Institute (2017).

or the material stock. In the research project "Sustainable Plastics Value Chain" (KUBA), for example, the quantities and qualities of plastics stored in existing German buildings are determined in order to be able to predict the disposal flows for relevant plastics during new construction, conversion and deconstruction. Ultimately, this allows best practice approaches to be defined for recording relevant plastic flows from the construction sector.[122] In Germany, about one fifth of the plastics produced are used in the construction industry.[123]

5.3 Selective deconstruction and dismantling

The demolition of buildings plays an important role in the closing of construction cycles. The demolition procedure has a decisive influence on the quality of the recycling process after the end of a building's life. Selective deconstruction and dismantling have the greatest potential for conserving resources, and these are examined in more detail below. However, before the building is demolished, it should be checked whether the preservation of the existing building is technically and economically possible or reasonable.

Extension of the utilisation phase

As a result of the conservation of the existing stock and the resulting extended utilisation phase, resource efficiency increases, as described in Chapter 3.1. This achieves the waste avoidance defined in the waste hierarchy of the Closed Substance Cycle Waste Management Act through further use. For this purpose, preventive maintenance, refurbishment or conversion should be considered. In the case of a renovation after about 40 years, only about 3 to 5 % of the "material stock" of a building construction is released.[124] The rest of the "material warehouse" is still in use. Especially buildings with a

[122] Cf. FH Münster (2018a).
[123] Cf. El khouli, p.; John, V.; Zeumer, M. and Hartmann, F. (2014), p. 62.
[124] Cf. BBSR (2017), p. 20.

high concrete content, i.e. commercial buildings, usually cause high demolition costs, but usually have reserves of durability and strength[125], so that further use should be taken into consideration.[126, 127]

Partial deconstruction

A further resource efficiency potential lies in partial deconstruction. Existing stock does not have to be completely terminated or dismantled. It can be adapted and upgraded to modern requirements through redesign and targeted partial deconstruction. The removal of projectiles and/or the division of long blocks of flats into solitaires are two helpful strategies. In this way, part of the building fabric or the resources used is used further and waste is avoided.[128]

Selective deconstruction

In selective deconstruction, material fractions are collected separately and kept constantly separate. The aim here is to avoid mixing of the various material fractions and to keep the proportion of impurities in the material fractions as low as possible in preparation for subsequent recycling. If the material fractions are not consistently separated during demolition, subsequent separation is often possible, but this is much more complex. Separation according to type provides the basis for recycling of the highest possible quality.[129] For specific waste fractions, separation is mandatory under the Industrial Waste Ordinance (see Chapter 3.2). There is still a widespread lack of qualified planners and a statutory regulation on business licensing as a demolition contractor.[130] In addition to the obligation to separate specific waste fractions, the high costs of disposing of mixed waste also mean that demolitions are rather rare. The sorting depth can be improved by selective deconstruction so that, for example, masonry fractures can be separated into further individual materials such as porous concrete, bricks, sand-lime bricks, etc. The sorting depth can be improved by selective deconstruction. Sand-

[125] Cf. Zeumer, M.; Hartwig, J. (2010).

[126] Cf. Gif, Gesellschaft für Immobilienwirtschaftliche Forschung e.V. (2016).

[127] Cf. Rosen, A. (2017), p. 56.

[128] Cf. Mettke, A. (2008).

[129] Cf. Mettke, A. et al. (2018), p. 86.

[130] Cf. Jehle, P. (2019).

lime bricks can also be added to the concrete fraction. Separate closed material cycles are required for lightweight concretes and porous concrete or bricks. Potential for further resource conservation exists above all in the additional separation of materials with their own recycling paths and in processes that improve material separation during deconstruction with as little time as possible through the use of suitable machine technology and that make the discharge of pollutants possible. The untapped potential for conserving resources through the selective deconstruction of gypsum plasterboards and heat interconnection systems is examined in more detail below.

Selective deconstruction of gypsum plasterboards

As described in Chapter 2, due to the limited availability of natural gypsum and the decreasing quantity of REA gypsum, the recycling of gypsum plasterboards is a possibility to obtain a new source of raw materials. Developments in recent years have made gypsum recycling profitable and technically developed it to such an extent that high-quality recycled gypsum can be used directly in the production of gypsum plasterboards.[131] In order to achieve this high quality, it is important that the broken gypsum plasterboard is sorted and recycled. Impurities that significantly reduce the quality include gypsum-containing screeds and plasters. According to the Industrial Waste Ordinance, however, all gypsum-based building materials (e.g. gypsum plasterboard, gypsum plaster, gypsum-containing screeds) are contained in the same waste code (AVV 170802). Further separation is not required, subsequent separation is not possible.[132] The potential of gypsum recycling can be further exploited by selective deconstruction and consistent grade purity of gypsum board breakage.

Selective deconstruction of external thermal insulation composite systems (ETICS)

In order to save energy during the utilisation phase, buildings are equipped with external thermal insulation composite systems (ETICS) to a large extent, in Germany from 1960 to 2012 around 900 million m², over 31 million m² in 2015 alone. The determining insulating material is expanded polystyrene (EPS), whose current market share is currently slightly declining and lies at around two thirds of the ETICS, but which has a market share of over 80 % in existing buildings.[133] The largest share of polystyrene produced and expanded polystyrene is used in the construction sector and here in ETICS. In EPS insulation boards, the mass proportion of polystyrene granulate is

[131] Cf. Bunzel, J. (2017).
[132] Cf. Mettke, A. et al. (2018), p. 86.
[133] Cf. FH Münster (2018b).

between 85 and 93 %. In addition, 2 to 3 % non-chemically bound hexabromocyclododecane (HBCD) as a homogeneous dispersion as well as pigments and material stabilizers are used as flame retardants.[134]

The insulation boards are glued directly to the outer wall or doweled to a mechanical fastening system and plastered from the outside. The largest mass fraction in the overall ETICS system is not the light EPS panels, but the mineral or organic plaster layer, adhesives, mechanical, metallic fastening systems and fabric fractions such as glass fibre. Nevertheless, it is precisely the insulation boards that are ultimately produced from crude oil that represent a high-quality raw material worth preserving. Since the manufacturers do not install any defined separating layers in the panels, it is difficult[135] to recover the EPS in its pure form, even though the quantities recycled will increase as a result of renovation or demolition measures. The direct bonding of the EPS with both the exterior wall of the house and the exterior plaster makes the deconstruction of ETICS costly. Either an external scaffold is erected and the ETICS is dismantled and disposed of in layers using manual methods, or the entire composite is scraped off with the bucket of an excavator. In practice, however, due to time constraints, the individual layers are not selectively deconstructed, but the scraped-off composite is fed to a mixed construction waste separation plant, which separates the mineral fraction from the organic fraction and only utilizes the latter energetically through controlled incineration.[136] There is still potential for resource efficiency and optimisation in the selective deconstruction and recycling of combined heat and power systems when sorting using sensor-supported systems.

Dismantling

During dismantling, fully functional components and elements are obtained. Compared to newly manufactured precast concrete parts, these not only save primary material, but also a considerable amount of production energy during reuse. The production of 1 t of reinforced precast concrete results in 242 kg of CO_2-Emissions, while the dismantling of a reinforced precast concrete

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[134] **Cf. Deilmann, C.; Krauß, N.; Gruhler, K. (2014), p. 67.**
[135] **Cf. Zeumer, M.; Hartwig, J. (2010).**
[136] **Cf. Albrecht, W.; Schwitalla, C. (2014), p. 52.**

element (1 t) only produces about 13 kg CO_2-Emissions. This results in an emission reduction of 95 %.[137] These advantages are closely linked to the design and construction of structures with high levels of prefabrication.

Efficient construction machinery

Not only the processes on the demolition site, but also the construction machinery can be resource-efficient, for example with tracked excavators equipped with hydraulic-based hybrid technology. Instead of using an additional electric motor in a hybrid drive, as in passenger cars, the braking energy of the constantly rotating and braking upper carriage is stored in a pressure accumulator with hydraulic oil in the excavator, so that it is released again when the excavator is turned again.[138] In practice, fuel consumption is reduced by 15 %.[139]

Research project: "Universal excavator attachment for targeted removal of composite thermal insulation system with integrated pneumatic removal"

Since large equipment such as hydraulic excavators are already available at the demolition site, the cooperation project "Universal excavator attachment for the targeted removal of composite thermal insulation systems with integrated pneumatic removal" is to develop an attachment for these, which facilitates economic handling for separation by machine using only one type of material and thereby completely removes insulating materials from the outer wall. The core of the process consists of combining the separation and collection operations by using a special brush tool to remove plaster and insulating materials as well as the bonding from the outer wall of the building (Figure 7). The brush head is housed and equipped with a suction device, the unavoidable dusts and chips are collected directly at the place of origin. The excavator operator should be able to operate the attachment intuitively like a shovel. The time required for peeling should not increase compared to peeling with the excavator shovel alone. The project runs until mid-2019.[140]

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[137] Cf. Mettke, A. (2019).
[138] Cf. Cat (2019).
[139] Cf. Feess (2018).
[140] Cf. KIT (2019).

Figure 7: Selective peeling of the individual layers of an ETICS. Top coat (left), insulating material (centre) and partially selective peeling in practice (right) [141]

Research project: "RESSOURCE.WDVS - Resource-efficient use of quality-assured secondary EPS and mineral fractions from ETICS"

In addition to this technical approach for the construction site, the project "RESSOURCE.WDVS - Resource-efficient use of quality-assured secondary EPS and the mineral fractions from WDVS" of the Münster University of Applied Sciences and several industrial companies pursues a broader approach for the optimisation of ETICS_recycling. The aim is, on the one hand, to use the resource potential of the material flows efficiently and, on the other hand, to destroy existing pollutants. This not only addresses the deconstruction itself, but also logistics processes and, as a central point, the mechanical preparation of the waste streams with suitable systems. This also includes a quality assurance system, an eco-efficiency analysis of the entire disposal chain and a decision matrix showing the disposal options of EPS-based ETICS. The project runs until 2021.[142]

Research project: "Development of an automated wet sand blasting system with pneumatic removal for removing asbestos-containing fillers from concrete" (FeSS)

While an increased degree of automation makes the selective deconstruction of plastic products and their recycling economical in the case of ETICS, the most efficient removal of the pollutant asbestos is the main priority in the

141 Photo: Albrecht, W.; Schwitalla, C. (2014), p. 53
142 Cf. FH Münster (2018b).

case of fillers containing asbestos. The Ordinance on Hazardous Substances stipulates that carcinogenic materials such as asbestos must be completely removed before demolition. The need for an efficient removal of asbestos is very great, since up to the general ban in 1995 in Germany chemical construction asbestos products such as plasters containing asbestos, fillers and tile adhesives were produced in large quantities. In 1975 alone, 10,000 tonnes of asbestos were produced for building products, including asbestos-containing fillers and grouts, which were then processed into an estimated 200,000 tonnes of building products. Filling compounds contain approx. 0.5 to 4 % asbestos and were only used in thin layers, but then over an extremely large area.[143]

In practice, these fillers are removed by hand by a worker with ambient air-dependent respiratory protection. Recent developments also allow the use of special milling and grinding machines with integrated extraction. As a rule, the entire remediation area must be completely enclosed and secured by negative pressure within the contaminated area. The Institute for Technology and Management in Construction Operations (TMB) of the Karlsruhe Institute of Technology (KIT) is therefore developing a system for the complete removal of asbestos-containing fillers from concrete by the end of 2019. In the project "Development of an automated wet sand blasting system with pneumatic removal for removing asbestos-containing fillers from concrete" (FeSS), a mobile test stand is sketched, which can be moved in width and height and in which a rotating pair of nozzles is integrated into an enclosure with suction system. Concept and testing of this rotating tool head are an important element of the project, whereby the overall system will later also be affordable for smaller companies due to a good price-performance ratio.[144]

Research project: "Demolition, deconstruction and recycling of C^3 components"

One example of a new material that was only introduced into use in this century is carbon concrete (also known as carbon concrete composite, C^3 in which the usual steel reinforcement is replaced by one made of carbon fibre mats or bars. Compared to reinforced concrete, carbon concrete partly offers

143 Cf. VDI (2015), p. 4
144 Cf. KIT (2017).

better mechanical properties and cannot corrode, so that the several centimetres thick concrete covering usual for reinforced concrete - the distance between the outer surface of the concrete and the reinforcement steel inside - can be considerably thinner, which enables material-saving, thin and lightweight concrete components.[145]

How the "demolition, deconstruction and recycling of C³ components" can take place was a research task in the sub-project of the same name of the joint project "2020 - C³ Carbon Concrete Composite", to which the Institute of Construction Management at Dresden University of Technology devoted itself until 2018. In the development of the new composite material, stakeholders agreed that unproven recyclability or emerging health risks during preparation or repreparation constitute a market entry barrier and that development should be suspended.[146] In addition to small-scale experiments and series of tests, the resulting dusts were collected via filters and examined for possible WHO fibres. Exposure experiments with lung cell cultures showed no increase of acute toxicity by carbon concrete particles.[147]

For further testing purposes, two small carbon concrete houses were erected from 6 and 8 cm thin prefabricated elements, in which both mats and bars were used as reinforcement. Concrete drilling and separation techniques as well as dismantling work could then be carried out. About 300 m² of mats and 80 m of rod-shaped carbon reinforcement were installed in[148] the 22 t of concrete. Compared to reinforced concrete, drilling and sawing were possible with standard, but smaller tools and less tool wear. The demolition work itself proceeded quickly and without any problems, and the concrete could be separated from the mat reinforcement almost residue-free.[149]

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145 Cf. C3 (no date).
146 Cf. Bienkowski, N. et al. (2017), p. 110 - 121.
147 Cf. Kortmann, J. et al. (2018), p. 37 - 44.
148 Cf. TU Dresden (2018).
149 Cf. Kortmann, J. et al. (2018), p. 37 - 44.

Research project: "Development and application of completely demountable residential units made of resource-conserving concrete"

In the current research project "Development and application of completely demountable residential units made of resource-conserving concrete" of the Brandenburg Technical University Cottbus - Senftenberg and the Technical University Dresden, Chair of Structural Design of Prof. Wolfram Jäger, a completely closed material cycle for massive, modular and transportable residential units was to be demonstrated. The life cycle begins with the production of RC concrete. The housing units can then be fully dismantled and are therefore flexible, as they can be dismantled quickly and can be used in a variety of ways. In the project the repeated reusability shall be demonstrated and optimized. For a sustainability evaluation of a construction, a dismantling coefficient was developed with which the necessary input and possible output can be recorded.[150]

Practical example: "Ahrensfelder Terrassen" in Berlin-Marzahn

In Berlin-Marzahn, a prefabricated housing estate could be converted into a modern housing estate. Due to structural change and the trend towards single-family homes, there has recently been a considerable vacancy rate in prefabricated buildings. With the "Ahrensfelder Terrassen" project, the housing association WBG Marzahn had the aim of thinning out the existing housing stock and at the same time upgrading the existing building fabric. A total of 1,670 prefabricated apartments were reduced to 409 modern and attractive rental apartments. Instead, the number of floors was reduced and only a few entire sections were demolished. Particular importance was attached to the attractive design of the floor plans: Kitchen and bathrooms have been designed with windows, all flats have balconies and 45 housing units have access to roof gardens. The great demand for the flats can be interpreted as a sign of the success of the careful deconstruction and conversion.[151]

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150 Cf. BTU (2016a).

151 Cf. alsecco GmbH & Co KG (no date).

5.4 Reuse of components

In the five-step waste hierarchy, preparation for reuse, i.e. use in the original purpose, is immediately after avoidance.

Reuse of reinforced concrete components

The reuse of concrete components is the long-standing field of work of Prof. Angelika Mettke of the Brandenburg Technical University Cottbus - Senftenberg, for which she received the German Environmental Award of the German Federal Foundation for the Environment in 2016.[152] Thanks to their extensive research work, more than 30 buildings were constructed from more than 1,000 concrete components, which were previously dismantled elsewhere and then temporarily stored and quality tested. It was noticeable that the concrete was generally in a good condition, as it was already quality-tested after 28 days during construction, but then cured even further. This reuse is particularly relevant for so-called prefabricated housing in residential, but also commercial and industrial buildings.[153]

The potentials for conserving resources in reuse/further use are most clearly shown when looking at the cumulative energy consumption in production (KEA_H) of a new reinforced precast concrete part. In a calculation example by Prof. Angelika Mettke, a reinforced concrete inner wall with a mass of 3.1 t is considered. About 7,200 MJ are needed to produce this wall. For example, 220 litres of heating oil would have to be used. If an equivalent precast old concrete unit is used, this production energy expenditure is eliminated.[154]

Although building with reused slabs can save about 25 % of the construction costs compared to conventional building shells, it is rarely practiced for various reasons. This includes the often necessary interim storage of the large-format concrete elements, because the new use is often not yet certain in the (partial) demolition. In addition, the potential conservation of resources and environmental protection motivate only a few clients, for whom costs are

152 Cf. BTU (2016b).
153 Cf. Seelig, L. (2018).
154 Cf. Federal Environment Agency (2015), p. 93 et seq.

usually the primary consideration. Also, the approval effort for the reuse of components is high and there are still questions regarding liability and warranty.[155]

Reuse of steel components

The steel construction method is mainly found in non-residential buildings (64.8 %, excluding agricultural buildings).[156] They are used, for example, in skeleton and truss constructions, supporting structures, composite steel structures, composite steel structures (reinforced concrete) and individual components. The reinforcing steel is not considered further at this point, as it is separated and directly recycled in the course of reinforced concrete processing. Steel is 100 % recyclable and can be recycled again and again without loss of quality.[157] 99 % can be recovered after use due to their technical properties (steel is mostly magnetic). It is estimated that 88 % of steel products are currently recycled and approx. 11 % reused.[158] The material cycle for steel products is largely closed. There is still potential to conserve resources by increasing the reuse/further use ratio. Steel products should, where technically and economically feasible, be reused and further used. Structural elements and façade claddings can usually be reused without problems.[159] In addition to the primary raw material, energy can also be saved, which is required for recycling, especially for energy-intensive smelting.

The dismantling of structural steel components is relatively easy because screw connections are usually used. But also welded joints can be solved by suitable separation methods such as flame cutting. The requirements regarding the product properties of reused or further used steel components do not differ from those of new steel components. The evaluation can be carried out by a specialist or structural engineer.

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[155] Cf. Seelig, L. (2018).
[156] Cf. Federal Environment Agency (2015), p. 97.
[157] Cf. Federal Environment Agency (2015), p. 102.
[158] Cf. Institute for Building and Environment (IBU) (2018), p. 4.
[159] Cf. Federal Environment Agency (2015), p. 100.

Reuse of wooden components

For centuries houses have been built in wood. In addition to being used as a construction element in exterior and interior walls (half-timbered, timber-framed, timber panel construction), wood is also used in roof areas and ceilings. Wooden elements can also be combined with bricks or concrete. Since wood is a renewable raw material, its use for construction purposes conserves natural resources.[160] In 2017, the timber construction[161] ratio was 17.7 % of approved residential buildings and 17.1 % of non-residential buildings. The proportion of timber construction in residential buildings has risen continuously since 2012.[162]

The reuse/further use of wooden components is already practiced in practice by many companies. In order to reuse or further use them, however, numerous factors must be taken into account. It is important that the wood components are examined for the content and release of harmful substances into the environment. Wood preservatives, flame retardants or paints often contain ingredients that are classified as hazardous to health. If the wooden components are contaminated with hazardous and toxic substances, they cannot be reused or further used. In addition, it should be examined whether the wood is damp or whether there is a fungal or pest infestation.[163]

It is common practice to reuse historical wooden components in particular. However, the potential for reuse/further use of other expanded timber components has not yet been fully exploited. A major reason for this is that selective and non-destructive deconstruction and the strict separation of untreated wood are usually not implemented due to time constraints. The nature of the connections (e.g. comb nail connections) often makes non-destructive removal even more difficult.[164]

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160 Cf. Federal Environment Agency (2015), p. 104.

161 Note: The timber construction quota in building construction is usually determined on the basis of the number of approved new building projects.

162 Cf. Holzbau Deutschland Bund deutscher Zimmermeister (2018).

163 Cf. Federal Environment Agency (2015), p. 107 et seq.

164 Cf. Federal Environment Agency (2015), p. 115 et seq.

Reuse of components – Component exchanges

In addition to reusing parts of the supporting structure, it is also possible to reuse small components and interior components. Various component exchanges with warehouses at five locations have[165] joined forces to form the cooperation network "Bauteilnetz Deutschland" in order to bring demand and supply together.[166] The Bremen-based initiative was awarded the German Environmental Prize by the German Federal Foundation for the Environment in 2010.[167] The primary materials traded are historical building materials such as doors and gates, windows, stairs, floors, bricks, roof tiles and tiles, radiators and sanitary equipment.[168] The largest turnover in terms of units is for interior doors.[169]

Research project/practical example: "Superlocal"

In the Netherlands, the HEEMwonen housing association initiated the "Superlocal" project in Kerkrade. In a shrinking mining town there are four blocks of buildings with 500 flats from the 1960s. In the future, components from the four buildings are to be reused for three houses with 125 apartments. Further use is out of the question, as the concrete production was carried out incorrectly during construction, especially for the external pergolas. The chair of the junior professorship for recycling-friendly construction at the RWTH Aachen University is involved.[170]

Since the housing demand in Kerkrade is decreasing, the first of the five buildings has already been completely dismantled, with the knowledge that the building fabric can not only be recycled and reutilised, but can also be further used. This is to be done with a highly local approach. For this pur-

165 Component net (2019).
166 Cf. Zeumer, M.; Hartwig, J. (2010).
167 Cf. component net (2010).
168 Cf. component net (2019).
169 Cf. Federal Environment Agency (2015), pp. 58 and 70.
170 Cf. IBA Thuringia (2016), from minute 7:30.

pose, the area to be developed will be fenced in and will be developed independently. The first prototypes have already been built.[171] Despite the construction errors of the time - incorrectly installed or even missing reinforcement in reinforced concrete - many building products can be reused, as a catalogue shows.[172] A first exhibition building has already been erected.[173]

Practical example: Planning and construction of the Neustadt municipal utility with reusable components

The new building completed by Stadtwerke Neustadt in 2018 shows how the resource efficiency of a building can be considered not only in the utilisation phase, but also in the selection of building materials and components. The planning of the building was accompanied by the project "Integration of reusable components and recycled building materials and the associated effects on the planning process", which was funded by the German Federal Foundation for the Environment.[174] By reusing and reusing components, large amounts of production energy could be saved and primary raw materials conserved. The elements for the glass partitions between the offices and the corridor come from the Philips headquarters in Hamburg. In the oak wood façade, wooden elements were used that had previously been part of a half-timbered building. The armchairs in the entrance area used to stand in the former Neustadt hotel "Wallburg". Even the combined heat and power unit for water treatment was not purchased. The existing factory of the old company headquarters of the municipal utilities in the Ziegelhof is used.[175]

Practical examples for the reuse of concrete components

There are numerous examples of the reuse of used concrete components. In order not to go beyond the scope of the brief analysis, only a compilation of practical examples is referred to.[176] This collection shows not only detached

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171 Cf. RWTH (2018).

172 Cf. RWTH (2017).

173 Cf. Superlocal (no date).

174 Cf. Rosenkötter, p. (2018).

175 Cf. Dechantsreiter, U. et al. (2016).

176 ~~Note: Die Zusammenstellung der Praxisbeispiele ist unter https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_93_2015_wiederverwertung_von_bauteilen_0.pdf ab Seite 207 zu finden.~~ Note: The compilation of practical examples can be found from p. 207 onwards at https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_93_2015_wiederverwertung_von_bauteilen_0.pdf.

and multi-family houses in which concrete components were reused or further used, but also non-residential buildings and other uses of used concrete components.

5.5 Preparation and production of secondary raw materials

The idea of considering the recycling of building materials as a means of conserving resources arose in Germany around the mid-1980s. Although the political and social requirements for the preparation and recycling of building rubble and the implementation of recycling projects have increased since then, technological progress in this field is rather sluggish.[177] From around the year 2000, the removal of pollutants from the material cycle became a priority. Since 2010 the aspect of resource efficiency has increasingly come into focus.[178]

Sorting and return systems

If the demolitions are not selectively separated at the construction site and disposed of according to type, traditional construction waste preparation plants reach their limits with regard to the quality of the RC building materials produced. In the case of building rubble components such as broken masonry, sorting into the various types of wall-building material is no longer carried out in practice, as suitable sorting techniques do not yet exist and only manual sorting is possible.[179] In the future, however, an even greater heterogeneity of demolition waste is to be expected. Only with the help of innovative sorting processes will it be possible in the future to recover pure material fractions from mixed demolition waste.

Sensor-assisted sorting is already frequently used for some fractions of municipal waste. In this way, waste glass and plastics in particular are separated from interfering fractions and separated according to glass colour or type of plastic. For this purpose, belt machines equipped with sensors are used. First, a spreading belt separates the material into individual pieces. The material is then fed through a chute and the material flow is recorded by

177 Cf. Müller, A. (2016a), p. 15.
178 Cf. Müller, A. (2016b).
179 Cf. Müller, A. (2016a), p. 25 et seq.

one or more cameras. For example, a computer determines the material properties from the colour spectrum or the impurities via shape and size, so that a subsequent series of compressed air units sorts the identified particles into different containers. In this way the foreign matter is discharged or uniform grains are sorted according to colour. In addition to cameras, spectrometers are also used to determine the material properties from the decomposed colour spectrum of the particles. X-ray detectors and inductive detectors are also used as sensors. The latter sort out different types of metal from the change in an alternating magnetic field.[180]

For the automated sorting of construction waste, the sensor-supported processes would offer great potential for conserving resources, for example to separate gypsum and brick particles from building rubble mixtures. This applies in particular to particles with a grain size of less than 45 mm, which are difficult to sort by hand.[181] However, this technique is not used in Germany. In Europe, only two plants are known: one in Spain, which separates gypsum from building rubble, and one in Switzerland, which separates concrete from brick particles.[182]

Take-back systems for materials such as plasterboard that can be recycled could lead to higher grade purity and recycling quantities. However, in[183] view of the long service life of buildings, take-back systems will only become established on the market for a few building materials/products.

Preparation of demolition waste

The preparation of demolition materials should lead to the highest possible level of recycling. A prerequisite for this is that the recyclability of materials is already taken into account during product development.

In addition, barriers should be dismantled in order to achieve higher utilisation of existing recycling facilities such as gypsum recycling plants. These are often not fully utilised due to lack of varietal purity, lack of take-back

180 Cf. Müller, A. (2016a), p. 36.
181 Cf. IAB (2018).
182 Cf. Müller, A. (2016a), p. 37.
183 Cf. Mettke, A. et al. (2018), p. 129.

systems, lack of knowledge of innovative recycling processes and insufficient demand for RC building materials. Unused potential exists above all in the preparation of gypsum plasterboard, insulation and mineral demolition waste.

Preparation of mineral demolition waste

In terms of quantity, concrete is the most frequently used building material. Around 42 million tonnes were used for the construction of residential and non-residential buildings alone in Germany in 2010. At the same time, more than 12 million tonnes were lost.[184] However, the recycled share, which is again used as a secondary raw material in building construction, is less than 1 %, as already described in Chapter 2.

Concrete consists of aggregates, cement, water, additives such as superplasticizers and property influencing additives, so-called additives. Instead of using only natural aggregates as the primary raw material, so-called R-concrete contains recycled aggregates (RC aggregates) obtained from building rubble. R-concrete is the abbreviation for “resource-conserving concrete"[185] and is used synonymously with the term "recycled concrete" (RC concrete).[186]

The composition of R-concrete is largely comparable to that of concrete from primary raw materials, although special superplasticizers are used in addition to RC aggregates. The cement content corresponds to that of standard concrete, which is important in view of the high climate-damaging carbon dioxide emissions during cement production and does not disadvantage R-concrete in this respect[187, 188]The life cycle evaluation depends on many parameters - not only the formulation but also the transport distances - and is similar for conventional and R-concrete[189, 190]Nevertheless, the mining of primary rock is associated with a considerable impact on the landscape. As a

184 Cf. BBSR (2017), p. 22.
185 StMUV (2017), p. 8.
186 Cf. pan (2018).
187 Cf. UM BW (2017), p. 8 et seq.
188 Cf. Striker, S.; Kulle, C. (2017), p. 126.
189 Cf. Striker, S.; Kulle, C. (2017), p. 115 - 125.
190 Cf. Knappe, F.; Reinhardt, J.; Schorb, A.; Theis, p. (2016), p. 27 - 33.

rule, the primary rock also has to be transported to the construction site from greater distances than secondary raw materials that can accumulate in the neighbourhood.[191]

In Switzerland, R-concrete is used much more frequently in building construction than in Germany. In 2015, a total of 67 concrete plants there produced R-concrete, which covered 10 % of the total concrete demand. Here,[192] too, the natural aggregate is often completely replaced by RC aggregate, not only in part. Public clients in some cantons only permit the use of concrete from primary raw materials if the R-concrete does not meet the structural requirements.[193] On average, the proportion of R-concrete in public construction measures in all cantons is around 15 %.In the Netherlands and Belgium,[194] too, the share of R concretes in building construction is in the double-digit percentage range.[195]

Although R-concrete can be used without adjustments in the planning of building constructions and must only be taken into account during the preparation for awarding the contract, it is largely unknown among architects and structural engineers.[196] However, once the building material is known in the market, demand could also increase.[197]

Research projects on innovative sorting processes

Sensor-based sorting is the subject of several research projects in Germany, both in the preparation of composite[198] thermal insulation systems and in the preparation of construction and demolition waste. The basic functionality of the latter has already been demonstrated at the Institute for Applied Build-

191 Cf. Knappe, F.; Reinhardt, J.; Schorb, A.; Theis, p. (2016), pp. 33 and 88.
192 Cf. MI BW (2016), slide 73.
193 Cf. SenUVK (2015), p. 14
194 Cf. idw (2017a).
195 Cf. MI BW (2016), slide 75.
196 Cf. MI BW (2016), slide 181.
197 Cf. MI BW (2016), slide 95.
198 Cf. FH Münster (2018b).

ing Research in Weimar, e.g. to sort out sulphate-containing building materials. Bricks can also be separated from concrete in building rubble, but this would currently only be economical with grain sizes over 10 mm.[199]

Research project: "ReWaste 4.0"

In the case of residual waste - both from residential and construction waste - the technological potential for increasing the recycling rate is far from exhausted. In Austria, many waste treatment plants are at the level of the 1990s, so that the establishment of a modern industry 4.0 approach with digitisation, networking and machine learning will lead to more secondary raw materials from municipal and construction waste. Since 2017, the Austrian competence centre "ReWaste 4.0", which stands for "Recycling and Recovery of Waste 4.0", has been pursuing this claim. Under the consortium leadership of the University of Leoben and the participation of the Institute for Infrastructure, Water, Resources, Environment of the Münster University of Applied Sciences and industrial partners, the current recycling rate of mixed waste of less than 5 % is to be significantly increased. In Austria, slightly more than 4 million tonnes of municipal waste are generated annually. 1.4 million tonnes of this is "mixed municipal waste", which is to be better recycled. In contrast to the sorted collections, in the case of mixed waste pollutants and contamination are distributed among the materials and are currently often not separable. This low-quality mixture is therefore unsuitable for recycling and is only thermally recovered, i.e. incinerated.[200] Therefore, in the four years of the project, in addition to overarching strategic concepts, technical topics such as the characterisation of mixed wastes in real time, the further development of new sorting, separating and shredding technologies and the development of models, control programmes and communication techniques for digitised devices in line with the industry 4.0 approach will be addressed.[201] One project partner is Saubermacher AG in Retznei, which has so far produced 1 million tonnes of substitute fuels for the neighbouring Lafarge cement plant in 15 years of operation - over 90 %

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[199] Cf. IAB (2018).
[200] Cf. APA (2017).
[201] Cf. Loeben (no date).

of the fuel requirement with an EU average of only 40 % - and in addition sorted out and recycled around 27,000 tonnes of scrap metal and around 5,000 tonnes of PET plastic waste. With ReWaste 4.0, even more recyclable materials are to be removed from the waste fully automatically.[202]

Research project: "BauCycle"

The Fraunhofer joint project "BauCycle" has set itself the target of using grain sizes smaller than 2 mm for its project. Of this fine fraction, also known as crushed sand, around 5 million tonnes are produced annually from the demolition of buildings and infrastructure. These end up in landfills as non-recyclable residual material. BauCycle strives for the best possible recycling by producing porous concrete as a secondary raw material from different building rubble fractions. This can be used as a load-bearing construction for two-storey houses or for sound and thermal insulation.[203]

The research consortium of four Fraunhofer Institutes focuses on sensor-based, selective sorting of building rubble from sand-lime bricks, bricks, concrete and gypsum. This can then be used to produce porous concrete from pure bricks or sand-lime bricks as well as from a mixture of 80 % sand-lime brick and 20 % old concrete (Figure 8). Compared to the primary material, the mixture has competitive strengths and can fulfil a load-bearing function. In the current project, it has now been possible to differentiate between particles with a size of one millimetre. A throughput of 1.5 t per hour is possible.[204]

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202 Cf. MSV (2018).

203 Cf. Fraunhofer UMSICHT (2018a).

204 Cf. Fraunhofer UMSICHT (2018b).

Figure 8: Porous concrete of brick (rear), porous concrete of sand-lime bricks (front) [205]

Research project: "Investigation of masonry demolition and derivation of criteria for the chemically and physically compatible and ecological application in RC concrete"

Despite initial practical experience, R-concrete or RC-concrete remains a research topic. Together with other partners, the research project "Investigation of masonry demolition and derivation of criteria for chemically and physically compatible and ecological application in RC concrete" was started in 2017 at the University of Constance. It will investigate how bricks behave in RC concrete instead of crushed concrete and what the ecological balance looks like.[206]

Research project: "Energy and material flows along the production and use of secondary raw materials in building construction"

The Leibniz Institute for Ecological Spatial Development's construction research project "Energy and Material Flows along the Production and Application Site of Secondary Raw Materials in Building Construction" will focus

205 Photo: Fraunhofer UMSICHT (2018b).

206 Cf. idw (2017a).

in particular on life cycle evaluations of R-concrete and other building products by 2019. The production and use of secondary raw materials in building construction will be investigated with regard to energy and mass perspectives.[207]

Research project: "R-Concrete: Resource-conserving Concrete - The Next Generation Material"

A major joint project is "R-concrete: Resource-conserving concrete - next-generation material" as part of the BMBF's "HighTechMatBau" initiative. Since 2014 and until 2019, universities and companies have been jointly investigating how building rubble from building construction can be returned to building construction. The entire value chain is[208] addressed in order to realise closed material cycles in building construction. In addition to concrete quarry, masonry quarry as well as fine RC aggregates[209] are to be used, as has already happened in the "BauCycle" project, whereby BauCycle is limited to the production of porous concrete. The "Small House III" on the premises of the Technical University of Kaiserslautern was erected as a large-scale demonstrator in the R-concrete project. This large-scale demonstrator is the first building in Germany to use R concrete in all components without exception.[210]

Research project: "SeRaMCo" (Secondary Raw Materials for Concrete Precast Products)

Based on the joint research project "R-Concrete", the EU funding project "SeRaMCo" (Secondary Raw Materials for Concrete Precast Products) was launched in 2017. His main focus lies in the transfer and implementation of the knowledge gained in closed, mineral material cycles, especially on precast concrete parts. Under the direction of the Technical University of Kaiserslautern, eleven partners from business, administration and science work together in five countries.[211] Concrete long-term goals were set: Ten years

207 Cf. Fraunhofer IRB (2019b).
208 Cf. BMBF (2019).
209 Cf. R-concrete (2019).
210 Cf. HeidelbergCement AG (2017).
211 Cf. idw (2017b).

after the end of the project, 13 million tonnes of building materials such as concrete, masonry, roof tiles and ceramics are to be recycled every year.[212]

Practical example: Production of RC aggregates

Heinrich Feess in Kirchheim/Teck is a well-known company that has been carrying out demolition work as well as producing recycled aggregates from it for a long time. Managing Director Walter Feess was awarded the German Environmental Prize in 2016 as a pioneer for recycled concrete. For the production of RC aggregates, he developed special sorting processes for the preparation of building rubble and washing preparation for the separation of soil and construction waste mixtures.[213] Feess was the first company to receive building authority approval from the German Institute for Building Technology for its recycled aggregate.[214]

Practical example: Development of RC concrete blocks

Feess developed concrete blocks called 'ecostones', similar to the mortarless masonry of the ReMoMaB research project (Chapter 5.1), which are stacked on top of each other by means of conical studs and corresponding troughs on the underside of the blocks. The unreinforced concrete of the concrete blocks contains up to 90 mass % RC aggregates from our own works. The ecostones serve as bricks for silo walls on storage areas. They can also be used in gardening and landscaping.[215]

Practical examples for the use of R-concrete

In Germany, R-concrete has increasingly been used in southern Germany in recent years. The federal states of Bavaria and Baden-Württemberg publish corresponding guidelines.[216, 217] In Berlin, the new research and laboratory building for life sciences of the Humboldt University in Berlin-Mitte was completed as a pilot project in 2014. It contained R-concrete in the supporting

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212 Cf. TU Kaiserslautern (2017), p. 9.
213 Cf. Ilg, G. (2016).
214 Cf. DBU (2016).
215 Cf. Striker, S.; Kulle, C. (2017), p. 102 - 106.
216 Cf. UM BW (2017).
217 Cf. StMUV (2017).

structure for the building construction and also in the diaphragm wall for the construction of the excavation pit. 1,700 m³ R-concrete was used for the diaphragm wall. Of this, 25 % by volume of the rock was replaced by RC aggregate. The load-bearing structure consisted of 3,800 m³ R-concrete with an RC substitution share of 40 % by volume. In total, more than 2,800 t RC aggregate were used.[218] For the environmental station of the city of Würzburg, 450 t RC aggregates were used for the production of 600 m³ R-concrete, the substitution share was 45 %. In both Berlin and Würzburg, concrete strengths were achieved that were higher than required. In comparison to the standard concrete, no differences were found in the R-concrete.[219]

In the meantime, there are numerous examples of good practice in building construction with R-concrete, some of which are presented on a website of the Institute for Energy and Environmental Research Heidelberg (ifeu).[220] These include not only commercial buildings, but also single-family and apartment buildings, such as the first single-family house in Germany to use R-concrete in Ludwigshafen in 2010.[221]

218 Cf. SenUVK (2015).
219 Cf. StMUV (2017), p. 12.
220 Cf. ifeu (no date a).
221 Cf. ifeu (no date b).

6 CONCLUSION

Construction is responsible for the largest share of waste mass flows. A large part of this comes from building construction. Although the recycling rate for construction and demolition waste is high, most of it goes to civil engineering. Through the reuse of components or recycling of the highest possible quality, even primary raw materials can be substituted in building construction, thus closing the cycle in building construction. The potential to conserve resources has not yet been exhausted. Due to landfill bottlenecks and/or resource bottlenecks, the focus at regional level will increasingly be on recycling of the highest possible quality, making the circular-flow economy even more interesting from an economic point of view.

The demolition of buildings is usually characterised by time and cost pressure. However, legal framework conditions such as the Industrial Waste Ordinance have also had a strong influence on the demolition of buildings in recent years. Conventional demolition (shattering and blasting) is hardly used anymore, as the landfilling of unsorted mixed construction waste is very expensive and the Industrial Waste Ordinance prescribes the separation of specific waste. In most cases, partial selective reductions are made in order to keep planning and personnel costs as well as time expenditure as low as possible. The aspect of conserving resources by reusing them or recycling them at the highest possible level has hardly been taken into account in demolition so far.

In order to make reuse and/or high-quality recycling possible, measures can be implemented in the planning, documentation, selective deconstruction / dismantling and preparation of secondary raw materials.

Recyclable planning

When planning a building, decisions are made for the entire life cycle. The deconstruction or recyclability of a building should also be taken into account. A general strategy for increasing resource efficiency is to extend the utilisation phase, for example by flexible floor plans. The two basic strategies to enable reuse and recycling of the highest possible quality are as follows

- the selection of recyclable building materials and

- the use of detachable connections and constructions.

Further advantages can be shown by the modular construction and the mono-material construction, both of which have to be carefully examined.

In the planning stage, used components should also be repaired or replaced as far as possible and RC building materials are used, because only if the existing recycling products are used can a market develop for them.

Due to the long useful life of buildings, the end of life is usually not taken into account in the planning. A further challenge lies in the fact that the higher planning costs are not remunerated separately in accordance with the fee scale for architects and engineers (HOAI). Moreover, planners and building contractors often lack the knowledge about the strategies of recycling-friendly planning. Integrating this knowledge into training, further training and information platforms accessible free of charge could fill the knowledge gap.

Documentation

The strategies used in planning help only half as much if information about the built-in materials and construction is not available. If this information is documented and kept up to date over the entire life cycle, this can facilitate deconstruction and result in economic advantages for the demolition company due to better planning (reliable calculations).

In most cases, this information is not even systematically recorded or kept up to date. A further question is often in which form the documentation should be stored. Building Information Modeling (BIM) offers an opportunity here. The data is stored digitally in a 3D model of the building. Since this tool can also be used for facility management, it could possibly be kept up to date within this framework. A material passport analogous to the EnEV certificate is also conceivable.

Selective deconstruction and dismantling

Before a building is demolished, it should be checked whether it can be renovated, because if the utilisation phase is extended, resource efficiency increases. Another possibility for a complete demolition is the partial deconstruction or partial deconstruction. Here, too, some of the installed materials are reused, thus saving material and energy. Only if neither is technically or economically feasible should dismantling be carried out.

Deconstruction has the highest resource efficiency potential in deconstruction, because if a component is dismantled and reinstalled at another location, not only primary raw materials are conserved, but also the production energy that would have been required is saved. Since not all components can be dismantled or reused non-destructively, a combination of dismantling and selective deconstruction makes sense. The aim of selective deconstruction is to separate the waste fractions by type and keep them separate. Varietal purity can determine the later quality of the secondary raw material. In addition, demolition fractions such as gypsum plasterboard should be selectively dismantled and kept separate if there are separate recycling routes for them.

Due to the additional effort involved in selective deconstruction, deconstruction is often only partially selective. The effort is mostly caused by non-detachable connections and missing information about the installed materials. Buildings suitable for deconstruction, at best with existing documentation, could reduce this effort.

Preparation and production of secondary raw materials

If a building is not selectively dismantled and the waste fractions are not kept separate, subsequent sorting is very costly or in some cases no longer possible. Through innovative sorting techniques, such as sensor-assisted sorting, this mixed construction waste can be better sorted in order to achieve the highest possible level of recycling. In addition, waste fractions such as broken gypsum plasterboard can be increased by our own take-back systems and brought to the preparation plant with a higher grade purity.

Obstacles to the preparation of secondary raw materials include the lack of varietal purity and the insufficient demand for RC building materials. Through intensive research, processes can be further developed and new ways of utilisation found. The environmental service branch also offers the opportunity to develop new business areas (e.g. leasing systems).

Outlook

In their life cycle, buildings have a long utilisation phase of several decades. This brings with it the challenge that today the evaluation of materials/materials and also the possibilities that exist in the future for materials and processes are unknown. This can have both negative and positive effects: Today, supposedly harmless building materials could be declared pollutants in the future, but it is also possible that new technical processes will soon be available with which, for example, currently used, insoluble composites can be reliably separated. The variety of materials will increase even further in the future, which is why the solubility of constructions and connections is essential for recycling of the highest possible quality. In addition, the knowledge on dismantlability and recycling capability should be integrated into the training of relevant specialist planners and into further training courses.

7 DOCUMENTATION OF THE TECHNICAL DISCUSSION

7.1 Programme of the expert discussion "Deconstruction in building construction - current practice and potentials of resource conservation"

Berlin, 24st January 2019

Moderation: Dr. Christof Oberender
(VDI Zentrum Ressourceneffizienz GmbH)

TOP 1: Welcome and introduction round

TOP 2: Presentation of the brief analysis "Deconstruction in building construction - current practice and potentials of resource conservation",
Oliver S. Kaiser (VDI Technologiezentrum GmbH)

TOP 3: Selective deconstruction in practice - recycling begins on the construction site,
Robert Halter (Managing Director Halter Spreng- und Umwelttechnik GmbH, Berlin)

TOP 4: Conservation of resources through circular management,
Prof. Dr. Angelika Mettke (Head of the Construction Recycling Department at the Brandenburg Technical University Cottbus-Senftenberg, Institute for Environmental and Process Engineering)

TOP 5: Moderated discussion of the presentations

TOP 6: Recyclable construction of buildings,
Bernd Köhler (Senior Architect, Werner Sobek Design GmbH, Stuttgart)

TOP 7: Resource efficiency, deconstruction and circular economy from the perspective of a hybrid construction specialist,
Dr. Jan Wenker (Brüninghoff group of companies, Heiden)

TOP 8: Moderated discussion of the presentations

TOP 9: Summary and outlook

7.2 Documentation of the technical discussion

On 24 January 2019, an expert discussion was held in Berlin on the subject of "Deconstruction in building construction - current practice and potential for conserving resources" with 36 participants from universities, companies, networks and associations. VDI Zentrum Ressourceneffizienz GmbH had invited to this expert discussion. In the discussions of the participants, current deconstruction techniques, recovery and disposal routes as well as opportunities for high-quality recycling of construction waste and recycling-friendly construction were discussed. It was pointed out that actors from the waste management sector and clients were not present, so that their points of discussion may not have been sufficiently taken into account.

Presentation of the brief analysis "Deconstruction in building construction - current practice and potentials of resource conservation", Oliver S. Kaiser (VDI Technologiezentrum GmbH)

The stock of residential and non-residential buildings in Germany, at 15 billion tonnes, is home to an enormous anthropogenic reservoir of material. With the deconstrution of buildings, this material can be selectively recovered, recycled and reused in building construction or elsewhere. The recycling rate in construction is more than 75 %, but only a small proportion is recycled and remains in building construction. Most of the building rubble is currently used for road construction or land filling. Only a small amount of recycled concrete for new buildings is produced. Also, the reuse of whole concrete slabs from demolition houses takes place only to a limited extent. In the planning stage, selective deconstruction and the highest possible level of recycling can be promoted, among other things, by selecting building materials that are easy to recycle, by detachable connections and by documenting the relevant information. Selective deconstruction can also help to ensure that high-quality recycling is possible through higher varietal purity. Various projects show how this is implemented in practice and in research. Challenges include the long utilisation phase, legal conditions and the additional work involved in planning and demolition.

7.2.1 Motivation for high-quality recycling of waste from the deconstruction of buildings

The participants of the expert discussion asked themselves the question, for what reasons above all a high-quality recycling should be aimed at, particularly since already now a recovery rate of more than 75 % can be assumed.

One reason for high-quality recycling is the conservation of primary raw materials. Although there are still sufficient capacities of primary raw materials at present, these are distributed differently from region to region and a large part cannot be used at the moment because the areas are cultivated, used for agriculture or are under nature conservation. In the long term, a shortage of resources in construction is to be expected if primary materials continue to be used as a rule. For reasons of resource protection, recycling building materials therefore makes sense.

When conserving resources through the high-quality recycling of construction waste, however, climate protection should also be taken into account and the sustainability of the entire preparation of secondary raw materials should therefore be reviewed. In addition to the potential to conserve resources, the energy required for deconstruction, transport and preparation should also be taken into account. The energy that would have been required for the production of components with primary raw materials should also be considered. This is especially important in the case of the reuse/further use of components.

Selective deconstruction in practice - recycling begins on the construction site, Robert Halter (Managing Director Halter Spreng- und Umwelttechnik GmbH, Berlin)

An essential point in deconstruction practice is the prior stocktaking. A pollutant report, a disposal concept, an analysis concept and the planning of disposal routes are drawn up. The economic efficiency of the selected waste materials is decisive when clearing out the trash. With metals this is given in contrast to e.g. gypsum. In selective deconstruction itself, pure-grade concrete fractures are easy to dispense. For gypsum and bricks, on the other hand, it is not worth the effort at the moment. The dismantling of entire components (e.g. slitting of concrete components) is usually faster and cleaner than breaking. In addition, less space is required and vibrations and spalling are reduced.

Barriers to selective deconstruction:

- economic efficiency (production of the individual substances in comparison with the price for the purchase of secondary raw materials),
- the high competitive pressure,
- lack of demand for RC building materials (usually only primary raw materials for building construction or road construction are in demand in tenders),
- lack of examination of the deconstruction concepts and compliance with the Closed Substance Cycle Waste Management Act and
- lack of checks on separation.

The motivation for selective deconstruction from the point of view of a dismantler is based on the Closed Substance Cycle Waste Management Act, economic efficiency, legal certainty and a clear conscience.

One question still to be clarified is whether the selection should take place at the construction site itself or at the recycling companies.

7.2.2 Selective deconstruction and high-quality recycling

Today's demolition and construction practice has many potentials, but also obstacles and questions. In principle, the selection of hazardous substances is very important during deconstruction. It does not matter whether these were introduced into the building material itself or only during use.

The economic efficiency and the still low acceptance of secondary raw materials are often a challenge in selective deconstruction. The question arises as to the sense of a further separation in addition to the legally required one if there are no established take-back and recycling systems yet for the waste fractions obtained in this way. If the separated waste fractions are not in demand for subsequent preparation or if the transport routes are too long, the additional expense for separating building rubble often proves to be uneconomical.

The question of which location is better suited for the separation also remains unresolved. If the fractions are separated directly at the construction site, this requires careful demolition work and trained employees. Sorting in the respective preparation plant could be advantageous if the technical equipment for automatic sorting is available there and, in particular, if the materials to be processed in the company are to be fractionated.

A further difficulty for selective deconstruction are composite materials for which there are no functioning or efficient separation processes. For this reason, systems should be used in construction for which suitable separation processes are available or which do not require foaming or adhesive bonding with plug-in, clamping or screw connections. Attention must be paid to details, such as the fact that screw connections cannot be reliably loosened after decades of compression or tension. Composite materials cannot be completely dispensed with. For example, carbon concrete has advantages in construction and is treated in the same way as reinforced concrete during demolition. But there is the question of the recycling of carbon fibres. The participants do not agree on how well the recycling of carbon fibres from carbon concrete currently works.

Waste legislation is already very comprehensively regulated by various ordinances within the framework of the Closed Substance Cycle Waste Management Act. One weak point, however, is that the specifications are not monitored after selective deconstruction. Controls are rarely carried out at demolition companies to check whether materials are collected separately and recycled to the highest possible standard.

A specific certificate from the German Sustainable Building Council (DGNB e.V.) relating to deconstruction properties is currently being planned.

Resource Conservation through Circular Management, Prof. Dr. Angelika Mettke (Head of the Construction Recycling Department at the Brandenburg Technical University Cottbus - Senftenberg, Institute for Environmental and Process Engineering)

Reuse of prefabricated concrete components – ecological advantages

The Kolkwitzer Sportverein 1896 e.V. sports club is a good example of the reuse of components. The ecological advantages lie in the enormous savings in raw materials and production energy required to manufacture new concrete elements. Production is particularly energy-intensive: 3,080 MJ (856 kWh) (converted to heating oil: approx. 72 l) are required for 1 t of ready-mixed concrete. The provision of used elements requires only the equivalent of about 3.7 l heating oil per t precast concrete element (= energy required for dismantling). This results in energy savings of 95 %. The level of energy consumption correlates with the release of climate-relevant pollutant emissions: Instead of 394 kg/t CO_2 only 12 kg CO_2 for the provision of used components (= 3 % of 394 kg/t). In addition to the ecological advantages, there are also economic benefits: The cost saving for the shell of the 400 m² building was € 30,000 through the reuse of 40 walls and 40 ceiling panels for the roof construction.

Use of RC concrete in the HU Berlin pilot project

In a pilot project of the Humboldt-Universität zu Berlin, the ecological advantages of RC concrete in the construction of the load-bearing structure compared to primary concrete were considered. Through the use of RC aggregates, 4.4 t could be saved for the 3,800 m³ RC concrete CO_2 compared to normal concrete. In addition, natural deposits were spared or preserved due to the non-utilisation of 680 m² of gravel extraction area. The saving in space corresponds to the size of almost four tennis courts or a football field. The short transport distances for RC aggregates to their place of use and their high-quality application possibilities offer the best conditions for optimum circular cultivation.

It should be noted that the use of RC concrete requires a case-by-case test for each construction project. It must be examined which ecological and economic advantages are achieved in each case. The location of the construction project is decisive. Urban agglomerations offer the best conditions for the use of RC concrete, as large quantities of building rubble are produced during demolition and demolition work, RC plants are located in the catchment area and at the same time large quantities of aggregates are required for concrete production in order to construct new buildings.

Recommendations for action

The following strategies are required to create a building that is as recyclable as possible:

- a constructive separation of components subjected to different stresses,
- detachable and flexible connecting parts and constructions,
- the use of pollutant-free, durable building materials and products, including RC building materials and products,
- the use of removable systems for interior walls and
- the use of low-residue materials and construction processes.

The more careful the planning of the demolition / deconstruction of a building is, the more differentiated the disposal of construction waste can be implemented and construction costs can be saved or even revenues generated for partial flows. The regional situation and requirements with regard to reuse and high-quality recycling must be taken into account.

7.2.3 Preparation and acceptance of recycled concrete and other recycled products

It is undisputed that recycled concrete and other recycled building materials can already be produced today in very good quality. In addition, the use of RC aggregates in concrete production does not normally result in more cement being required than in the production of concrete with primary raw materials. Many implementation examples also prove that it is possible in practice to reuse dismantled components. This is the preferred way to conserve resources, since primary raw materials can be saved in this way and the production energy is no longer required. In addition to the potential to conserve resources, the energy required for deconstruction (e.g. cutting to size), transport and preparation should also be taken into account in the balance sheet.

The participants of the technical discussion come to the conclusion that the legal framework represents an obstacle to high-quality recycling and component reuse. One of the main problems is that the Closed Substance Cycle Waste Management Act and the building law do not contain any coordinated requirements. As a result, the declaration of waste and construction products in the context of recycling products is not clearly regulated.

The situation is similar with the concretisation of the legal concept in the Closed Substance Cycle Waste Management Act (KrWG) and a possible adaptation of the Ordinance on Hazardous Substances, which is necessary from the point of view of some actors. According to the KrWG, recycling may only take place if it is safe for humans and the environment. This is currently being interpreted in a precautionary manner. In addition, it should be checked whether certain pollutants can remain in the concrete, for example, if they have no effect on humans and the environment when they are incorporated. Such an approach could, for example, facilitate the production of recycled concrete.

One obstacle to the reuse of components lies in the still open questions regarding legal certainty.

Despite the high quality of the secondary raw materials, there is only little demand for recycling products. It was noted that most planners and architects do not consider the use of recycled materials and - especially private - clients do not ask for it.

The participants in the technical discussion assume that this is due in particular to a lack of knowledge and expertise about the possibilities of using recycled materials. In addition, many clients do not want any components made from materials that have already been used and processed, as these are still considered to be of lower quality. In addition, public tenders for new or refurbished buildings seldom require and/or take into account recycling products.

An argument that has been discussed several times concerns the lack of economic efficiency at various points in the deconstruction and new construction process. For mass flows, transport is a decisive cost factor. Demolition companies are often unable to deliver their waste profitably to recycling companies because the transport route there is too long. This also applies to the procurement of building materials. Even if recycled concrete is cheaper, it may be worthwhile to obtain primary raw materials from a nearby quarry due to the high transport costs. Transport must also be taken into account in the ecological analysis.

The core statement can be summarised as follows: both for demolition companies and for building construction companies, the knowledge and economic efficiency must be given, otherwise the demand for high-quality recycling can only be achieved through promotional measures.

Recyclable construction of buildings
"Experimental Unit Urban Mining & Recycling (UMAR)", Bernd Köhler (Project Manager / Senior Architect, Werner Sobek Design GmbH, Stuttgart)

Werner Sobek with Dirk E. Hebel and Felix Heisel have designed and built the research house "UMAR" in cooperation with other partners. It became clear that it is quite possible to erect a recycling-friendly, well-designed building from predominantly recycled products.

It has been noted that all materials can be returned to technical or biological cycles and are available for equivalent application uses after recycling. However, it turned out that finding suitable products on the market involves a great deal of effort.

When planning the building, care was taken to ensure that all structures and connections were detachable (even in wet areas), that the individual components were reusable, recyclable, compostable and that recycled building materials/parts were used.

Examples of this are:

- a revolving wall whose stones have been baked from mineral building rubble,
- modular components made of untreated wood that can be reused after deconstruction,
- insulating material made of mushroom mycelia,
- a façade made of copper plates, which were used, for example, for a hotel roof,
- door handles from a former bank and
- a glass cut-off wheel made of recycled glass and reusable.

The project also proves that a recycling-friendly building made of recycled materials can also meet high architectural standards.

7.2.4 Product design and planning of a recycling-friendly building

When planning buildings suitable for recycling, several planning strategies must be taken into account, such as the recycling-friendly selection of building materials or construction with detachable connections. The knowledge and data material on products and design methods represent a particular challenge in the implementation of these planning strategies. This is described in more detail in chapter 7.2.5 of the documentation. In addition, the coordination effort during planning is already high these days. In addition, a solution should be found for systematically integrating the end of a building's life into the planning process.

Realised examples show that it is possible to implement recycling-friendly planning and construction and that this can also be combined with a high architectural standard. Behind the implemented projects are often still the idealism of individual clients or a research purpose.

The examples also show that planning is complex, particularly because of the search for suitable construction solutions and products.

The participants in the discussion therefore come to the conclusion that high-quality recycling must be taken into account as early as the product design stage. Construction product manufacturers should be made more accountable. The recyclability of construction products should be taken into account as early as the development stage. The entire life cycle is to be considered and at this stage it is to be checked which deconstruction techniques and which waste collection points or infrastructure are available.

It was also discussed whether the standardised product labels are sufficient or whether they need to be extended. Against the background of the large variety of recipes for building products, further information may be necessary for the recycling company in the future.

Resource efficiency, deconstruction and circular economy from the perspective of a hybrid construction specialist, Dr. Jan Wenker (Brüninghoff Group, Heiden)

Resource efficiency is an essential component in the planning and implementation of sustainable, life cycle-oriented and sustainable buildings. Resource efficiency describes the ratio of benefits to technical and natural resources used - ideally viewed over the entire life cycle of a building, including possible deconstruction. Resource-efficient construction therefore aims to make the use of resources as efficient as possible and thus to keep it as economical, ecological and socially compatible as possible.

Hybrid construction means intelligently combining different materials such as wood, concrete, steel and aluminium to achieve new properties that are unattainable through the simple use of individual materials. As an essential element of hybrid construction, the renewable raw material wood offers special advantages in terms of efficiency, site speed and sustainability. The combination of wood and concrete within the supporting structure proves to be a particularly economical solution - for example within the framework of a wood-concrete composite ceiling.

A possible deconstruction should be considered as early as the planning stage of a building - as a final measure if renovation, revitalisation and/or conversion can be ruled out for economic or technical reasons. The aim of the deconstruction itself should be to obtain the highest possible quality recyclates. A challenge here is often the lack of knowledge about the materials used or the presence of pollutants in the stock.

It is therefore important to plan, construct and build structures in such a way that the aspects of pure deconstruction and recycling are taken into account. Decisive factors include the choice of raw materials used, the quantity of material used and the choice of suitable joining processes and connections for deconstruction. The implementation of these concepts should permit the repeated use of the building materials used in the sense of a circular economy. The hybrid construction method, which stands for a high use of renewable raw materials, unfolds great potential here. In the life cycle of a hybrid building, all phases - starting with integral planning, through operation and maintenance to deconstruction - must be considered holistically. Hybrid construction is also characterised by a high degree of prefabrication and easily separable constructions at component and building level, when intelligently planned.

In this context, the potential of Building Information Modeling (BIM) should not go unmentioned. With BIM, all physical and functional properties of a building as well as project-relevant information such as material properties and component designs are recorded and combined in a digital model. In the event of a deconstruction, this current and complete data basis can be used. However, this meant that BIM had to be integrated throughout the entire life cycle of the building. However, this is often not the case today. Often not all project participants support BIM, or the method is not implemented in all phases and with all information necessary for the later deconstruction. In the future, the use of BIM over the entire life cycle would therefore be sensible and desirable.

7.2.5 Documentation

If a building is to be dismantled after around 70 years of useful life and the materials recycled, it is helpful - also for the future - to know all the materials used. This can be achieved by documenting the planning and construction phase as well as the use with conversions, renovations or retrofits.

There has been extensive discussion on how to achieve such documentation. It is undisputed that the documentation must cover the entire service life of the building, so that at the end of the utilisation phase the best procedure for deconstruction can be decided. It is also clear, however, that the complete coverage of components, construction products and their design methods can only rarely be ensured because of the different parties involved in the individual life cycle phases. In addition, materials used today may contain previously unknown pollutants and therefore cannot be recorded as such. This could lead to unforeseeable difficulties at the start of deconstruction.

There was disagreement over the type of data collection, storage and documentation. Digital data acquisition with software and databases available today may not be readable after 70 or more years because these systems no longer exist. Examples of this were microfilm or CD storage, which became obsolete after a relatively short period of time. There is, however, a demand for continuous data collection and storage, so that data can very probably be transferred and adapted to new requirements when the systems change. It was argued that it would be better not to rely on digital storage for such a long period of documentation.

Possible digital methods for marking construction products during the construction phase are RFID chips (Radio Frequency Identification). However, these are not suitable for documenting all materials in the building. Here, methods for building data modelling such as BIM are primarily suitable. This makes it easier for all parties involved in the construction to coordinate during the construction phase and can then be reused for construction management during the utilisation phase. However, the effort involved in creating a BIM model and the compatibility of all parties involved must be taken into account. In principle, the use of this model also seems to make sense for the long-term documentation of building data - the extent to which BIM is actually suitable for this will have to be seen in the future. However, there was agreement that it was necessary to make preparations today in order to achieve complete documentation of the building data.

Regardless of how the documentation of the building stock will be done, the question of who is responsible for data collection needs to be clarified. Planners and architects are in demand during the planning phase. In the construction phase, many different trades are also involved in the installation of material. Once the building has been handed over to the client, he is responsible for changes such as renovations or conversions of the building. Craft businesses can then also become active. It was argued that from the moment the building was handed over, the client alone was responsible for the continuation of the storage and for further documentation, since only this client could decide on measures to be taken on the existing building. However, the majority of the participants were in favour of all actors involved in the building at different times and for different purposes being responsible for data collection. This concerns the client as well as the planner, the construction company and the craft businesses. Progress in digitisation offers opportunities to do this together if the right conditions and requirements are created.

7.2.6 Expertise and dialogue

A decisive obstacle to high-quality recycling of deconstructions and sustainable construction is seen in the expertise of many of the parties involved. As a rule, clients already have no knowledge or understanding of building that is suitable for recycling or the possibility of building to a high quality standard using recycled materials. It is still unusual today for planners and architects to recommend or offer building with recycled products to clients. This is also due to the training of the planners, in which recycling-related process and deconstruction strategies do occur as individual aspects, but there is a lack of consistency, so that the knowledge can only flow very slowly into construction practice. The same also applies to the executing trades, for which the current state of knowledge on dismantlability and recycling in the construction industry is not yet part of the training. Ideally, planners should include the expertise of the demolition contractors. This obstacle is reinforced by the growing shortage of skilled workers, which is also reaching the construction industry.

Overall, the discussion during the expert discussion showed that it is necessary to involve all actors in all processes of construction and deconstruction. A dialogue between the parties involved is necessary to ensure that the later usable and recyclable deconstruction is already taken into account in the planning phase. Disposers and demolition companies should be consulted as well as the executing trades and production companies. One example of how this could work is the "UMAR" research building[222]. Even though the design principles used in this model house are not suitable for the construction of

[222] **Further information is available at: https://www.empa.ch/de/web/nest/urban-mining**

standard buildings, they can be used to show how recycling-friendly construction with recycled materials and dismantling at the end of life could become possible in the future.

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The brief analyses of VDI ZRE provide an overview of current developments related to resource efficiency in research and industrial practice. They each contain a compilation of relevant research results, new technologies and processes as well as examples of good practice. The brief analyses thus provide a broad audience from business, research and administration with an introduction to selected areas of resource efficiency.

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Im Auftrag des:
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