Material and product recycling - using the example of prefabricated buildings

Summary of 66 own publications

HABILITATION THESIS

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by

Dr.-Ing. Angelika Mettke

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Reviewer: 1. Prof. Dr.-Ing. Wolfgang Spyra

2. Prof. Dr. rer. nat., habil. Ing., Dipl. Chem. Reinhard Frey

3. Assoc. Prof. Karol Grünner

This document is the translation into English of an excerpt from Prof. Angelika Mettke's habilitation thesis, which explicitly concerns the **reuse of precast concrete elements**. The chapters on material recycling are available in the original document at Opus.

We have left the original table of contents. The chapters marked in *cursive* have not been translated and are only available in the original document. The chapter numbering has remained as in the original document.

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Table of contents

1 Introduction

The following thesis comprises the summary of 66 publications solely written by the author of this thesis.

Each chapter begins with a reference to the publications that can be categorised according to the respective content of the chapter. The information is provided in square brackets from [1] to [66] (corresponding to Annex g) A1 postdoctoral research proposal).

The author's own publications are superordinate to the thematic subject of "Material and product recycling in the construction industry".

All the proprietary publications underlying the thesis have been reviewed and updated with regard to the latest scientific findings/state of the art. In the meantime, new findings from both the author's own research and from external sources have been included.

1.1 Background and motivation

Recycling and the demand of today's society to act in an environmentally conscious manner is an issue that can no longer be ignored. In the 1980s, the focus was on remedying negative environmental impacts, however, the priority has now shifted to preventive environmental protection. This precautionary aspect constitutes the foundation of sustainable economy, resulting from the growing awareness that human society and the economy are at risk of being deprived of their natural resources.

The Sixth Environmental Action Programme of the European Union (2002) is aimed at reducing the overall volume of waste and using resources more effectively in terms of the management of natural resources and waste. In terms of waste recycling, the EU suggests (2005) that measures be taken to promote waste prevention, recycling and reuse, considering the entire life cycle of a product/resource.

The 37th St. Gallen Symposium (Switzerland) held between 31 May and 2 June 2007, demonstrated once again that 200 years after the beginning of the Industrial Revolution and 30 years after the oil crisis, natural resources are once again in the centre of our attention as a determining factor in the global development.

According to the [1]WWF's[2] "Living Planet Report 2008", the ecological state of the Earth has further deteriorated as compared to the 2006 report. Some of the main indicators listed include in particular the increasing consumption of resources, deforestation, climate change, pollution and overfishing.

The alarming conclusion is that, if resource consumption remains unchanged, planet Earth will be consumed twice by the 2030s. Significant rises in commodity prices, e.g. energy, food, and construction materials, already reflect the increasing global instability of natural resources. Optimisation of the management of our resources is essential in order to meet the increased demand for energy by 2050 while simultaneously reducing greenhouse gases. In other words, in order to pursue the path of sustainability, we must finally move away from flow-through economy towards the efficient circular economy.

Concrete construction plays an exceptionally important technical and economic role in the construction industry. Due to the quantities of concrete used, as well as its diverse applications, durability and

[1] Published by WWF (World Wide Fund for Nature), Zoological Society of London (ZSL) and Global Footprint Network; press release 29.10.2008 WWF Germany

[2] "WWF (World Wide Fund for Nature) is one of the largest nature conservation organisations in the world and is active in more than 100 countries." [www.wwf.de/der-wwf/]

performance, concrete is described as the "fascinating construction material of the 20th century". Prefabricated concrete elements and in-situ or ready-mix concrete are used for construction in order to minimise construction times and costs.

This is why an exorbitant number of buildings constructed from industrially manufactured concrete elements were built in the former German Democratic Republic, especially in residential construction, and they still determine the skyline of many cities today (see Chap. 3). After the reunification of Germany, these prefabricated buildings, commonly known as 'Plattenbauten' or 'Concrete Slab Buildings', ended up being increasingly criticised due to their monotony, new housing preferences, and political issues.

Demographic and economic structural changes have also caused thes structures being strongly characterised by a particularly dynamic vacancy rate. The eastern German housing market is severely affected by the outward migration.

Over the past few years, a number in vacancies has risen in numerous eastern German cities, with an unprecedented severity and scope of this phenomenon. The threat of structural decay and social erosion are imminent if this is not countered. Urban redevelopment is therefore one of the most urgent issues in housing and city development.

All parties involved in urban redevelopment will have to face the new challenge of the paradigm shift from growth to decline. According to the principle of sustainability, we are required to act in a future-oriented and resource-conscious manner and not just react. The recirculation of building materials and products is of fundamental importance.

Reasonable, architecturally appealing reconstruction of the standardised buildings, tailored as far as possible to individual living preferences, coupled with high-quality reuse of the existing building components, presents an approach that cannot be achieved by modernisation or traditional demolition and new replacement buildings.

The author has been dealing with the diverse scientific issues of waste prevention, reuse and recovery of mineral construction materials and construction products since mid-1980s.

Initially, her research focused on industrial and commercial buildings. Since the end of the 1990s, there has been a need for clarification in the field of residential construction. The quantities of construction waste generated annually (see Chap. 9) are exorbitant and emphasise this claim both at the national and European level. The research activities focus on the priority objective of circular economy, i.e., the implementation of the waste prevention concept in vacancy management, against the background of achieving sustainable solutions and in the context of urban redevelopment measures. Consequently, the stress is made on the secondary use of concrete construction elements (product recycling = reuse). Secondly, the aim is to maximise the use of recycled construction materials (material recycling = reuse).

The EU Commission is also currently pursuing this strategy with a long-term waste strategy to transform Europe into a recycling society

- with the aim of moving away from a waste-oriented
- towards a raw materials-oriented

perspective.

According to the draft of the new Waste Framework Directive[3], modern waste policy is based on the following 5-tier hierarchy:

Waste prevention before reuse, recycling, recovery and disposal.

Despite a number of successes achieved in recent years in the field of preventing the generation of construction waste due to pilot reuse measures (see Chapter 7) and environmentally friendly disposal (recycling and disposal, see Chapter 9), it is clear that the existing potential is far from being fully exhausted.

1.2 Objective

The applicant's research work aims to demonstrate the current state of knowledge on product and material recycling in a scientifically sound manner in order to push for the potential utilisation and recycling paths for the previously unexploited potential of the building stock against the background of sustainability. Priority is given to the primary objective of circular economy, i.e., prevention of waste and conservation of natural resources through

- the reuse of the concrete elements (product recycling) and
- utilisation of the mineral recyclates (material/substance recycling)

as equal alternatives to primary construction materials and primary construction products.

The weighting of the specifics from the perspective of sustainability forces us to holistically evaluate the reuse and recycling in economic, social, and ecological terms. The theoretical foundations need to be linked to practical conditions, iteratively tested, and reassessed if necessary. Consequently, the path to a comprehensive assessment as well as the specific opportunities can be elaborated.

The focus of the research is to evaluate industrially constructed residential buildings from the GDR era that are scheduled for demolition/dismantling with regard to the highest grade form of recycling (reuse). The discussed primary focus of the material recycling is the utilisation of RC aggregates for RC concrete.

Furthermore, the investigation is focused on the contaminated construction materials that are installed a priori. Innovative recycling options are to be identified in addition to an analysis of the individual contaminants that can be found in prefabricated buildings (asbestos-containing materials, synthetic mineral fibres, bituminous roofpaper) and their effects on health.

The presented thesis is intended as a continuation of the existing fundamentals and a contribution to the practical implementation of the theoretical findings. The explanations serve as a basis for decision-making in planning, construction, dismantling, and disposal.

Nevertheless, this thesis is to serve as a compendium for students attending courses on "Structural Recycling" at the Brandenburg Technical University in Cottbus.

In order to achieve the objectives, the following tasks need to be prioritised:

[3] As part of the intensive long-term process of amending the EC Waste Framework Directive, an agreement was reached in the 2nd reading of the European Parliament on 17 June 2008. The new directive constitutes the basis for improved environment, climate and resource protection in waste management.

- Analysis of the housing vacancy situation, derivation of possible strategies to combat vacancies, and the impact of existing policy instruments on the main strategy to be applied.
- Analysis, summary, and discussion of available findings on the recycling of construction materials and construction products, including the verification of economic and ecological impacts.
- Analysis and summary of findings on the structural condition and serviceability of concrete elements.
- Summary of the results of dismantling of prefabricated buildings by crane, including evaluation of the influence of the utilised technologies on the structural condition of concrete elements and derivation of the preventive measures to minimise damage.
- Summary of the current state of knowledge on the incorporated contaminants, including a description of the locations where they occurred, the utilisation periods, and the specific disposal requirements or respective options.
- Presentation of reutilisation options for reclaimed concrete elements including the requirements and an overview of previous practical solutions/case studies and current research work.
- Overview of general requirements for recycling-friendly construction.
- Drawing conclusions for product and material recycling as well as addressing further problems.

This thesis is centred on the overall issue of prefabricated buildings to be demolished or modified and is intended to demonstrate the complex interrelationship of the requirements to be addressed in terms of product and material recycling. At the same time, the thesis intends to eliminate the numerous uncertainties, conservative behaviour patterns, and knowledge deficits that still exist in practice in order to promote high-quality recycling options.

1.3 Focus of investigation, delimitation, structure

The research focuses on residential reinforced concrete buildings. Recycling of mineral products (component reuse) and mineral construction materials (material reuse) is analysed and evaluated. The main focus is on product recycling.

The thesis is concerned with the essential sub-processes for the disassembly of the shell construction and preparation processes for the reuse of concrete elements. Alternatively, material recycling is evaluated from a structural and environmental perspective. The state of knowledge will be further developed beyond the previously established own foundations.

Research results from currently published research papers has been integrated into the presentation of the state of the art in reuse and recycling alongside the findings of the author's own research. The existing correlations are analysed more closely and innovative solutions are examined holistically on the basis of the current state of knowledge.

The thesis includes relevant framework conditions (legal, technical, economic, and ecological) for material and product recycling.

The goal of every recycling option is to reduce the consumption of energy and resources in order to minimise the impact on the environment as far as possible. Therefore, "sustainability" and "reference scenarios" were used to determine the preferred option based on ecological parameters in order to replace the current decisions that are largely based on economic factors, with a well-founded holistic basis.

Finally, the current state of knowledge is summarised and open issues are discussed in terms of ensuring high-quality product and material recycling.

In terms of focus, the publications [1] to [66] can be subdivided into the **following sub-areas**, as reflected in the present thesis:

- Classification of product and material recycling in circular economy (Chap. 2)
- Dismantling concepts in the housing industry (Chap. 3)
- Dismantling of prefabricated buildings (Chap. 4)
- Harmful substances in prefabricated buildings and their specific disposal (Chap. 5)
- Quality properties of used concrete elements 6)
- Subsequent use options for used concrete elements (Chap. 7)
- Economic and ecological assessment of product recycling (Chap. 8)
- Construction elements/material recycling (Chap. 9)
- Modern, future-oriented developments in structural engineering (Chap. 10)
- Summary and drawing conclusions for material and product recycling (Chap. 11)

The thesis focuses on issues that demonstrate significant potential in terms of conservation of resources and energy.

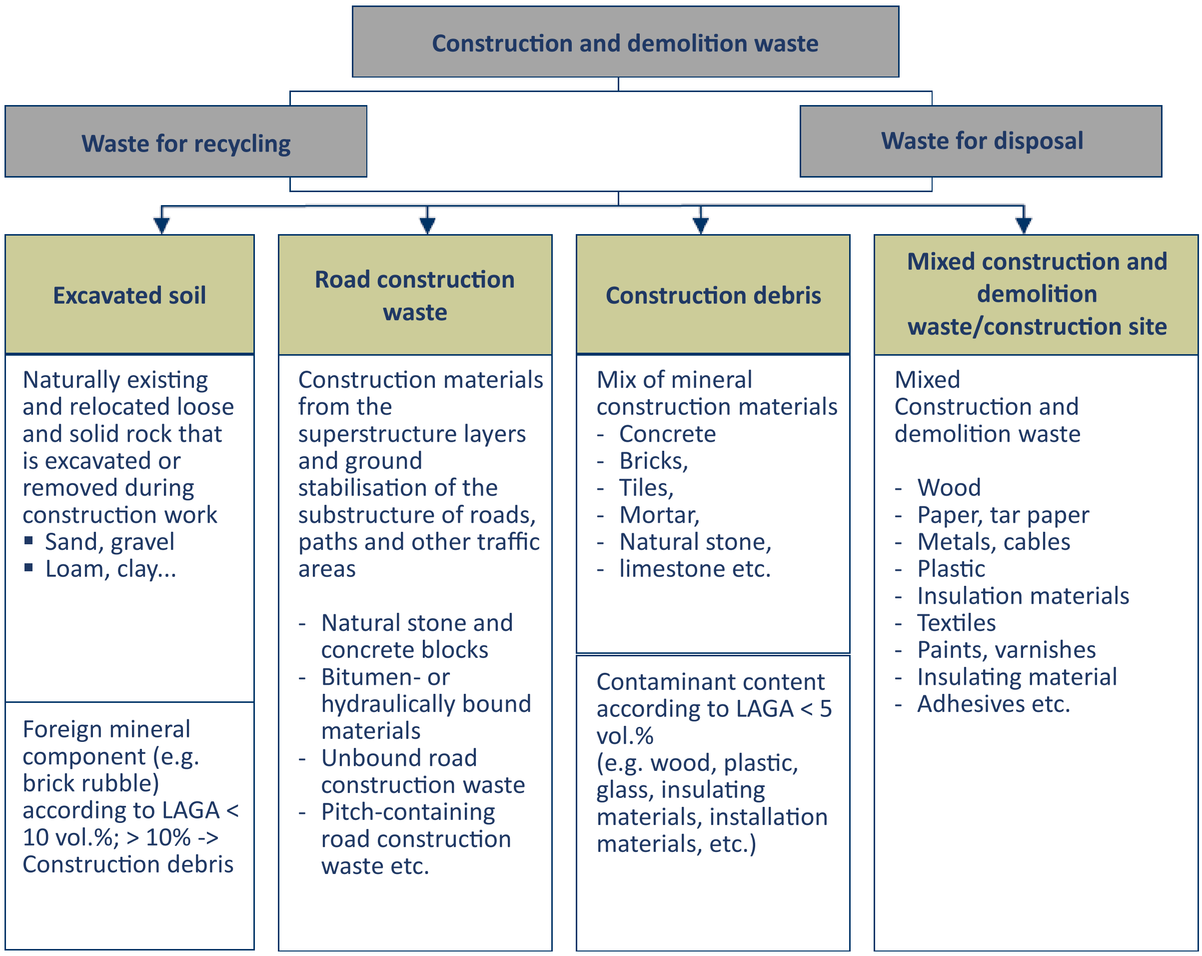
2 Background

2.1 Conceptual clarifications

The following terms are used in the context of the following explanations:

Construction and demolition waste

Construction and demolition waste is generated during actions involving new construction, refurbishment, demolition, and excavation (see Fig. 2.1).



LAGA (Federal/Provicial Workgroup for Waste): Requirements for the recycling of mineral waste (LAGA M20; see Chap. 9)

Fig. 2.1: Construction and demolition waste - categories

The term "waste" is defined in the Closed Substance Cycle and Waste Management Act (KrW-/AbfG) in accordance with the EC Waste Framework Directive 81/156/EEC. According to Art. 3 par. 1 sec. 1 of the Closed Substance Cycle and Waste Management Act (KrW-/AbfG), waste refers to movable objects that are disposed of, intended to be disposed of or have to be disposed of by the owner. This means that the owner/contractor of construction and demolition waste is responsible for all steps required to analyse the material and obtain all necessary permits. Furthermore, the owner/contractor is obliged to allocate the generated materials to a specific waste category and waste code number.

According to the European Waste Catalogue[4], the categories of waste are labelled with a six-digit waste code:

- The first two digits refer to the chapter that considers the origin and the formation process,
- the middle two digits, indicate the subgroup representing a particular group of substances,
- the last two digits correspond to the successive numbering.

Altogether, there are 20 chapters listing 839 different categories of waste. Construction and demolition waste (including excavated material from contaminated sites) is registered in Chapter 17 (see Fig. 2.2). Waste that cannot be allocated must be specified in Chapter 16 as "Waste that is not listed elsewhere in the inventory".

Depending on the level of environmental hazard, waste is categorised according to waste management aspects into:

- hazardous construction waste, labelled with * after the waste code number, and
- non-hazardous construction

waste.

The Waste Catalogue lists 14 hazardous categories (from explosive to ecotoxic).

If it is possible to assign the substance to a chapter but not to a substance category, then it shall be categorised in a 99 sub-category.

17 Construction and demolition waste				
1701 Concrete, bricks, tiles, ceramics	17 01 01 Concrete	17 01 02 Bricks	17 01 03 Tiles, bricks, ceramics	17 01 07 Mixes of concrete, bricks, tiles, and ceramics with the exception of those mentioned in 17 01 06*
1703 Bitumen mixes, coal tar, and tar products	17 03 02 Bitumen mixes with the exception of those mentioned in 17 03 01*			
1705 Soil, stones, and dredged material	17 05 04 Soil and stones with the exception of those mentioned in 17 05 03*	17 05 06 Dredged material with the exception of that mentioned in 17 05 05*	17 05 08 Track ballast with the exception of that mentioned in 17 05 07*	
1709 Other construction and demolition waste	17 09 04 Mixed construction and demolition waste other than those mentioned in 17 09 01*, 17 09 02*, 17 09 03*			

Fig. 2.2: Sources of mineral waste

The occurrence figures enable statements to be made on the absolute or specific quantity of construction waste. Their purpose is:

- to plan capacities for recycling or disposal,

[4] Ordinance on the European List of Waste, AVV of 10 December 2001

- to record the substitution potential of natural resources
- and to determine recycling rates.

Material recycling or substance recycling

Material recycling is subdivided into recycling and reutilisation measures.

- Recycling (restructuring of the product's shape)

  This refers to the reuse of construction and demolition waste, such as processing construction waste in recycling plants to manufacture RC construction materials and their secondary utilisation in buildings and structures.

  Recycled construction materials (RC construction materials) are mixtures of aggregates that have already been used in bound or unbound form.

- Reutilisation

  This includes, for example, utilisation of excavated material as backfill material without processing in the sense of shredding material. Only a sieving process is carried out.

Product recycling

Product recycling includes reuse and reutilisation measures.

- Reuse (retention of product's shape; up-cycling)

  Reuse involves repetitive use of a construction product in its original shape and form. This applies, for example, when construction elements are removed or dismantled/disassembled and reused for the same or similar purposes for which they were originally intended.

- Subsequent use

  Repurposing includes the reuse of dismantled construction elements for other (secondary) purposes, e.g. wall elements from residential buildings are used to construct noise barriers.

2.2 Classification of product and material recycling in circular economy

It was the Closed Substance Cycle and Waste Management Act (KrW-/AbfG), which came into force in October 1996, that laid the foundation for the closure of material cycles. The purpose of the Act is to promote low-residue circular economy for the conservation of natural resources and safeguarding the environmentally sound disposal of unavoidable waste (Section 1 KrW-/AbfG). Consistent material flow management is required in order to comply with the requirements of the Closed Substance Cycle and Waste Management Act (KrW-/AbfG). Consequently, substances and products should be kept in the smallest cycles possible for maximum length of time in order to utilise the applied substances (material and energy) as far as possible or use them up completely (see Fig. 2.3).

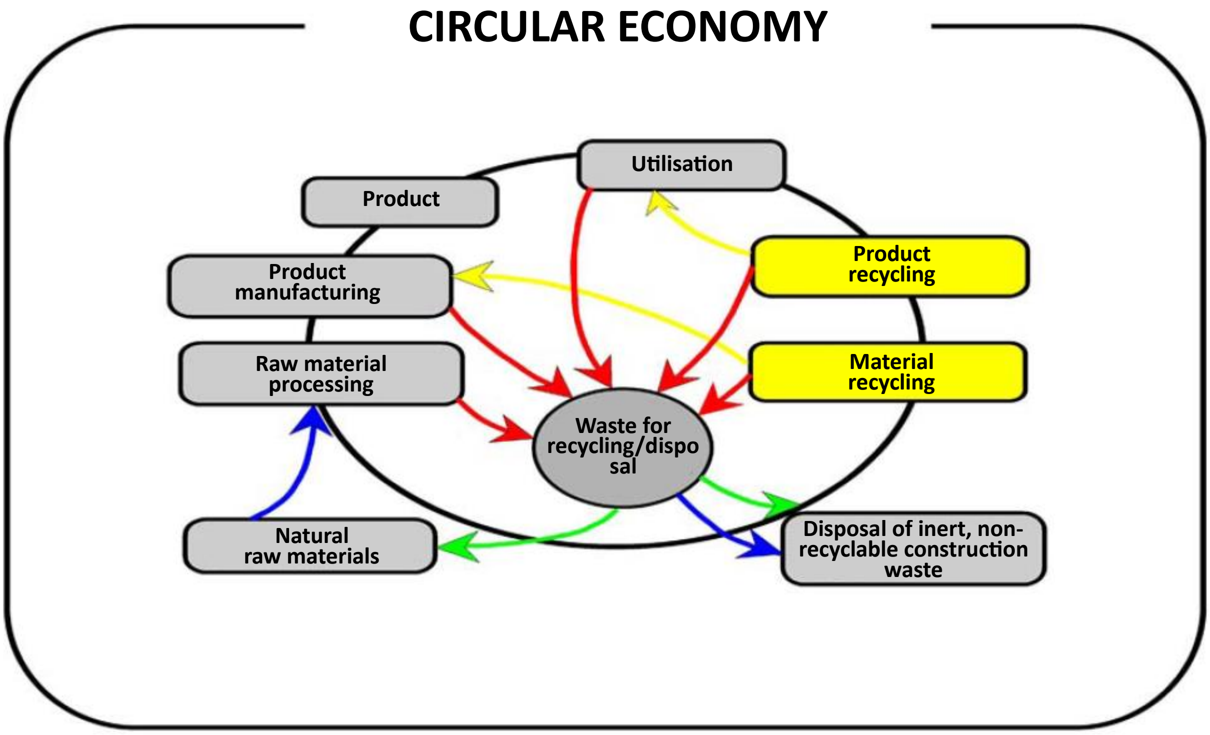


Fig. 2.3: Visualisation of the targeted circulation system

Controlling the circular flow of materials from raw material – construction material – building component – building structure – construction waste indicates that it has been recognised that waste can be classified as utilisable along with its inherent values. Although it is not possible to achieve a completely waste-free circulation system in practical conditions, product recycling can significantly reduce the waste stream nonetheless, i.e., the generation of waste can be prevented if the component is reused as a component. The benefit of this is that the objectified added value in the components is retained and at the same time the "environmental consumption" associated with new production is limited.

The following diagram (Fig. 2.4) is meant to demonstrate which measures can be used in the construction industry to fulfil the overriding goal of environmental protection – the primary focus on the precautionary principle.

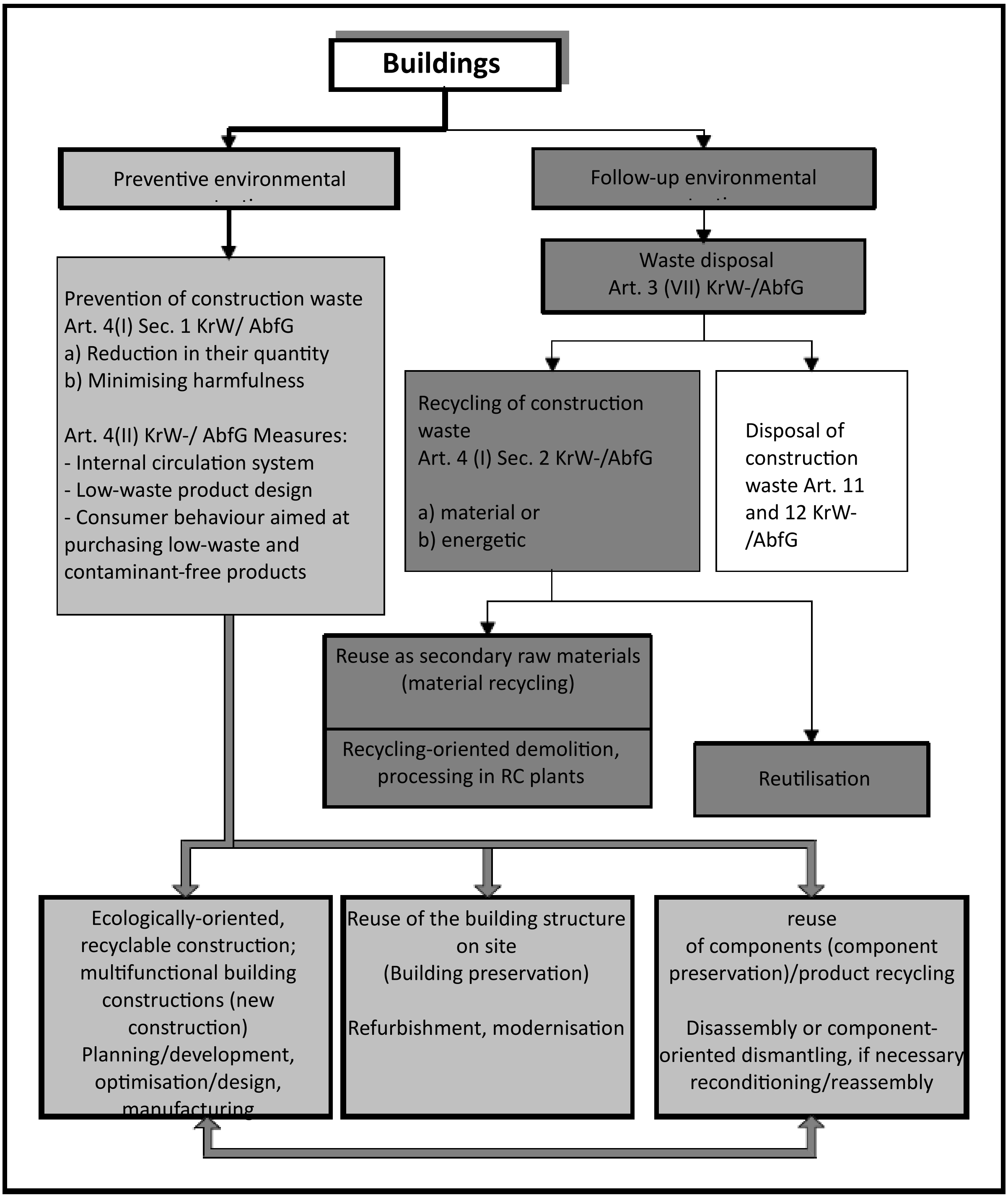


Fig. 2.4: Allocation of measures for the sustainable development of buildings, including relevant regulations of the KrW-/AbfG

The following are considered as **prevention opportunities at source** with regard to the reduction of the quantity and/or hazard level of waste and emissions in the construction industry (see Fig. 2.4):

1. **Construction of multifunctional structures** from the perspective of ecologically-oriented and recycling-friendly construction by

   - using environmentally friendly construction products (product changes or modifications),
   - change or modification of the manufacturing process and the process itself as well as
   - changes in the use of raw materials and operating materials,
   - change in the methods of construction.

2. **Subsequent and continued use of buildings**

   in terms of building preservation (maximising the durability of components, land coverage, etc.)

3. **Reuse and further utilisation of construction products (product recycling)**

   from the perspective of preserving construction products in their original form to the greatest possible extent and reusing them subsequently as construction products (conservation of resources, utilisation of the durability of components, etc.).

Furthermore,

4. **recycling measures inherent to the plant or production processes**

   contribute to waste prevention, if

   - production waste is reintroduced into the production process (production waste recycling), such as the recycling of sand-lime brick - fractured material for sand-lime brick production or recycling of surplus concrete mixtures by processing them in concrete and precast concrete plants for the use of aggregates or recycling of plastic waste for the production of construction foils, i.e., waste materials are used for the same or a different production process.
   - Substances or emissions are recirculated in the plant (plant-internal recirculation), such as the recirculation of used and treated water in construction material recycling plants for wet separation of recyclates.

The intention is, on the one hand, to highlight the fact that buildings should comply with more multifunctional requirements in future by being ecologically-oriented and recycling-friendly (cf. Chap. 10). The terms 'construction ecology', 'eco-construction' or 'environmentally friendly construction' are synonymous. The goal is incumbent upon comprehensive improvement in the environmental compatibility of construction. Addressing issues such as consumption of raw materials and energy, compatibility of construction materials, maintenance of buildings, their renovation and disposal of construction waste are just as relevant as the intangible objectives of construction in order to minimise the impact on the ecosystem as far as possible. Therefore, all planning and construction decisions - in comparison to conventional construction planning - must also be reviewed with regard to environmental compatibility.

Consequently, the target of construction projects should increasingly focus on ecologically optimised and sensible solutions and not on cost-effective investment solutions, as this is currently the case.

Nevertheless, the option of retaining buildings on site after the end of their utilisation period should actually be given more consideration than it is currently the case in many instances. Decisions to eliminate buildings that either aren't physically worn or are only slightly worn, or merely aesthetically deteriorated, are far too often made with the assumption that modern replacement buildings must be constructed or vacancies need to be reduced. Hardly any relevance is given to the idea of environmental protection, as even if refurbishment or modernisation measures are required, it is possible to integrate the existing building stock to create sophisticated, contemporary, modern solutions. An obvious advantage here is that the added value of the product (building) is preserved, even if not always in its entirety.

If buildings cannot be reused or have become superfluous, the first step in the case of buildings scheduled for dismantling should be to examine the extent to which at least the added value of the products (components/construction elements) can be retained. In other words, the question must be clarified as to whether the used products can be used for secondary purposes or can be reused and/or recycled. The question of recycling should only be investigated if the answer regarding reusability is negative (subsequent environmental protection).

The common feature of all the aforementioned precautionary options is the realisation of the idea of prevention. The formation of (construction) waste should be prevented, energy and material flows should be reduced, and materials that are contaminated or harmful should be avoided or treated selectively.

Accordingly, circular processes run on different levels[5], among others:

- as internal industry cycles within the construction industry:
  - in-house recycling: plant-internal and production process-internal circulation of construction materials and/or emissions,
  - off-site recycling: Circulation of construction materials and/or emissions outside the company or utilisation of construction waste as secondary raw materials, e.g., for the production of the so-called concrete chippings,
- as a construction industry with a consumer cycle or as a consumer-construction industry cycle based on the interaction between the construction industry and the consumer:
  - sale of (used) construction products that have been in use as replacement for new products, such as the reuse of refurbished parquet flooring, doors or prefabricated concrete elements (hollow planks, ceiling panels, inner wall panels, etc.),
  - sale of recycled construction materials as a substitute for primary raw materials such as brick chippings utilised in soil substrates for green roofs,
  - recovery of used construction materials and construction products in the construction industry, such as plasterboard in the plasterboard industry for remanufacturing.

[5] cf. Moser, Franz: Kreislaufwirtschaft und nachhaltige Entwicklung, in: Produktions- und produktintegrierter Umweltschutz, Brauer, Heinz (ed.), Berlin et al., 1996, pp. 1072, 1076

In summary, it can therefore be stated that moving towards closed material cycles, which is the intention behind the circulating management of materials and products, is one of the methodological components of the integrated environmental protection concept. Although the term "sustainability" does not appear anywhere in the Closed Substance Cycle and Waste Management Act, it pursues a resource-economic approach and contains various information on how to implement this concern.

2.3 Basic data on the building stock

The building stock in Germany amounts to almost 19 million buildings, thereof 17.3 million residential buildings and 1.5 million non-residential buildings.[6] The value is estimated at EUR 8.1 trillion, including EUR 4.5 trillion or 55.34% accounted for by residential buildings and EUR 3.6 trillion or 44.66% by non-residential buildings (as of 2002).

The housing stock amounts to a total of almost 40 million apartments. The housing stock in the former federal territory comprises around 29.687 million residential units and around 8.867 million residential units in the new federal states including Berlin.[7] Categorised by the year of construction, the majority of the residential units was built between 1949 and 1978 (before the first Thermal Insulation Ordinance) (see Fig. 2.5).

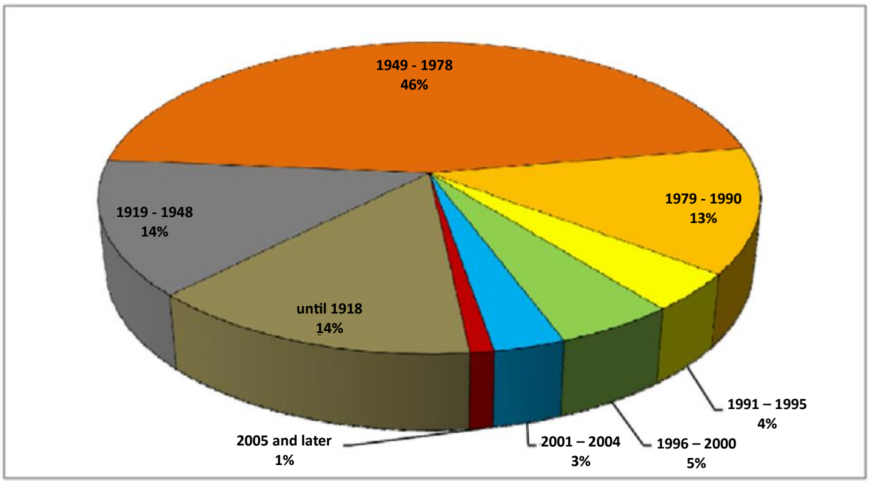


Fig. 2.5: Residential units in buildings with living space according to the year of construction

The proportion of residential units in rented accommodation in the new federal states, including Berlin, totalling 4,652 million in 2006, according to the year of construction was as follows:[8]

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[6] www.bmvbs.de/klima-Umwelt-Energie/Bauen-Wohnen...accessed on 17.11.2008 7

[7] Federal Statistical Office, Statistical Yearbook 2008. p. 289

[8] Federal Statistical Office, Statistical Yearbook 2008, p. 292

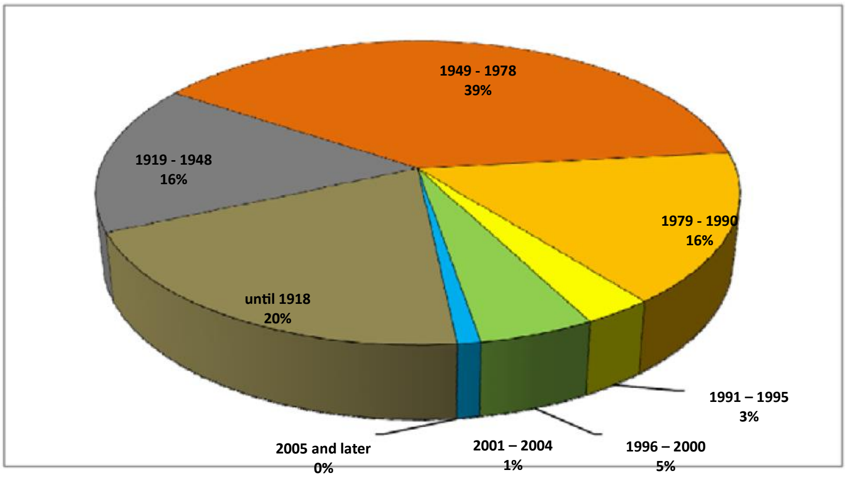


Fig. 2.6: Proportion of residential units in rented accommodation by the year of construction in the new federal states (as of 2006)

The figures show that the largest proportion of rented residential units (around 54%) was constructed between 1949 and 1990.

Since the end of the 1950s, a large number of residential units in the GDR have been industrially constructed. Out of a housing stock of over 8 million residential units, 2.17 million units have been constructed in series – which is an above-average number of new-build flats in multi-storey, prefabricated residential buildings when compared with other countries.

An overview of the scope of application of the residential units erected in various construction series is provided in Table 2.1 below.

Tab. 2.1: Number of residential units in prefabricated systems by type series, year of construction and federal state (SCHULZE, 1996)[9]

Construction method	Year of constructio n	Berlin	Brandenburg	Meckl.-Vorp.	Saxony	Saxony-Anhalt	Thuringia	Total
Block 0.8 t	1958 - 1990	28,600	118,800	91,300	200,400	94,600	88,700	622,400
Block 1.1 t	1976 - 1990	600	11,000	16,700	8,800	8,200	1,800	47,100
Total block		**29,200**	**129,800**	**108,000**	**209,200**	**102,800**	**90,500**	**669,500**
Strip 2.0 t	1958 - 1990	3,300	7,100	0	17,900	1,500	13,200	43,000
Total strips		**3,300**	**7,100**	**0**	**17,900**	**1,500**	**13,200**	**43,000**
Panel 3.5 t	1958 - 1990	0	35,600	0	44,400	0	6,000	86,000
P1	1958 - 1970	3,000	5,000	0	0	0	4,500	12,500
P2 (only 5.0 t)	1958 - 1990	16,400	81,700	21,700	66,500	88,400	88,900	363,600
P Hall	1958 - 1990	0	44,600	65,900	0	37,600	0	148,100
QP	1958 - 1985	35,000	4,100	0	3,000	500	0	42,600
WBS 70	1971 - 1990	140,000	44,200	84,600	181,800	116,200	78,100	644,900
Other 5.0 t and 6.3 t	1958 - 1990	23,100	16,200	15,800	55,000	19,600	32,100	161,800
Total panel		**217,500**	**231,400**	**188,000**	**350,700**	**262,300**	**209,600**	**1,459,500**
Total prefabricated construction		**250,000**	**368,300**	**296,000**	**577,800**	**366,600**	**313,300**	**2,172,000**

[9] Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäudeteilen, Materialien zur Abfallwirtschaft 1999, on behalf of the Saxon State Office for Environment and Geology in the Free State of Saxony, BTU Cottbus 1999, p. 8

The industrially manufactured residential buildings, commonly known as prefabricated buildings, still determine the urban image of many cities and communities in eastern Germany today.

The statistical data on the building stock shows enormous economic potential. In terms of energy and resources, the building stock represents a crucial sector with regard to sustainability in construction.

For the purposes of the research, the years of construction from the end of the 1950s to the turn of the millennium in eastern Germany are of particular interest, as they are eminently affected by vacancy or, if they are not already vacant, require an energetic modernization. Sustainable and energy-efficient construction is an important measure to meet the federal government's construction policy objectives. Therefore, it is essential to establish scientifically sound and future-proof innovative solutions for construction in and with the existing building stock and to implement them in practice.

3 Vacant flats – dismantling concepts of the housing industry

The following section discusses the necessary stock changes in the housing industry with reference to [9], [14], [15], [16], [17], [39], [40], [42], [44], [57].

This section traces the development of vacancies in the new federal states.

3.1 Vacant flats in the new federal states of Germany

3.2 Causes of vacancy

3.3 Responsibilities of cities and the housing industry

Dealing with the vacancy problem is a highly complex matter, therefore comprehensive and thorough problem analyses must be carried out on site before action plans can be drawn up. In a position paper published in September 2000, the German Association of Cities[28] outlined the following important tasks:

1. Preparation of municipal action plans with the aim of permanently promoting inner-city development and counteracting urban sprawl.

2. The municipal action plans are meant to provide the basis for decision-making on how to reduce the housing surplus.

3. The unavoidable demolition/dismantling has to be organised in such a way as to improve the quality of the environment as well as the living standards and residential surroundings in the cities.

In order to achieve these objectives, the following procedures have been requested:

- rapid joint development (cities and housing associations) of the necessary municipal action plans,

- solidarity expressed by all major local housing enterprises,

- control of vacancies within cities, as uncontrolled vacancies lead to further loss of the city's attractiveness and interested parties lose their willingness to invest,

- extensive public debate on all measures, offering people the opportunity to participate and contribute.

Furthermore, the German Association of Cities emphasised that vacancy management should be financially supported by the federal and state governments. Apart from this, there were calls to strengthen the promotion of existing buildings as opposed to new construction, the provision of urban development funds and the cancellation of old debts.

The resulting tasks for cities are both new and challenging, as a new type of urban development planning needs to be conceived and implemented. The downsizing process needs to be managed. The development of the population and households has to be forecast, vacancies and the expected construction of new flats need to be analysed. This forms the basis for decision-making on necessary

[28] The Association of German Cities (DST) is the largest municipal umbrella organisation in Germany, representing the interests of independent and district cities. 4.100 Städte und Gemeinden mit 51 million Einwohnern haben sich zusammengeschlossen [www.staedtetag.de, accessed on 28 November 2008]

demolition and dismantling measures, determining upgrading measures for old and prefabricated buildings, assessing space requirements and their location for new construction measures and developing concepts for the utilisation or subsequent use of vacant space. This means that local authorities are taking on an increasing responsibility.[29]

[29] cf. Pfeiffer, Ulrich; Simons, Harald; Porsch, Lucas: Wohnungswirtschaftlicher Strukturwandel in den neuen Bundesländern, Report of the Commission, Nov. 2000, p. 8, 77 f., 92

3.4 Strategies for combating vacancies in industrially constructed residential buildings

The following strategies (individually or in combination) are generally possible when addressing the issue of vacancies:

STRATEGY 1 - PRESERVATION AND MODIFICATION OF BUILDINGS (UPGRADING)

Partial deconstruction, modernisation and refurbishment measures, merging of flats, conversion

There are numerous ways to create user-friendly offers. They range from floor plan changes for creating larger living spaces to the merging of flats (vertically into maisonettes, horizontally by opening doorways). The floor plans can be modified in such a way that barrier-free requirements are also complied with in order to utilise the flats in age-appropriate and disabled-friendly manner. The structural design of prefabricated construction provides an advantage in this aspect. The large span width of the supporting structure allows for flexible room layouts. Partition walls and non-load-bearing walls can be removed and/or lightweight walls can be erected if necessary. The relocation of kitchens and bathrooms (e.g. P2 type) without windows to the outside wall provides for additional improvement in the quality of living.

Concierge solutions (Fig. 3.11) provide for a service that is well received by the residents. Tenant gardens are another way to increase the quality of living (see Fig. 3.12).

Fig. 3.11: Concierge, Cottbus

Fig. 3.22: Tenants' gardens, Berlin

Conversion of flats for commercial or service purposes, for example (see Fig. 3.13 and 3.14) may also contribute to the stability of a residential area.

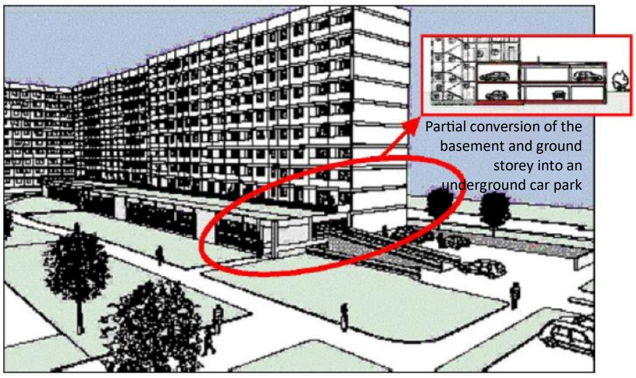


Fig. 3.13: Residential building with an underground car park
(Design: S & P Sahlmann)[34]

Fig. 3.14: Residential building with an underground car park in Plauen (Planning: Prof. W. R. Eisentraut)

Structural alterations involving the reduction of storeys are a real alternative to the retrofitting or installation of lifts in five and six-storey buildings. Terracing not only loosens up the urban landscape, but also significantly improves the quality of living.[35] Apart from reducing the number of storeys, the removal of sections/thinning out of city squares (see Fig. 3.15) offers a further possibility for eliminating surplus flats in the industrially manufactured residential buildings. This measure is also intended to break up former monotonous structures, with the added value of the improved lighting conditions for the remaining flats and reduction of the noise emissions.

Fig. 3.15: Dresden-Gorbitz "Kräutersiedlung"[36] - old condition (left), interim status (middle), condition after dismantling (right)

Partial dismantling/deconstruction and modernisation of the remaining stock counteracts vacancy rates while preserving capital and increasing the asset value. Moreover, the existing technical infrastructure (roads, paths, lighting, media, etc.) can be further utilised. De-densification and modifications /staggering of building heights improve the urban development of residential areas. The former settlement structure is transformed into a completely new quality. The existing building stock can basically be further utilised, yet a change in the building forms and the range of flats on offer can also be achieved.

[34] s. Mettke, Angelika (ed.): Anwenderkatalog II - Plattenumbauten, Wieder- und Weiterverwendung, Cottbus, 2003, p. 56
[35] Eisentraut, Wolf Rüdiger: Plattenbausiedlungen. Nutzung der Substanz und nachhaltige Umgestaltung, in: Beton- und Stahlbetonbau 96, July 2001, p. 518
[36] s. Hesse, Jürgen: Erfolge und Probleme des Stadtumbaus am Beispiel Kräutersiedlung Dresden-Gorbitz, contribution to the conference proceedings "Alte Platte - Neues Design - Die Platte lebt", Cottbus, 2005, p. 67

One further decisive advantage of partial deconstruction is the fact that, in addition to preservation and continued utilisation of the existing building fabric, the question of further use of the dismantled construction elements can be addressed (see Chap. 7).

STRATEGY 2 - REMOVAL / ELIMINATION

Demolition of individual buildings or large areas

Complete demolition of individual blocks of flats, rows of flats, entire streets or residential areas is a common practice (see Fig. 3.16). This is because traditional demolition methods incur lower costs as compared to partial deconstruction, while housing companies with a vacancy rate of 15 % are also affected by the Old Debt Assistance Act. However, exclusive concentration on this strategy is not sufficient. After all, it is impossible to satisfy the urgent pressure to act, especially with regard to upgrading.

Fig. 3.16: Demolition of an 11-storey P2 type building by means of a hydraulic excavator and long front boom in Cottbus-Sachsendorf, 2003 (left); by means of a hydraulic excavator and demolition boom in Cottbus-Stadtring, 2007 (right)

STRATEGY 3 - CLOSURE

Securing/locking blocks of flats or individual flats

The closure of individual flats or top storey(s) in a block of flats is another alternative for the reduction of surplus flats. The top storey serves as an attic or is often used as hobby room by the residents.

Vacating and sealing off entire blocks of flats is conceivable, though it also incurs costs for securing the buildings. Even temporary closures are not exempt from this.

If buildings remain vacant for a long period of time and are not adequately secured and maintained, enormous structural damage - not least caused by vandalism - and unwanted tree growth may occur. Such buildings are subject to structural decay.

From the perspective of the housing industry, there are economic (costs, revenues, changes in value) and social consequences that arise depending on the chosen strategy. These include[37]

- if the decision is made to demolish/dismantle (= strategy 2):
  - costs for decommissioning of supply and disposal media,
  - costs for tenant relocations (relocation compensation, vacancy premiums, preparation of new flats)
  - costs of demolition (planning, authorisation, execution, disposal),
  - loss of rental income,
  - servicing debt (interest and amortisation of residual debt, mortgages),
  - capital loss,
  - improvement in liquidity after demolition due to e.g. reduced property tax for undeveloped land, reduced management and administration costs,
  - social erosion due to declining identification with the remaining housing stock in the neighbourhood, etc.,
- if the decision is made to partially deconstruct and maintain the remaining stock including its modernisation (= strategy 1):
  - kosts for partial decommissioning of supply and disposal media,
  - costs for any temporary tenant relocation (creating interim use options, relocation compensation) if partial deconstruction and modernisation is carried out in unoccupied state; possible temporary loss of rental income,
  - temporary loss of rental income,
  - dismantling and modernisation costs,
  - costs for improvements to the quality of the housing surroundings,
  - servicing debt,
  - the capital value is increased after completion of the measures,
  - stabilisation of rental income,
  - satisfied tenants who identify with their residential neighbourhood,
- If the decision is made to close the existing stock (= strategy 3):
  - costs for tenant relocations,

[37] No claim is made as to its completeness

- costs for decommissioning of supply and disposal media,
- costs for technical security of the building as well as for maintenance,
- loss of rental income,
- servicing debt,
- danger of social erosion.

The conclusion to be drawn is that Strategy 1 (partial deconstruction with upgrading of the remaining housing stock coupled with sensible reuse of the remaining components) is far more interesting and sustainable solution for urban redevelopment as compared with demolition (Strategy 2) and closure (Strategy 3). One of the main advantages of partial deconstruction is that infrastructural facilities such as roads, paths and supply media can still be used. There is also evidence that prefabricated buildings can be reshaped or modified to become marketable. This applies to the dissolution of the formerly monotonous appearance as well as to changes in the floor plans/flat layouts corresponding to the actual demand. The former contributes to loosening up the stringent building structure and reducing the building density, as well as improving the lighting and noise conditions.

Moreover, if the construction components resulting from partial deconstruction are reused for secondary purposes, this results in synergies in both economic and ecological terms (see Chap. 7 and 8).

Demolition measures (strategy 2) cannot be avoided or are justified if they improve the quality of the urban development or if it is necessary to counteract building decay.

Closure of buildings is an equally unsustainable solution. It can be assumed that even closure of the top storey of a residential building will be restricted to exceptions.

It becomes clear here that demolition/dismantling is not least associated with the problem of adequate waste and product treatment.

3.5 "Urban Redevelopment East" program - a key element in shaping shrinking cities and municipalities

4 Dismantling of prefabricated buildings - feasibility, requirements, selected results

The following section deals with crane-based dismantling of buildings constructed by means of the assembly method. The results of the research are based on investigations accompanying the dismantling of various building types at several locations in the new federal states. In this regard, reference is made to the publications [6], [14], [16], [19], [24], [25], [28], [29], [33] to [37], [40], [46], [51], [54], [57], [58].

4.1 Introduction and basic information on dismantling

Crane-based dismantling of industrially manufactured buildings is a special form of demolition (see Fig. 4.2) and the only technology that can be considered in order to avoid damage to the remaining building stock. Sectional or partial deconstruction measures are carried out either horizontally by dismantling individual storeys and/or vertically by removing individual building segments (see Fig. 4.1) or connectors. Furthermore, it is also possible to open up parts of the façade by disassembling individual outer walls. The aim here is to enlarge certain living spaces, for example by constructing bay windows.

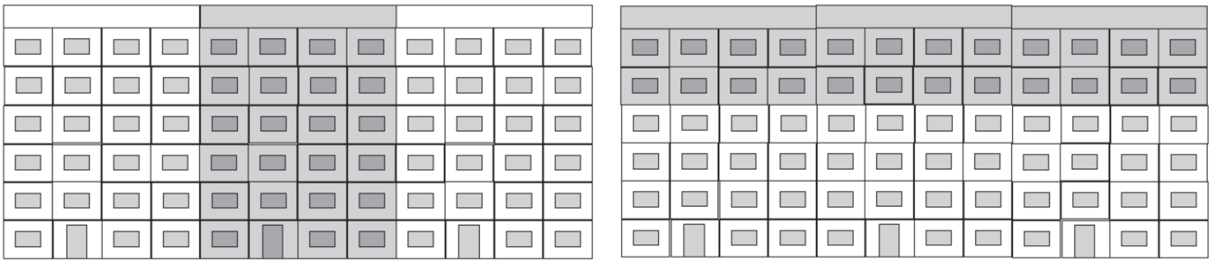


Fig. 4.1: Schematic representation of possible partial deconstruction alternatives

In general, crane-guided dismantling is not considered for the removal of entire buildings unless specific conditions such as contaminated building materials, usage-related restrictions or design requirements make it necessary. In comparison to conventional demolition, crane-based dismantling requires more extensive planning, preparation and execution due to the increased technical, technological, and safety requirements.

In the early years, dismantling measures were generally carried out in unoccupied properties, whereas in the recent past there has been an increase in such operations being carried out on buildings that still were occupied. The removal of the upper storeys in occupied condition safeguards the tenant base, thus serving the commercial interests of the housing companies and also supports the development of new architectural qualities, thus facilitating urban development.

Dismantling in occupied conditions can be implemented with or without a safety storey.[41]

[41] cf. Primm, Ingolf: Rückbau unter bewohnten Bedingungen sicher und wirtschaftlich bewältigen – Vorbereitung, Handlungsoptionen, Medienversorgung – Fallbeispiel Meerane, in: conference proceedings „Alte Platte – Neues Design“ part 2, ed. Angelika Mettke, 2008, pp. 47-59;
Gottschling, Dietmar: Rückbau unter bewohnten Bedingungen sicher und wirtschaftlich bewältigen am Fallbeispiel Meerane – aus Sicht der Baurealisierung, in: conference proceedings „Alte Platte – Neues Design“ part 2, ed. Angelika Mettke, 2008, pp. 61-63. However, this special feature will not be discussed in detail here. Additional sources of reference are: Mettke, Angelika; Sören Heyn; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, 2008, pp. 161 ff.

Initially, the focus of the scientific research on dismantling was to analyse whether the industrially constructed residential buildings were actually suitable for dismantling. The reason for this is that the building series were a priori not constructed with potential dismantling in mind (see Tab. 2.1; Fig. 4.3, 4.4). The question of innovative value and promising solutions on their way from planning to construction practice could only be actively pursued in the second instance. At the same time, adequate aspects of high-quality subsequent utilisation were investigated with the support of independently developed decision-making aids (see Chap. 6 to 8).

4.2 Clarification of the term "dismantling"

Before discussing selected aspects of dismantling of industrially manufactured buildings, technical terms need to be clarified in order to eliminate misunderstandings and different interpretations among experts. In practice, dismantling is often equated with selective demolition. The following explanation demonstrates that this is not the case.

Dismantling is a special form of demolition (see Fig. 4.2) and is specified by the crane-based or component-oriented operations. Crane-based dismantling is synonymous with a disassembly.

According to DIN 18007[42], disassembly is defined as follows: "The components are separated from each other by loosening the connections and then removed in a non-destructive manner." Main areas of application for disassembly are the reduction of contaminant releases and safeguarding for secondary utilisation.

Crane-based dismantling or disassembly[43] is therefore a controlled process for the systematic dismantling or removal of buildings erected using prefabricated/assembled construction methods with the support of lifting equipment or systems. It corresponds to the totality of all processes that are used for detachment of products into components by means of separation. Basically, disassembly is the opposite process to assembly, whereby special technical, technological and safety features are considered. The components are separated from each other by loosening the connections and/or opening the joints and removed without causing damage.

Dismantling and disassembly work is characterised by the following:

- the property is/can be entered and/or operated on while the measure is in progress,
- in addition to the use of lifting equipment, manual and mechanical demolition procedures are required (e.g. boring, autogenous flame cutting),
- uncovering the load-bearing eyelets of the concrete elements, opening the joints and cutting through the connections.

[42] DIN 18007: 2005-05 Abbrucharbeiten – Begriffe, Verfahren
[43] Mettke, Angelika (ed.): Rahmentechnologie, Rückbau- / Demontagevorhaben Plattenbauten, 2004, p. 8

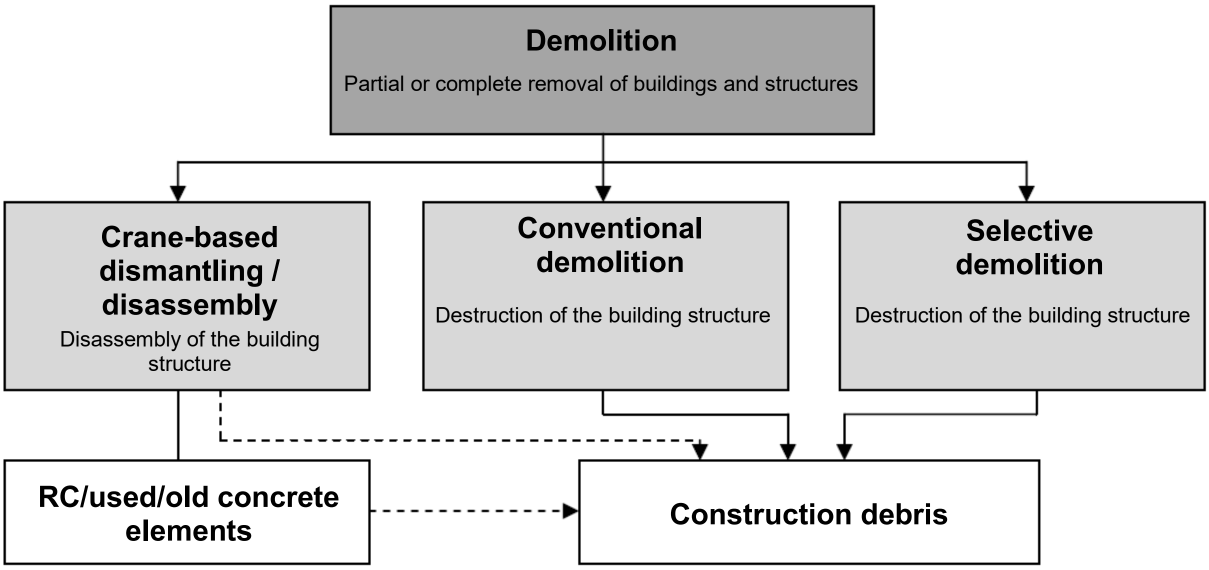


Fig. 4.2: Schematic representation of the categorisation of crane-guided dismantling as a specific form of demolition

The crucial difference between dismantling/disassembly and selective demolition is that in the former the building structure is carefully dismantled while in the latter the building structure is destroyed.

Selective demolition differs from conventional demolition in the way that clearing and internal installation removal are mandatory in order to enable construction materials and substances to be collected and disposed of according to their specific category. However, in the case of conventional demolition, there are no such mandatory requirements.

Partial demolition and partial dismantling are understood as a partial demolition or partial dismantling of certain building sections, building parts or components without jeopardising the stability of the remaining building stock. While demolition – either complete or partial – always results in the destruction of the building structure, partial deconstruction preserves the structure.

Complete demolition or total demolition means the complete removal of a building or structure.

4.3 Structural characteristics of industrially constructed residential buildings in the new federal states

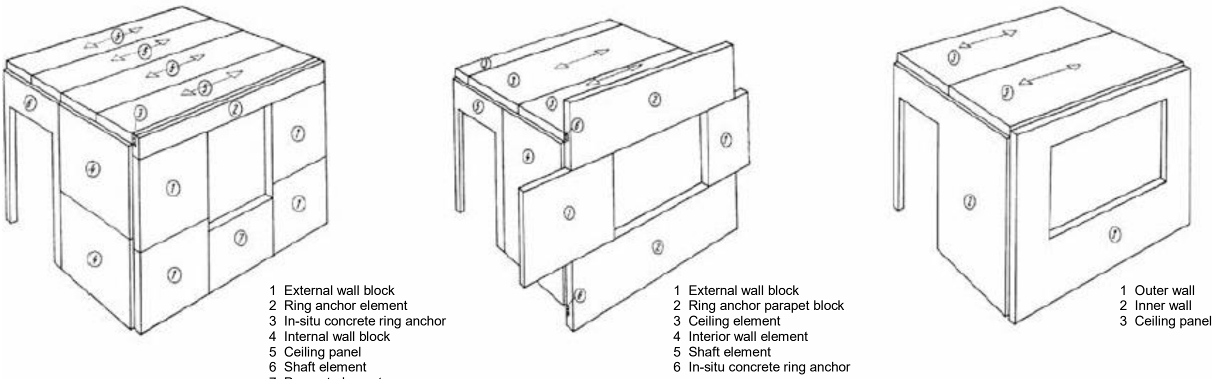
The following section focuses only on a few selected structural features that are relevant for both disassembly and reassembly (cf. Chap. 7).[44]

The predominant construction system in industrial housing construction is the wall construction method. Residential buildings were only occasionally erected in reinforced concrete skeleton construction or as an assembly building with a sliding core, as a room cell construction or by means of the lift-rod method (ceiling lifting method). However, combinations of wall and skeleton construction methods, such as residential buildings with functional underpinnings, were also constructed.

[44] The structural features are comprehensively described in Rahmentechnologie Rückbau-/ Demontagevorhaben Plattenbauten - exemplified by the type series P2, ed. Angelika Mettke, 2004, pp. 28-38 and in: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, Angelika Mettke et. al., 2008, pp. 22 - 117.

The development of industrialised housing construction in the GDR took place in several stages, from block construction through strip construction to prefabricated construction or large panel construction[45] (cf. Fig. 4.3). The advantage of the wall construction method is the favourable coupling of partition and load-bearing elements.

Block construction | **Strip construction** | **Prefabricated construction**



Block construction:
e.g. IW 64, Q3A, Q 6

- constructed between 1958 and 1990,
- Load levels 0.8t; 1.1t,
- Large number of different elements (approx. 150 elements per residential unit)

Strip construction:
e.g., IW 72

- constructed between 1964 and 1990,
- Load level 2.0 t,
- approx. 65 elements per residential unit

Prefabricated construction:
e.g., WBS 70, P2, PN 36-NO, WBR Erfurt

- constructed between 1966 and 1990,
- Load levels 5.0 t; 6.3 t; 9.0 t,
- approx. 30 elements per residential unit

Fig. 4.3: Structural principles of industrial construction types in residential construction in the new federal states

Each of the constructed series of buildings is characterised by

- standardised components,
- standardised load levels for prefabrication, transport and assembly,
- high degree of prefabrication.

We are therefore faced with a large number of similar buildings that allow for general procedural solutions for dismantling.

The main differences between the construction types (old designation: construction methods) can be summarised as follows:

[45] according to: IEMB: Leitfaden für die Instandsetzung und Modernisierung von Wohngebäuden in der Plattenbauweise – Blockbauart 0,8t/ - Blockbauart 1,1t/ -Typenserie P2, 5,0t, ed. Federal Ministry for Regional Development, Construction and Urban Development, 1992/93

Block construction is characterised by a large number of different elements (approx. 150 units per flat (residential unit), only half-storey-high wall blocks), which were assembled in a relatively long construction period (≈ 0.6 residential unit per shift with 7 work units).

The load-bearing walls are formed from elements that are ≥ 0.80 m high and ≥ 0.70 m wide. Within one storey, only up to three wall elements are arranged vertically. The proportion of manual labour, especially for the formation of the reinforced in-situ concrete ring anchor, the numerous horizontal and butt joints as well as the subsequent fitting (windows, doors), was very high due to the low degree of prefabrication and the poorly developed completion of the elements. Block construction was used for the construction of buildings with three to five storeys (two or three residential units per storey).

Further development of the block construction method resulted in wall structures of load level 2.0 t in **strip construction**. The inner wall elements are storey-high; the strips are between 1.20 m and 1.80 m wide and approximately 5 m² in size. Due to the higher load level, only 65 components per residential unit were required, so that 0.9 to 1.1 flats could be built per shift.

The **prefabricated construction method** (also known as large panel construction) introduced in Hoyerswerda in 1957 is superior to the construction methods described so far. The prefabricated construction method with load levels of 5.0 t, 6.3 t and also 9.0 t (room cell construction methods such as 'Niesky 69', 'Dresden II', 'Oranienburg') is characterised by the room-sized outer- and inner walls, half-room-sized ceiling panels, large roof panels, a systematic reduction of special elements and high degree of completion. As a result, an average of only 30 elements per residential unit were required resulting in the construction of 1.1 to 1.4 residential units per shift. The elements are connected by means of welding and mortar joints (see Fig. 4.4).

The connection of the prefabricated elements to form stiffening plates was carried out storey by storey by means of ring anchors, which were arranged within the lintel reinforcement in the outer walls and connected to the ring anchor reinforcement of the inner walls by means of welding.

In the case of multi-storey buildings (11 storeys or more), a second 'belly tie' ring anchor is also arranged in the inner and gable walls - connecting the outer walls at parapet height. The front sides of the walls are interlocked to transmit the shear forces (teeth with round steel loops that overlap and are 'sewn' together).[46]

[46] Mettke, Angelika: Stadtumbau durch Rückbau von Plattenbauten und (Wieder-)Neubau, presentation on 21 September 2001 in Travemünde on the occasion of the demolition conference of the German Demolition Association

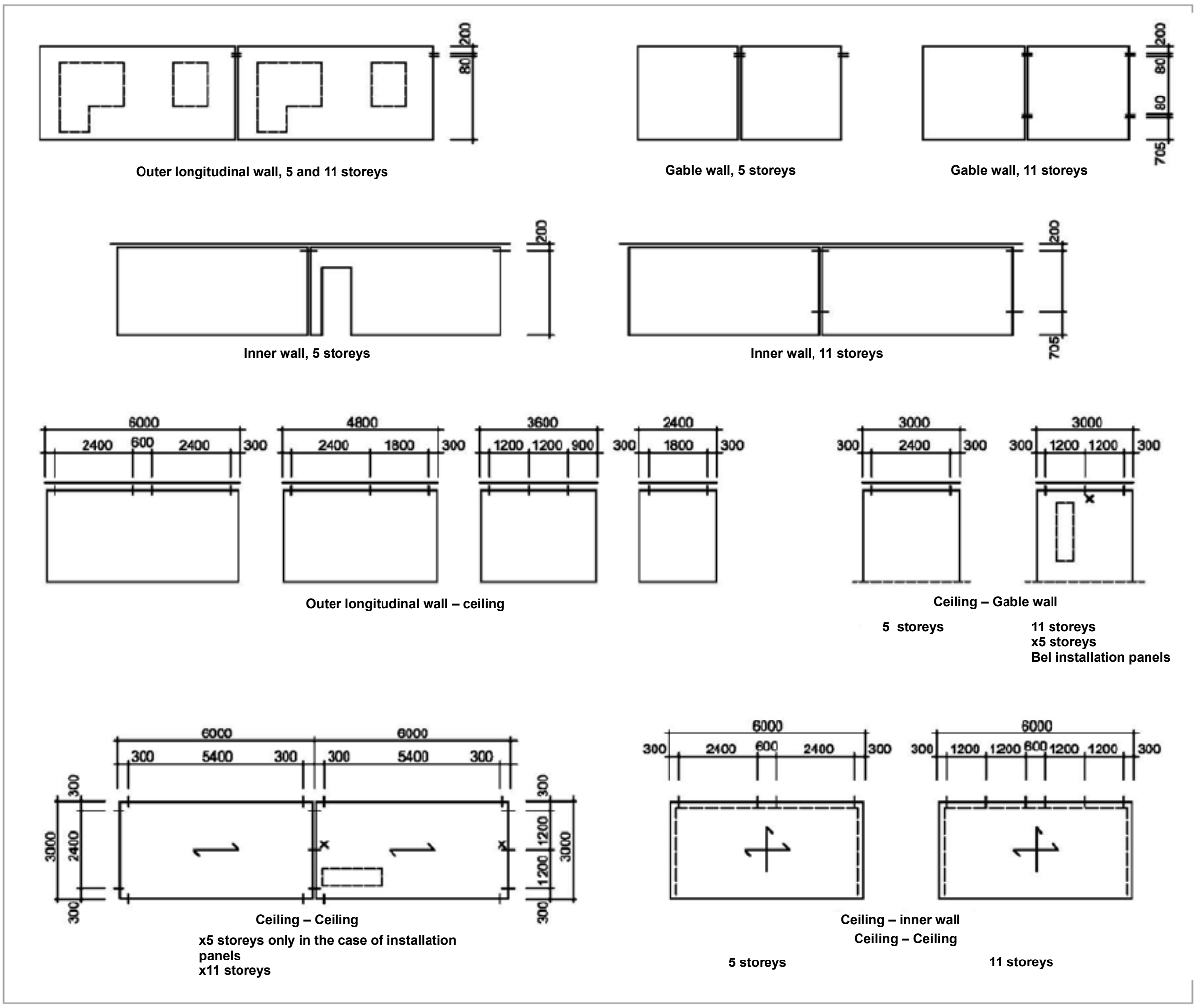


Fig. 4.4: Schematic representation of the location of welded joints in prefabricated components[47]

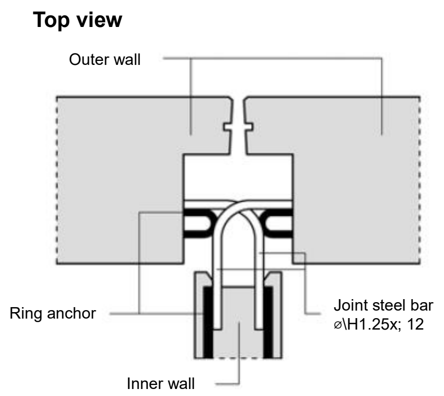
The analysed typified building methods – block, strip and prefabricated buildings – demonstrate differences with regard to the connections between each other and within a building type.

In the block and strip construction method, the connections of the elements via ring anchor and ceiling welding as well as mortar joints or mortar locks ensure the statically necessary shear effects. If required, the elements are also connected to each other via anchor bars in parapet elements.

In the prefabricated construction method, the ring anchor reinforcement is integrated in the lintel area of the wall elements (see Fig. 4.5.

The connections are established by means of additional reinforcement steel bars (Fig. 4.6) and closed with joint-sealing concrete. The ceiling elements are also connected to each other multiple times on the long and front sides (Fig. 4.4, 4.6) and cast with concrete to form a ceiling slab.

[47] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, 2008, p. 82



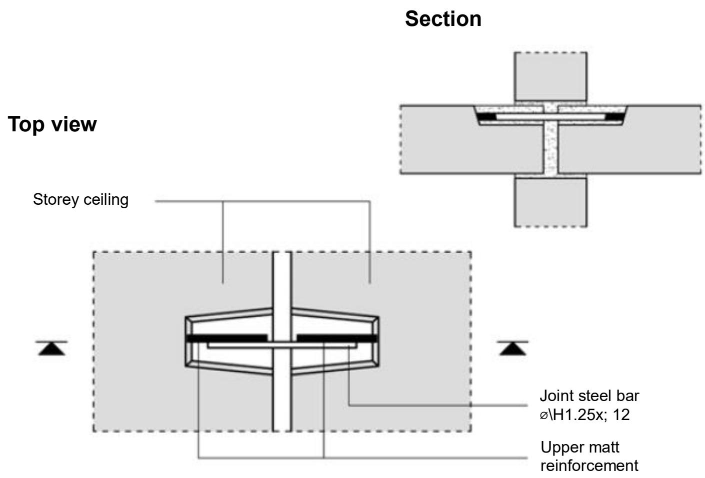


Fig. 4.5: Connection outer walls - inner wall[48]

Fig. 4.6: Connection ceiling – ceiling lengthwise to the clamping direction[49]

Depending on the number of storeys, the outer wall joints have been finished as a closed or open joint system.

The closed joint system was implemented in multi-storey prefabricated buildings (up to 6 storeys), with asbestos-containing joint sealant (Morinol)[50] being used mainly on the outside (see Fig. 4.7). In the case of open joints, a PVC strip forms the outer sealing (see Fig. 4.8)

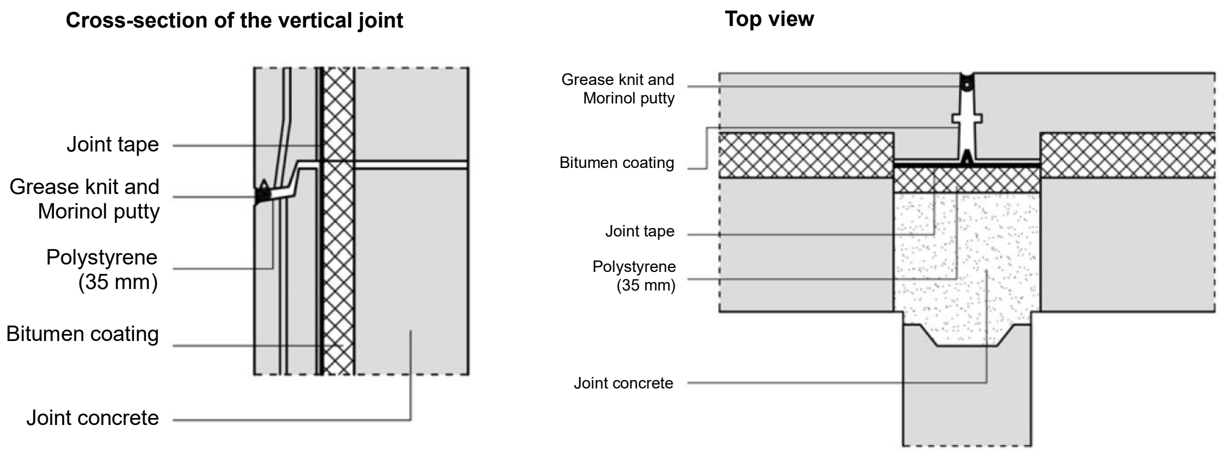


Fig. 4.7: Closed joint system[51]

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[48] revised after Mettke, Angelika (ed.): Rahmenechnologie, Entbau-/ Demontagevorhaben Plattenbauten – am Beispiel der Typenserie 2, Cottbus, 2004, p. 39
[49]Ibidem
[50] for more details, see Chapter 5.
[51] revised after Mettke, Angelika (ed.): Rahmenechnologie, Entbau-/ Demontagevorhaben Plattenbauten – am Beispiel der Typenserie 2, Cottbus, 2004, p. 38

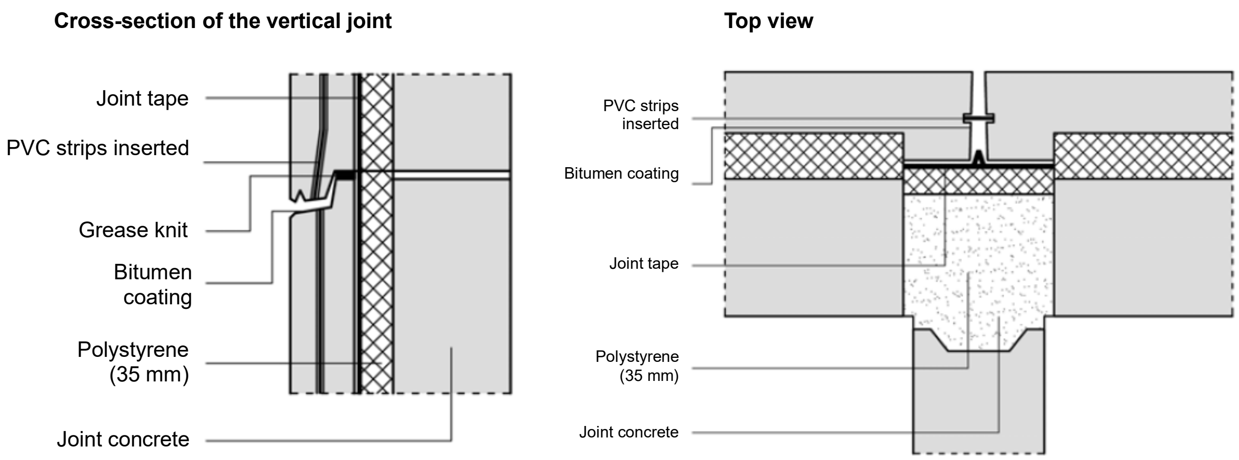

Fig. 4.8: Open joint system[52]

Further and more detailed information on structural features can be found in the final report on the research project "Dismantling industrial building fabric - large-format concrete elements in the ecological closed cycle"[53].

4.4 Building key figures

Building key figures were determined to support planning and execution work for the dismantling and demolition of the industrially constructed buildings. Calculations of quantities are relevant for estimating the demolition and disassembly time and thus the demolition and disassembly costs and, in particular, the disposal costs. However, the design variants of the standardised constructions vary not only from one another but also within a building series. Therefore, the following key figures for buildings can only be used as a rough guide.

Tab. 4.1: Selected key figures for building types PN 36-NO, P2, WBS 70, and IW 64[54]

	PN 36-NO	**P2**	**WBS 70**	**IW 64**
	Prefabricated construction			**Block construction**
Load level	5 t	5 t	6.3 t	0.8 t
Number of storeys	4 and 5	4 to 6, 8 to 11	5 to 11	3 to 5
Assembly	Two/three flats per storey	Two/three/four flats per storey	Two/three flats per storey	Two flats per storey
Key figures				
Calculated total mass of concrete elements in relation to 1m² living space	approx. 1.315 kg	approx. 1.390 - 1.480 kg	approx. 1.215 kg	approx. 1.450 kg
Calculated total mass of concrete elements in a standard storey in relation to 1m² of the storey area	approx. 820 kg	approx. 854 - 845 kg	approx. 775 kg	approx. 820 - 845 kg
Calculated total mass of concrete elements on the top storey in relation to 1m² of the storey area (flat roof)	approx. 420 kg	approx. 345 - 350 kg	approx. 415 kg	approx. 200 kg

52 revised after Mettke, Angelika (ed.): Rahmenechnologie, Entbau-/ Demontagevorhaben Plattenbauten – am Beispiel der Typenserie 2, Cottbus, 2004, p. 39

53 Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, Cottbus, 2008, pp. 22-83

54 Mettke, Angelika: Verallgemeinerbare Ergebnisse zum Demontageprozess verschiedener industrieller Bautypen, in: Tagungsband „Alte Platte – Neues Design – Die Platte lebt“, Angelika Mettke (ed.), Cottbus, 2005, p. 93

Calculated total mass of concrete elements in the basement in relation to 1m² of the storey area	approx. 870 kg	approx. 845 kg	approx. 800 kg	approx. 1.080 kg
Number of installed elements – top storey (1 segment)	37 – 42	38 – 45	10 – 34	66
Number of installed elements - standard storey (1 segment)	48 – 58	52 – 59	54 – 79	255 – 261
Number of installed elements – basement (1 segment)	52 – 71	50 – 64	56	263

4.5 General information on planning and execution of dismantling projects

In general, dismantling projects require the same preparation as demolition projects. They usually require the initiation and implementation of construction law administrative proceedings as defined in the construction regulations of the federal states.[55]

The fundamental authorisation to be obtained is the demolition or dismantling permit. This is the responsibility of the local building supervisory authority.

The demolition permit does not include proof of compliance with waste legislation or any necessary notifications under water legislation in cases where, for example, the processed material (RC material) is used to backfill the excavation pit. The responsibilities of the parties involved are stipulated in the building regulations of the federal states[56]. The owner/building contractor is responsible for planning, monitoring and disposal.

They are required to appoint a technical draftsman, contractor, and a site manager for the preparation, supervision and execution of a construction or demolition project that is subject to authorisation.

The owner/contractor is responsible for:[57]

- awarding the planning to a professionally qualified planner as specified in the building regulations,
- development of a protection scheme (work and safety plan),
- development of a disposal concept,
- assignment of the dismantling services.

Disassembly requires more planning effort than demolition. This is the result of comprehensive safety and technological processes.

[55] The application and authorisation procedure for demolition projects is not standardised nationwide.
[56] e.g., in the Brandenburg Building Code (Bbg BO) in Part 4, Parties involved in construction §57 ff.
[57] The services are listed in: Rahmentechnologie, Rückbau-/ Demontagevorhaben – am Beispiel der Typenserie P2, ed. Angelika Mettke, Cottbus, 2004, p. 22 ff.

The planning of disassembly/dismantling can be divided into the following action steps:

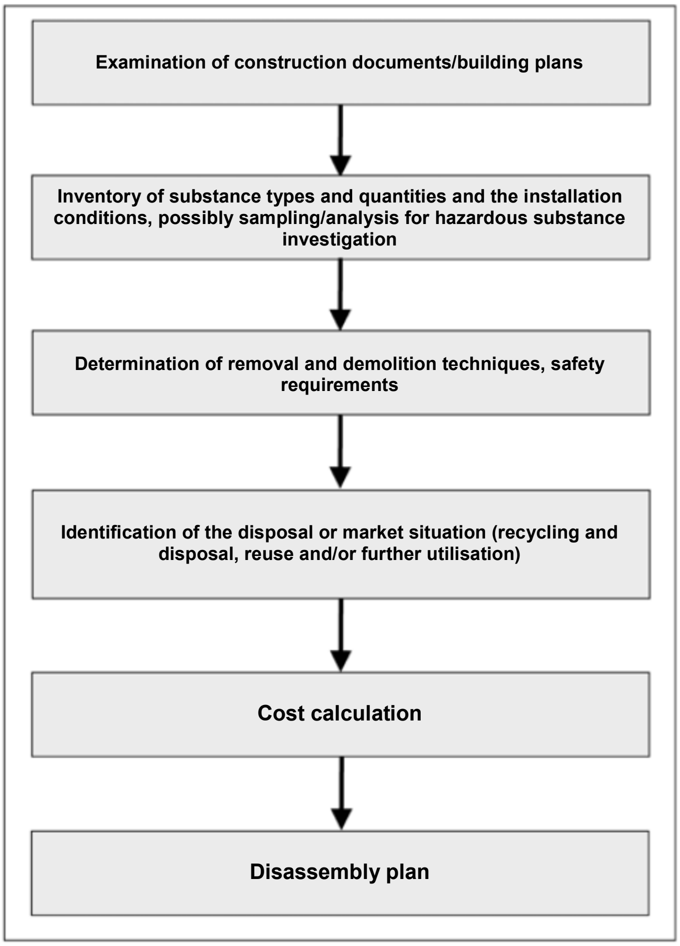

Fig. 4.9: Planning stages for dismantling projects[58]

The planning engineer has a special responsibility for a detailed tender for the dismantling project including corresponding specifications for the dismantling technology in order to guarantee safety in every stage of the dismantling process (removal of contaminants during the disassembly process and for the remaining building fabric). This also applies to the storage and loading of dismantled components and the resulting construction waste. In the case of partial deconstruction while the building is still occupied, it is also essential to ensure safety of the tenants.

4.6 Basic disassembly procedure

The dismantling or disassembly of prefabricated buildings requires a structured process which, in addition to the points mentioned in section 4.5, ensures the segregation of hazardous substances and contaminated building components (see section 5) as well as the pre-separation of individual building materials and component fractions down to the original blank/shell. Basically, the procedure is as follows:

[58] ibidem, p. 27

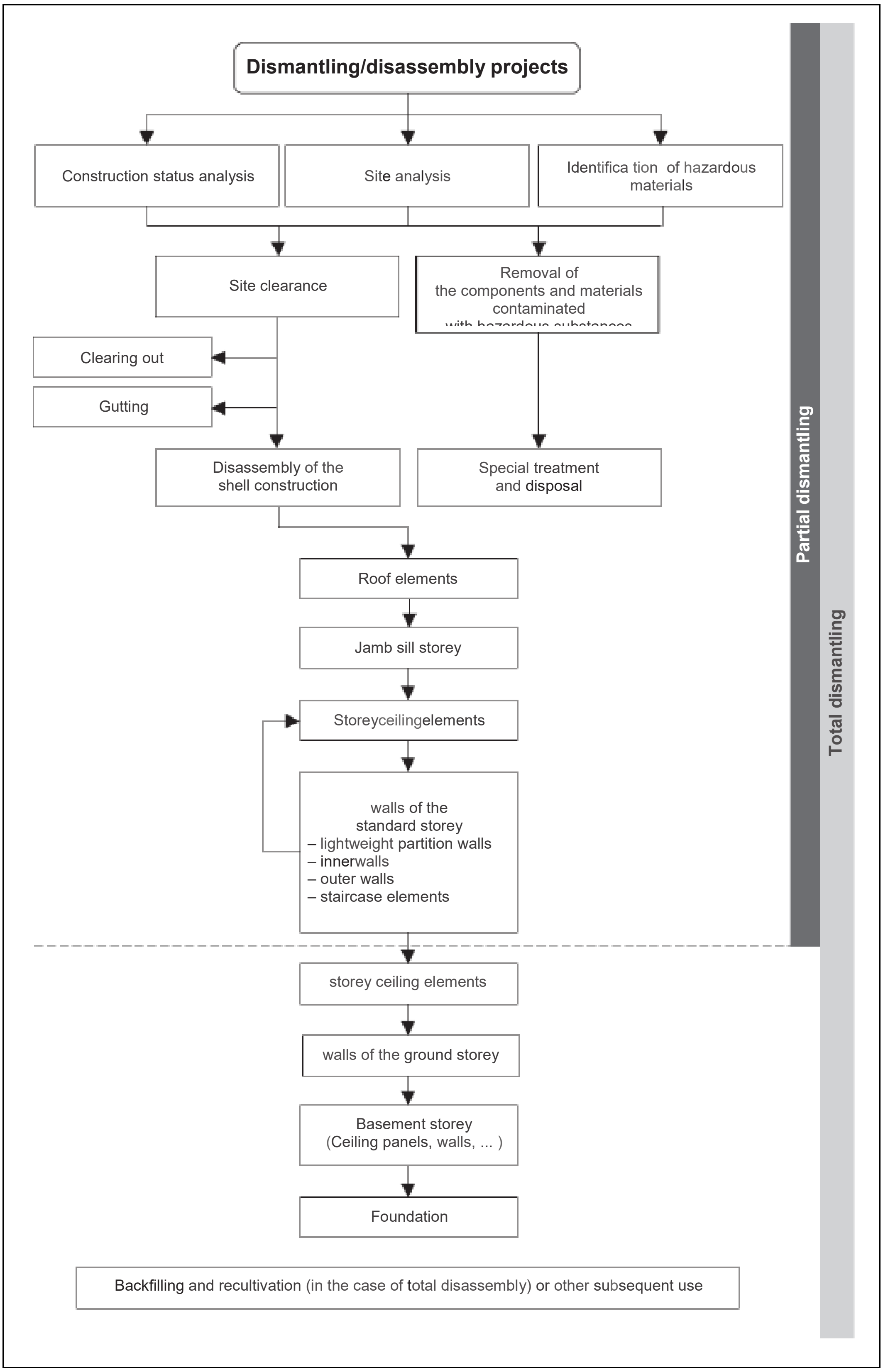

Fig. 4.10: Basic disassembly procedure for partial and complete dismantling[59]

[59] Mettke, Angelika (ed.): Rahmentechnologie, Rückbau-/ Demontagevorhaben Plattenbauten, Cottbus, 2004, p. 41

The basic disassembly process can be broken down further into seven disassembly stages, which are primarily due to structural conditions (see Fig. 4.11).

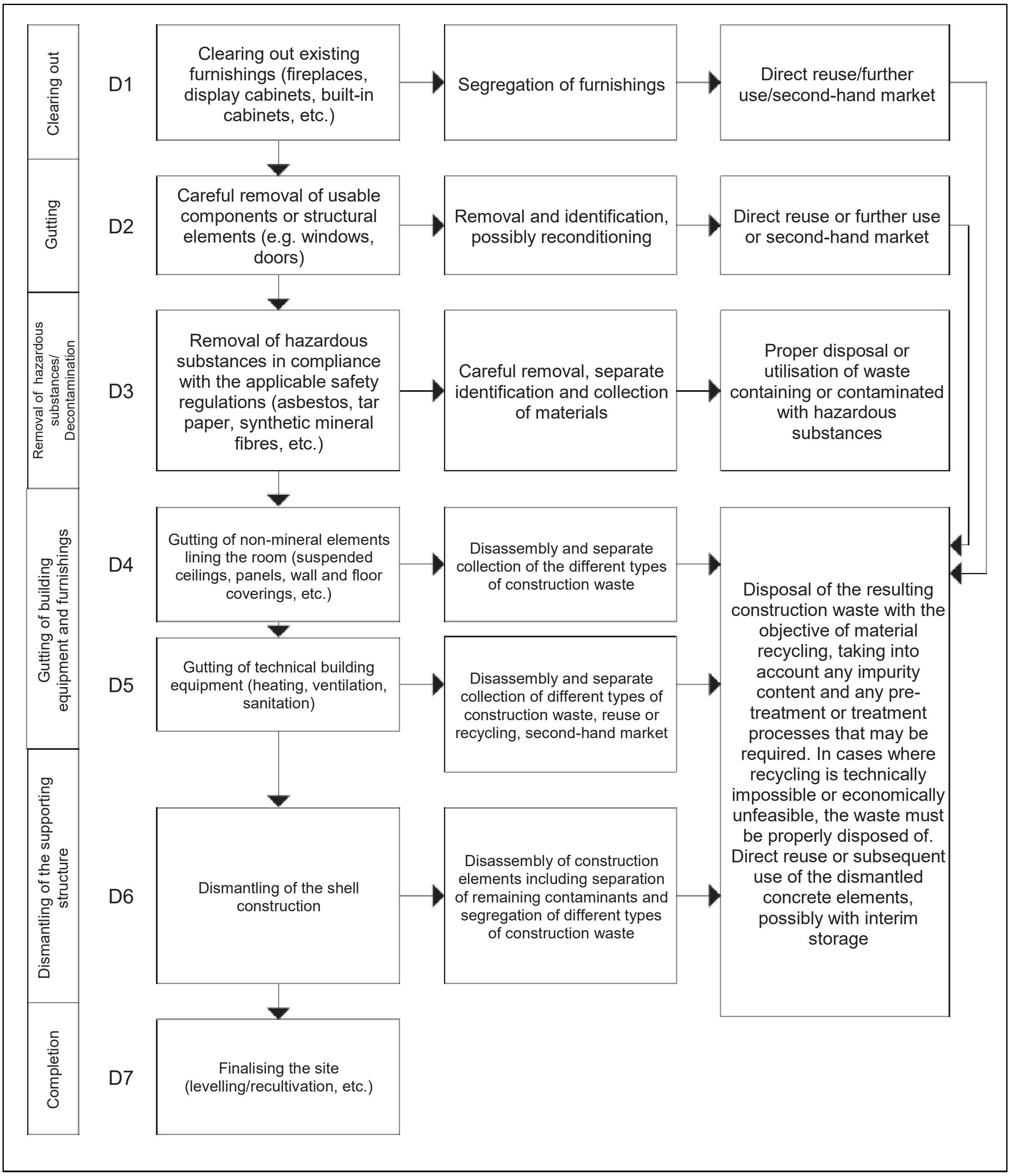

Fig. 4.11: Disassembly stages[60]

[60] extended after Silbe, Katja: Wirtschaftlichkeit kontrollierter Rückbauarbeiten, Diss. 1999, Darmstadt, in: Tiefbau 1/2004, p. 25; essay by Motzko, Christoph; Klingenberger, Jörg: Kalkulation kontrollierter Abbrucharbeiten – Ausgewählte Schwachstellen und Empfehlungen aus baubetrieblicher Sicht, pp. 22 - 28 and Mettke, Angelika: Rückbauen statt Abreißen, in: BaustoffRecycling + Deponietechnik, 8/2003, p. 44; cf. also work aids Recycling, ed. Federal Ministry of Regional Development, Construction and Urban Development + Federal Ministry of Defence, 1998, p. 19

The hierarchical disassembly structure enables detailed planning and supports the execution and monitoring of processes.

4.7 Requirements for dismantling/disassembly of the shell construction

Following the clearing of the building (clearing out and gutting; disassembly stages D1, D2, D4, D5 Fig. 4.11) and removal of contaminants (D3), disassembly of the shell construction can begin.

In principle, the following requirements must be met when dismantling the shell construction:[61]

- The structural elements must be secured against falling or tipping over before being separated or detached. Apart from technical safety aspects, this also largely preserves the shape and functionality of the components after the connections have been loosened.
- In the case of partial disassembly, damage to the remaining building structure must be ruled out.
- In particular, the use of environmentally friendly machines and equipment is to be favoured in order to avoid or at least reduce noise, dust and vibrations.
- The opening or separation of the joints between the prefabricated concrete elements has to be carried out in such a way as to prevent damage to the components intended for reuse or further utilisation.

The disassembly technology to be developed should contain the following information:

- Quantity/number and category of parts to be disassembled, quantities of contaminated building materials and uncontaminated construction debris and/or mixed construction and demolition waste,
- The method of dismantling incl. lifting gear (type, location), position of the attachment points and type of attachment and load-bearing devices,
- The sequence of disassembly and stabilisation of the structures in the individual disassembly stages (securing of components and load transfer of equipment, people, construction debris; demolition statics),
- Exposing and loosening of connections,
- Machine and equipment deployment plan,
- Support structures, e.g., scaffolding,
- Protection against falling,
- Disassembly depths and possible effects on adjacent buildings,
- Safety measures, e.g., fencing dangerous areas off,

[61] Mettke, Angelika (ed.): Rahmentechnologie, Rückbau-/ Demontagevorhaben, Plattenbauten, Cottbus, 2004, p. 48

- Occupational health and safety measures,
- Interim storage areas,
- Container parking space,
- Specifics and details
- regarding the components intended for reuse and/or further use (labelling of the elements).

Similarly to the assembly scenario, building stability must also be ensured during all disassembly stages. Interaction between horizontal ceiling slabs and vertical bracing elements is crucial for ensuring stability. However, if elements of these slabs, especially the wall slab, are removed during disassembly, measures must be taken to support the adjacent wall elements by means of mounting struts or stability of the wall slab is to be ensured by means of adjacent walls (load-bearing or bracing inner or outer walls) that initially remain in place to establish self-bracing units. The elements must be secured by means of mounting struts. In the event of work interruptions, it is necessary to disassembly all the precast concrete parts welded joints of which have already been cut.

4.8 Selected procedural and technological results and the effects on the costs of dismantling and disposal

The technical feasibility of dismantling prefabricated buildings by crane or in a building element-orientated manner was initially questioned, but has now been proven in practice several times. The focus is now on optimising the dismantling processes so as to provide reliable cost calculations. After all, reliable costs form the basis for investment decisions and are a prerequisite for any successful construction or development project. Demolition and dismantling projects. Nothing has changed in this respect over time. Although there are quite precise calculation approaches for new construction measures, this was not the case for the dismantling of industrially constructed buildings. Therefore, the time-consuming work and the parameters that have significant influence on the costs and the course of the project have been identified within the scope of the accompanying analyses of dismantling[62]. The first foundations have been developed by scientifically analysing the determination of working hours for gutting measures, crane-independent and crane-dependent services and establishment of calculation approaches.

The main factors influencing the dismantling and disposal processes need to be identified prior to the presentation of selected research results.

4.8.1 Major factors influencing the costs of dismantling and disposal

Some of the major criteria that influence the costs are

- in case of partial dismantling
    - boundary conditions of the dismantling site/integration of the building into the surroundings (space conditions, accessibility, construction site facility areas,...),

[62] comprehensively published in: Mettke, Angelika (ed.): Rahmentechnologie, Rückbau-/ Demontagevorhaben Plattenbauten, Cott-bus, 2004, pp. 50 - 76 and in: Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausub-stanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, pp. 136 – 161/213 - 274

    - regulatory and legal requirements,
    - building geometry, type, construction, number of storeys,
    - component geometry and weight,
    - stability and structural condition of the building (load-bearing capacity of the structural elements),
    - dismantling method and choice of equipment,
    - type and scope of the dismantling measure,
    - type and extent of construction materials containing hazardous substances,
    - quality of the construction elements and materials,
    - measures for the protection of the remaining stock,
    - restrictions on working hours,
    - tolerance of noise, dust, vibrations (occupational safety and environmental protection; subsequent damage claims),
    - transport routes etc.
- disposal,
    - selection effort,
    - level of contamination with hazardous substances,
    - pre-shredding,
    - federal state-specific, regional regulations (transfer/indemnity obligations; see Table 5.6),
    - number and size of containers,
    - transport distances/costs,
    - disposal charges,
    - sales returns.

These numerous criteria demonstrate that the calculation of dismantling work must be carried out with due care. Practical experience shows that there are deficits in this area. The data obtained for selected complexes is therefore presented below.

4.8.2 Crane deployment

In the case of dismantling, the choice of the crane depends on the following parameters:

- building geometry,
- max. loads to be lifted,

- duration and scope of the measure,
- ground and soil conditions,
- available space.

Mobile cranes and tower cranes are used for disassembly of industrially manufactured buildings. In order to make optimal use of the crane's load range, side disassembly (positioning the crane on the long side of the building) is performed, just as it is the case during the assembly.

Proof must be provided for the crane for each specific deployment. Accordingly, the crucial element is the heaviest outer wall or loggia parapet element on the long side of the building facing away from the crane. Data from the project planning catalogue concerning element weight is insufficient here, since it has been determined in the course of the scientific evaluation that mass surplus must be factored in. The latter results mainly from adhering grout and moisture penetration; in the case of storey ceilings also from adhering sealing membranes and screed layers, and for roof panels, also from bonded roofing membranes. The results are as follows:

Tab. 4.2: Calculated changes in element weights during disassembly in relation to project planning documentation in [%][63]

Element range	P2 11-storey	P2 5-storey	WBS 70 11-storey	WBS 70 5-storey
Roof panels with roofing membranes				+30 to +5
Storey ceilings	+8 to -19	+22 to -2	+40 to +8	+50 to +5
Inner walls	+6 to -4	+2 to -32	+4 to -18	+30 to +2
Outer walls	+3 to -15	+3 to -1	+53 to -3	+25 to +2

The results of the measurements indicate that the weights of the elements deviate considerably from the project planning specifications. For the proof of the load capacity of the crane, it is recommended to use the specific maximum disassembly weight (critical element).

A cost comparison between tower cranes (TDK) and mobile cranes (FZK) based on examples of 5-, 11- and 16-storey residential buildings revealed

$$K_{ges} = K_f + K_v \cdot t \tag{4.1}$$

K_{ges}	Total cost
K_f	fixed costs (transport to the site, assembly and dismantling, removal)
K_v	variable costs (rent, electricity costs, crane operator, insurance)
t	Duration of crane deployment [months]

the following result:

[63] extended according to Mettke, Angelika; Heyn; Sören Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Groß-formatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, Cottbus, 2008 p. 147

Tab. 4.3: Comparison of costs and determination of the break-even point for the deployment of TDK and FZK (values rounded)[64]

Building size	**5 storeys**	**11 storeys**	**16 storeys**
Costs of a tower crane			
Fixed costs	€ 10,000	€13,000	€17,000
Variable costs	€9,550	€ 9,900	€10,650
Costs of a mobile crane			
Fixed costs	€ 160	€1,590	€ 5,400
Variable costs	€13,940	€29,410	€56,100
Break-even point			
Months	2.24	0.58	0.26
Days	47	12	5

The rise in the variable costs of FZK is particularly apparent (see Tab. 4.3).

The break-even point (t_0)[65] specifies the time from which onwards specified crane type is more cost-effective; determined by:

$$t_0 = (K_{f(TDK)} – K_{f/FZK)}) / (K_{v(TDK)} – K_{f/FZK)}) \qquad (4.2)$$

The results of the selected case studies can be summarised as follows:

- The crane costs for both crane types increase in parallel with the height of the building (see Fig. 4.12)

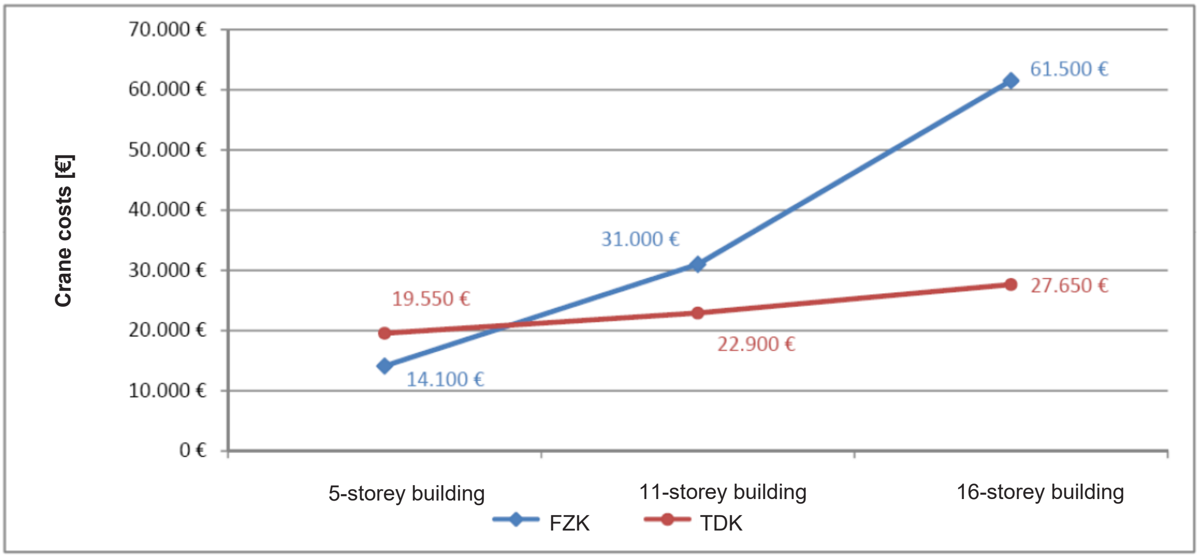

Fig. 4.12: Graphical representation of the cost development for TDK and FZK depending on the height of the building

[64] Mettke, Angelika (ed.): Rahmentechnologie, Rückbau-/ Demontagevorhaben, Plattenbauten, Cottbus, 2004, p. 53
[65] in German: Gewinnschwelle (break-even point)

- Depending on the height of the building, the break-even point
    - for 5-storey buildings is up to 47 days (2.24 months) of disassembly in favour of FZK,
    - for 11-storey buildings is up to 12 days (0.58 months) of disassembly in favour of FZK,
    - for 16-storey buildings is up to 5 days (0.26 months) of disassembly in favour of FZK.

Due to the constantly changing market situation (regional, local, seasonal, economic and market policy conditions), the results presented here can only serve as a rough guide. Consequently, each individual dismantling project must be recalculated.

4.8.3 Disassembly/dismantling times – time measurements for the disassembly of concrete elements

Approximately 2,000 measurements were conducted as part of the BMBF-funded research project "Dismantling industrial building fabric – large-format concrete elements in the ecological cycle" to determine the crane operating times for the disassembly of individual concrete elements and for the preparatory work required for exposing and separating the connecting bars and opening the joints. The background to the analysis was to determine the time required for disassembling the installed range of elements. The measurements were broken down into crane-dependent times (pure disassembly times) and crane-independent times (ancillary work/preparatory work). Furthermore, the crane utilisation rate was determined. Moreover, it was analysed whether and/or what influence the (planned) reuse of concrete elements has on the disassembly time. In this way, practitioners are provided with a basis for the calculation of disassembly costs and at the same time weak points can be identified.

- **Work time required for the preparation of the elements for disassembly/crane-independent times (ancillary work)**

Labour times measured for chiselling the joints, opening the joints, making stop openings for alternative stop options and separating the connecting bars are pure labour times. Breaks for physically demanding work, changing and cleaning tools, etc. are not included.

The following crane-independent times (values rounded) were determined:[66]

Tab. 4.4: Calculated crane-independent times/time required for the preparation of components for disassembly (values rounded)

Element range	Working time [min]	
	Prefabricated 6-storey building	Block construction 4-storey building
Roof cassette panel	30	23
Ceiling panel (without screed)	22	13
Outer wall	12	4
Inner wall	8	-
Bathroom	39	-

[66] according to Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, Cottbus, 2008, p. 236 ff.

It is apparent here that more time needs to be planned for the roof cassette panel as compared to the other predominantly installed elements. This is primarily due to cutting the tar paper layers open by means of an asphalt cutter, chiselling off the roof membrane

and creating 4 openings per element in preparation for the alternative attachment. This means that preparation for disassembly of the roof panels has considerable influence on the overall duration of the measure, particularly in the case of dismantling of one or two storeys.

In the case of a screed layer designed as bonded screed, approx. 7 min/m² (chiselling and clearing) must be assumed for the removal.

This data is used to calculate the duration of the preparatory work for component removal.

- **Time required for pure disassembly/crane handling of concrete elements (crane-dependent times)**

The following average times were calculated for pure disassembly of concrete elements:

Tab. 4.5: Calculated crane cycle times (slinging, lifting, lowering, returning the load handling attachment) for disassembly of concrete elements installed in prefabricated and block structures[67]

Type of building	**Pure disassembly time [min]** (averaged, rounded values)	
	Prefabricated buildings 5- and 11-storey buildings	**Block construction 5-storey buildings**
Number of measurements	1,295	604
Element range		
Roof elements	10	17
Jamb wall elements	6	11
Ceiling panels	8	12
Outer walls	11	9
Inner walls	11	6
Partition walls	9	11
Bathroom	10	-
Loggia shaft	10	-
Loggia ceiling	5	8
Stairs	11	9
Average value	**10**	**10**
Number of elements/day	31	45

It can therefore be assumed that an average of 31 prefabricated components or 45 block components are dismantled in one shift. Irrespective of the building type and height, the pure disassembly of (any) concrete element takes approx. 10 to 15 minutes.

[67] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, p. 214, excerpt from Tab. 117

The summary of crane-independent and crane-dependent disassembly times in relation to enclosed space, storey space and individual element (Tab. 4.6) shows that the dismantling/disassembly time depends on the number of installed elements. Despite the short time of approx. 19 minutes for the disassembly of a block construction element as compared to approx. 36 minutes for the disassembly of a prefabricated construction element, there is an advantage for the prefabricated construction method per a square metre of living space or one cubic metre of enclosed space.

Tab. 4.6: Comparison of the determined total disassembly times[68]

Type of building	Disassembly time [mm:ss]	
	Prefabricated buildings (WBS 70)	**Block construction (IW 64)**
per m³ of enclosed space	2:43	9:00
per m² living area	12:38	41:23
per element	35:50	18:45

The fact that this data can only be used as a guide is explained by the respective initial situation for the dismantling measure (different stock situation, different type and unequal scope of services). Last but not least, disassembly time is influenced by the quality of the planning and qualifications of the commissioned dismantling company.

Furthermore, it was also observed that there is no difference in the pure dismantling time irrespective of whether a component is to be reused or subsequently used.

Crane utilisation needs to be discussed in the context of the calculated crane operating times and the resulting costs. This is due to the crane downtimes determined in the course of the analyses. The downtime during the disassembly of a WBS 70 was 41% and 28% during the disassembly of a block structure (see Fig. 4.13, 4.14).

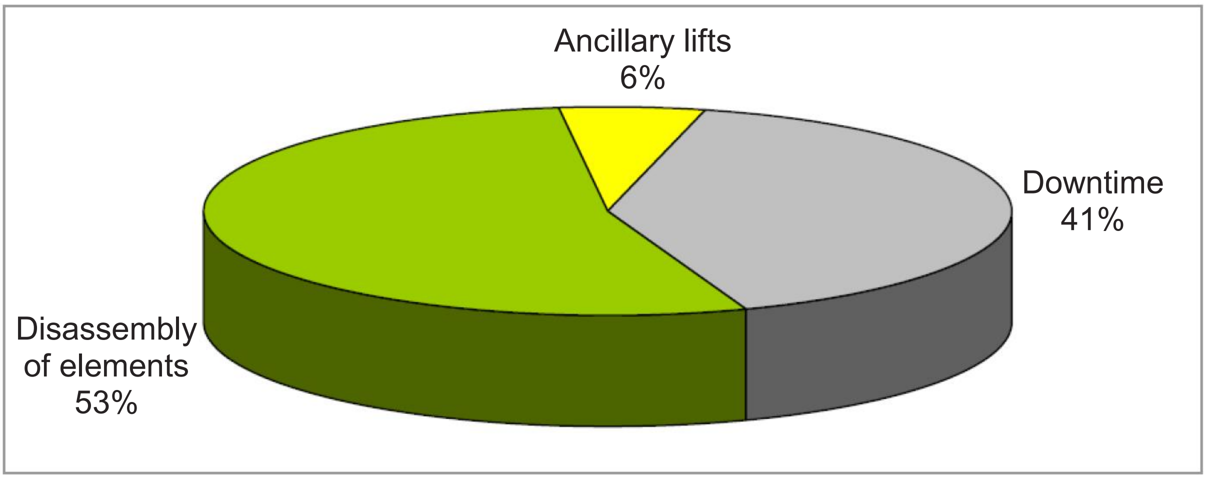

Fig. 4.13: Crane utilisation example disassembly – WBS 70[69]

[68] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, p. 256, excerpt from 147
[69] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, p. 234

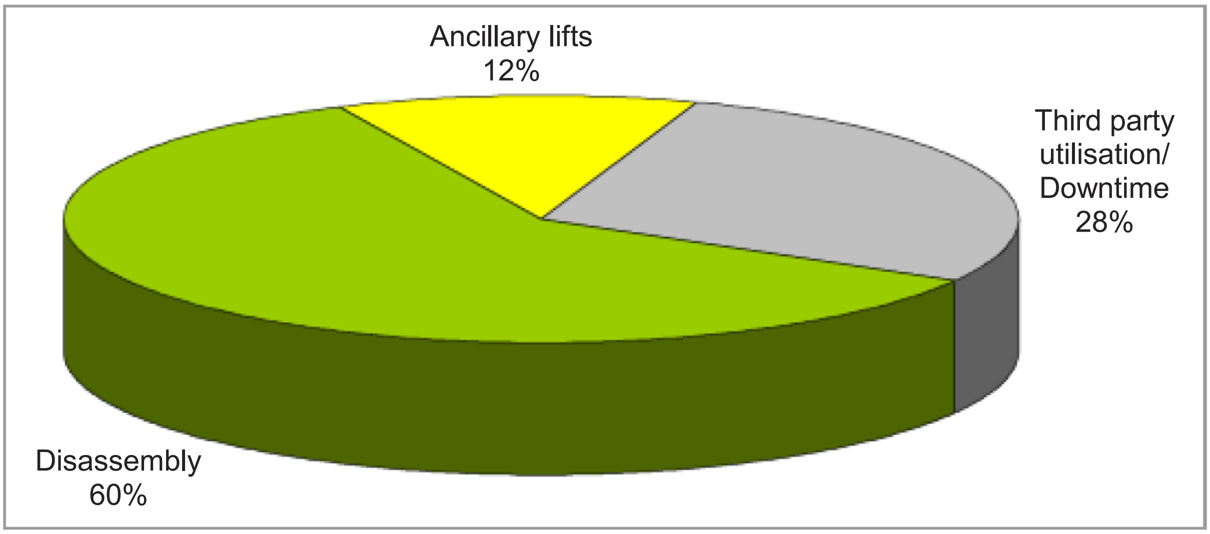

Fig. 4.14: Crane utilisation example disassembly – block construction[70]

Ancillary lifts include lifting rubble buckets from the disassembly level, including emptying, moving mini-excavators and loading of concrete elements onto low-loaders.

The reduction of crane downtimes is a clear starting point for the shorter dismantling time and consequently also the lower costs. Particular attention must therefore be paid to ensuring that crane-independent work is carried out well in advance. Careful preparation and execution of the technological process is therefore of particular importance.

4.8.4 Attachment options

Initially, lifting eyelets were used as attachment points for load-bearing and lifting equipment in all types of industrially manufactured buildings. Depending on the respective condition of the individual lifting eyelet, a decision must be made as to its subsequent usability. This means that the functionality of the lifting eyelets is to be checked by a professional visual inspection on site by the slinger/rigger. The lifting eyelet must not be used if indentations, deformations, forced openings or constrictions, weld spatter and burn marks are detected. In such cases, alternative attachment points have to be installed. The same applies when the original lifting eyelets are no longer present in the component (have been burnt off or wrenched off after assembly).

Experimental investigations into the reusability of lifting eyelets on ceiling panels were carried out at the end of the 1990s on behalf of the State Office for the Environment and Geology, Free State of Saxony, as a part of own research into waste prevention in construction projects.[71] Three lifting eyelets in different conditions (visible rusting, mechanical damage) proved that the permissible tensile force had already been exceeded by 60 % to 140 % by the time they finally failed. These results provided the basis for the above-mentioned statement that lifting eyelets can be reused in principle, though in individual cases the condition of the respective lifting eyelet becomes a decisive factor. Since the load on the lifting eyelets is largely dependent on the type of load-bearing or slinging equipment used, load-balanced lifting slings should be used to minimise the load input wherever possible.

[70] ibidem, p. 234
[71] performed in cooperation with Unruh, Hans-Peter in the FMPA of the BTU Cottbus and published in: Mettke, Angelika, Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, Materialien zur Abfallwirtschaft, 1999, p. 43 ff.

Alternative attachment points/possibilities that have proven to be effective in practice (see Fig. 4.15 to 4.17[72]):

- the push-through system (supporting bolt with hanger) for the disassembly of wall panels; in this system, an existing opening (door or window) can be used or a drill hole has to be planned.
- Lifting straps for disassembly of ceiling panels or walls,
- Pliers for disassembly of wall blocks.

Fig. 4.15: Push-through system

Fig. 4.16: Lifting straps

Fig. 4.17: Pliers

Since the condition of the lifting eyelets can generally only be assessed in the course of the disassembly, there is a risk in terms of cost calculation. That's due to the fact that the more alternatives there are, the more time-consuming and costly dismantling becomes.

As far as the contractor is concerned, the contract with the owner/client should be concluded in such a way as to allow for amendments to be made for unforeseeable additional expenses in this regard.

4.8.5 Dismantling and disposal costs

The disassembly costs, like demolition and construction costs, are subject to the variables related to the time and area. Generalised statements are only possible if all framework conditions such as storey height, type, and size of the building to be dismantled, accessibility, hazardous materials, quality and design of the joints, reusability of the load-bearing eyelets, secondary use, etc. are identical. The disassembly costs also depend on whether the dismantling is carried out in an unoccupied or occupied state and with or without a buffer storey.

The nuances occuring in the costs of the various partial deconstruction projects of the Ahrensfeld Terraces shown in Fig. 4.18 can be attributed to varying occurrences/quantities of hazardous substances, in particular in the case of outer walls insulated with the mineral wool. In many cases, it was observed that the multi-layered outer walls within a building had been constructed with the use of different insulation materials (see Chap. 5.3.4).

[72] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, p. 149

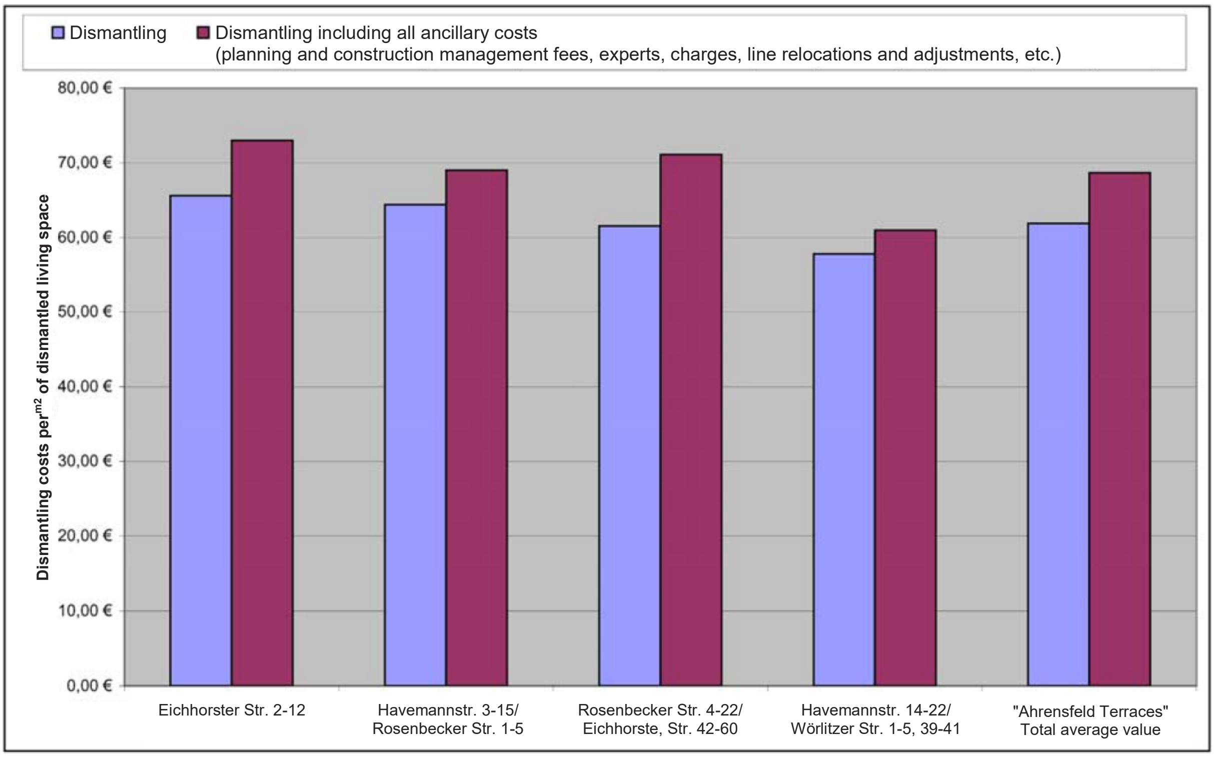

Fig. 4.18: Cost analysis for partial dismantling - Ahrensfeld Terraces[73]

The dismantling costs have decreased significantly over the last 10 years, as demonstrated in Fig. 4.19.

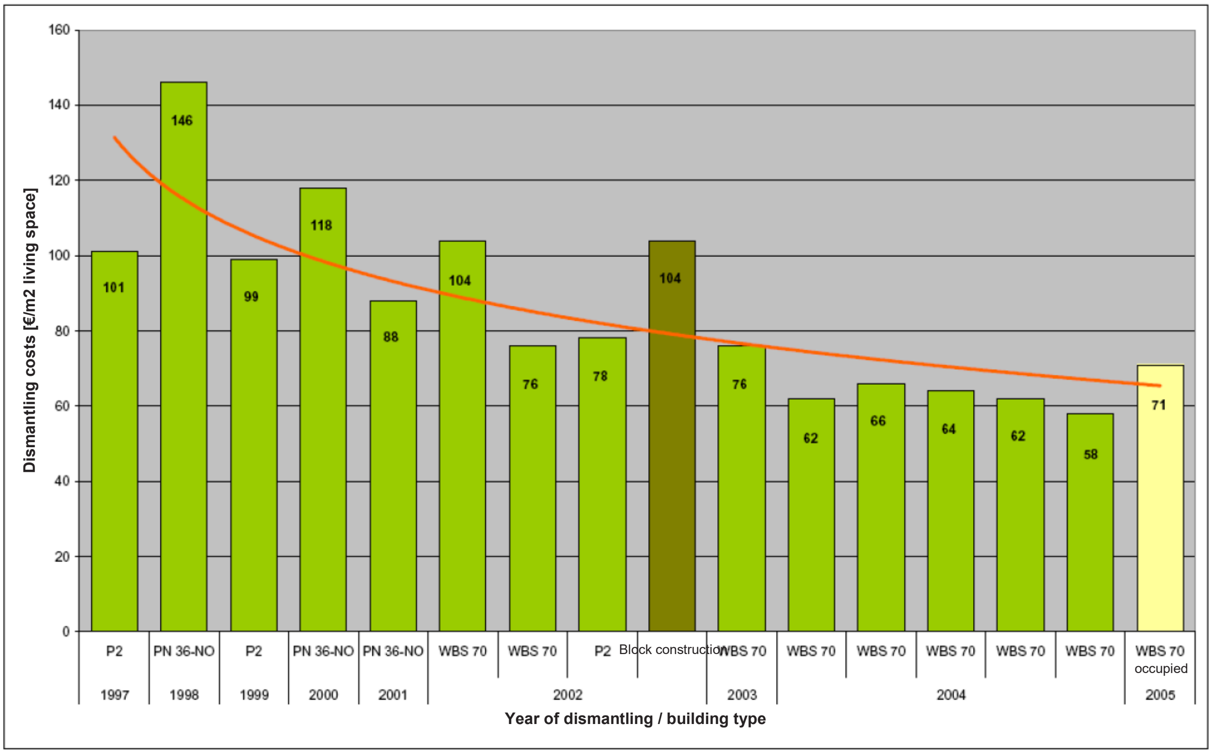

Fig. 4.19: Development of dismantling costs[74]

[73] Al-Ahdab, Jacqueline: Das Projekt „Ahrensfelder Terrassen", WBG Marzahn, 2005
[74] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, p. 263

The dismantling costs including construction site equipment, gutting and disposal are currently between approx. 58 - 66 €/m² of the living space and 76 - 84 €/m² of the living space. Only 10 years ago (1998), they were up to 65% higher.

Overall, the cost structure for dismantling is as follows (orientation):

- Construction site equipment 9 – 29 %,
- Gutting 4 – 27%,
- Disposal 10 – 29%,
- Contaminants 12 – 35%,
- Scaffolding 7 – 10%,
- Disassembly 17 – 57%.

The demolition costs identified in the course of the accompanying scientific analyses amount to approx. € 25 – 45/m² of living space. (as of 2007). Accordingly, the disassembly costs are around twice to three times as high as the demolition costs.

The disassembly costs per element (installed in prefabricated buildings) are between € 133 and € 198:

- € 173/element [UNRUH/NAGORA, determined at the Cottbus site, 11-storey building P2][75],
- € 157 - 198/element [own investigations at the Eggesin site, 5-storey building, PN 36-NO],
- € 176/element [own investigations at the Gröditz site, 6-storey building, WBS 70],
- € 133/element installed in the top storey [ASAM, determined in cooperation with the Expert Group for Structural Recycling at the Templin site, 5-storey building, WBS 70][76],
- € 189/element installed in a standard storey [ASAM, determined in cooperation with the Expert Group for Structural Recycling at the Templin site, 5-storey building, WBS 70][77].

The costs for dismantling measures in occupied conditions vary depending on the measure (storey by storey, segment by segment and/or terraced) from approx. € 71 /m² to € 205/m² of dismantled living space.[78] In the case of partial deconstruction while the building is still occupied, the disassembly costs increase due to the necessary safety and protective measures for the flats located below the disassembly level (protection against water ingress, protection of the stairwell area, etc.).

In 2003, a survey was conducted at RC plants in the new federal states with regard to the gate-fees for broken reinforced concrete. Fig. 4.20 is an example of gate-fees for broken reinforced concrete

[75] Unruh, Hans-Peter; Nagora, Anja: Rückbau von Plattenbauten, 2002, p. 191
[76] Asam, Claus et.al.: Untersuchungen der Wiederverwendungsmöglichkeiten von demontierten Fertigteilelementen aus Wohnungsbautypen der ehemaligen DDR für den Einsatz im Wohnungsbau, Entwurf, 2004, pp. 7 – 32, published in 2005
[77] ibidem, pp. 7 - 33
[78] Janorschke, Barbara; Rebel, Birgit: Schlussbericht „Rückbau unter bewohnten Bedingungen“, iff Weimar, Entwurf, 2008/2009, p. 57, published in 2009

- ▶ with 60 cm edge length. Although the price survey was conducted 6 years ago, it demonstrates that acceptance prices are subject to strong regional fluctuations - and this has not changed to this day. The current local acceptance/tipping fees for recyclable concrete material
- ▶ of 60 cm incl. reinforcement (waste code 170101) are € 25/t. The charge for large-format concrete elements is € 77/t.

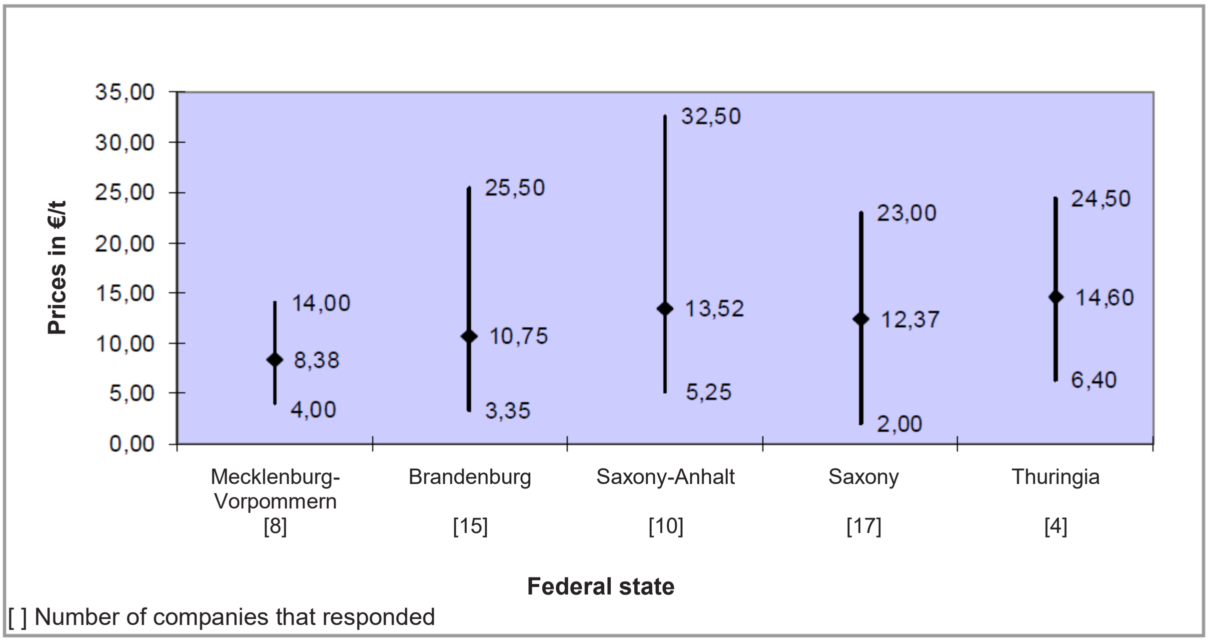

Fig. 4.20: Acceptance prices for reinforced concrete rubble (edge length > 60 cm)[79]

The following cost structure, based on two case studies, illustrates that the disposal costs account for a significant proportion of the total costs (see Tab. 4.7). Particularly in the early days of the dismantling sector, this position was incorrectly evaluated by many contractors, i.e., the figures were underestimated or the regional differences were taken into account.

Comparison between partial deconstruction of 1.5 segments of a 6-storey residential building of WBS 70 and partial deconstruction of 2 storeys of a residential building in 0.8 Mp block construction (the results of the investigation correlate with the above information on cost calculation in general.)

[79] Mettke, Angelika; Doll, Manuela; Lanzke, Cynthia: Marktanalyse zu Annahmegebühren von Bauschutt und Stahlbetonbruch in den neuen Bundesländern, 2003

Tab. 4.7: Percentage share of costs for construction site equipment, deployment of equipment. Case studies of personnel and disposal as a proportion of total costs[80]

Costs for	segment-by-segment dismantling of WBS 70 [%]	storey-by-storey dismantling of block construction [%]
Construction site equipment	9	4
Deployment of machines and equipment	31	25
Personnel	39	57
Disposal	21	14

The reuse potential (reuse and/or further use of the concrete produced/suitable elements in the residential building in the course of dismantling) for the P2 type, e.g., in terms of mass, is between 53 % and 76 % (cf. Chap. 7). Accordingly, half to three quarters of the concrete mass would not need to be disposed of as waste. Furthermore, the pre-crushing of the concrete elements into transportable or recyclable masses (reduced excavator deployment) on the disassembly construction site and the transport volume to the RC plant are not required for these quantities. The resulting cost savings are considerable.

What's more, it is possible to generate profit by selling the old concrete elements. In most cases, the price is currently negotiated individually between the partners (the dismantling company and the interested party/customer). For example, between 3 and 4 €/m² of concrete element surface are paid for (dismantled) ceiling panels. Thus, for example, a prestressed concrete ceiling panel of the P2 type, 6.00 m long and 1.80 m wide (system dimensions), costs between €33 and €43. A newly manufactured ceiling panel of adequate dimensions costs approx. € 252 to € 380 (as of II/2008)[81]. Had the entire panel been sent to the RC plant, tipping fees of € 270 per element would be incurred. This means that disposal is about as expensive as a newly manufactured panel.

Personnel costs account for the largest share of the total costs, with 39% for partial deconstruction of WBS 70 and 57% for partial deconstruction of a block building (see Tab. 4.7). Usually 6 workers are employed for partial deconstruction measures:

- 1 crane operator,
- 1 slinger,
- 1 banksman,
- 2 workers for chiselling work,
- 1 assistant.

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[80] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Schlussbericht zum Forschungsvorhaben „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 1 Krangeführter Rückbau, p. 266

[81] Mettke, Angelika: Die Verwendung von rückgebauten Plattenbauelementen aus Norddeutschland in Russland – Anforderungen und Chancen, presentation documents, presentation at the 12th symposium „Spannungsfeld Abbruch – Preise, Nachträge, Qualität, Vertrauen“, 29.05.2008 in Rostock

This staffing can hardly be reduced further. Thus, this cost item can only be reduced by optimising the coordination of activities. Therefore, the preparatory work (crane-independent work) in particular must be planned and executed in close coordination with the actual disassembly. This includes among others, determination of the disassembly sequence of the elements, with consideration of the static requirements, lead time of crane-independent work prior to the actual disassembly as well as an efficiently organised construction site, incl. systematic arrangement of the containers and their provision as well as preparation of interim storage areas.

The higher proportion of labour costs for the dismantling of block buildings is due to the high number of elements installed - approx. 150 per flat - as compared to approx. 30 elements in prefabricated buildings (see Fig. 4.3) - and the resulting increase in manual workload.

The deployment of machinery and equipment accounts for 31% of the total dismantling costs for prefabricated construction and 25% for block construction. The fact that the type of the deployed crane has an impact on the costs was explained in Chap. 4.8.2. Furthermore, the deployment of an excavator for pre-shredding of the construction elements accounts for a large proportion of the costs (see Fig. 4.21).

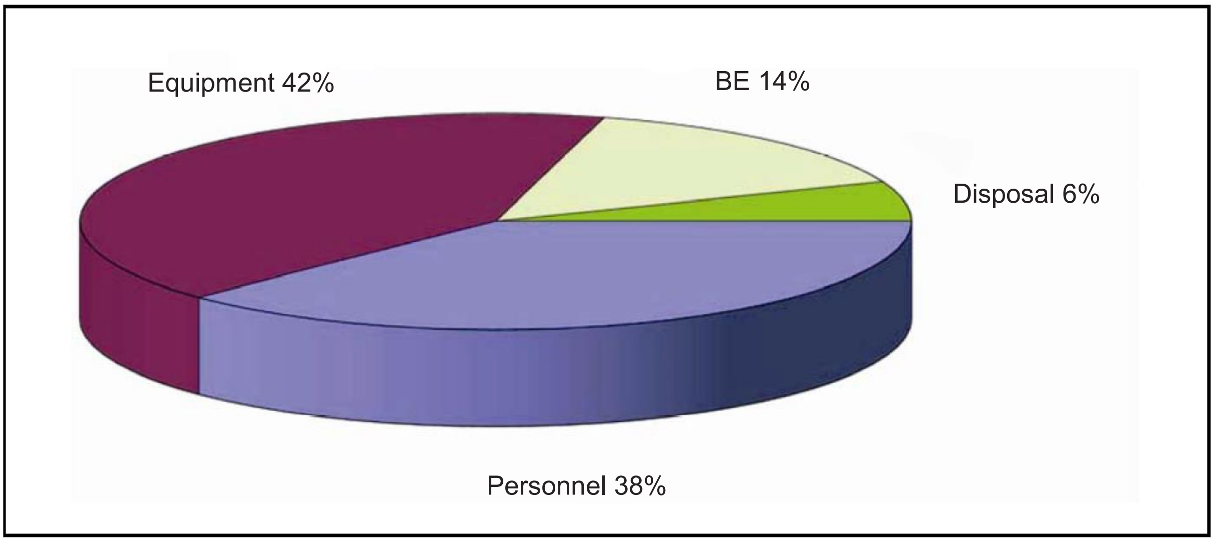


Fig. 4.21: Presentation of the proportionate costs for disassembly[82]

4.9 Process-related effects of disassembly on the structural condition of the concrete elements and derivation of preventive measures

With few exceptions, either no damage or only minor damage was identified, with regard to the quality of the grouting and joint concrete and the method of opening the joints and separating the fasteners.

The question of potential impact of disassembly (including transport, transshipment and storage processes (TUL)) on the structural condition arises in connection with the decision-making process for the reuse and/or further utilisation of concrete elements (cf. Chapter 7.2).

[82] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1 Krangeführter Rückbau, 2008, p. 274

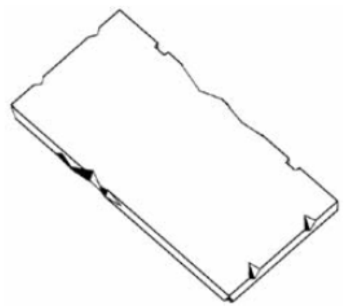
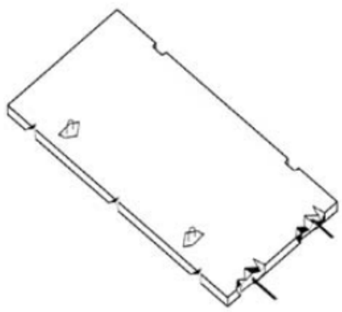
4.9.1 Typical damage resulting from disassembly

The following changes, damage or deterioration were observed on dismantled concrete elements in the course of the accompanying scientific investigations as compared to the original installed condition[83]:

- mechanical damage/chipped concrete in the area of the lifting eyelets,
- localised concrete spalling and chipping at corners and edges and consequent partial exposure of the reinforcement bars,
- adhesions of concrete and mortar residues of various dimensions on joint edges,
- cracks of different shapes and sizes,
- missing, deformed or corroded lifting eyelets and connecting bars,
- adhering installation and finishing materials (tiles, empty pipes, screed, blind frames, etc.).

Some of the most significant changes, manifestations or damage to ceiling panels, inner and outer walls of prefabricated buildings are presented below.[84]

Tab. 4.8: Damage patterns on disassembled ceiling panels

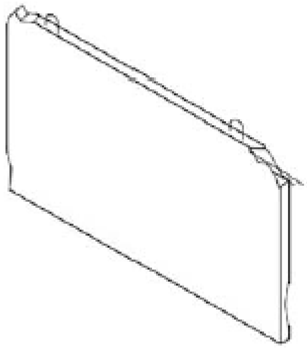
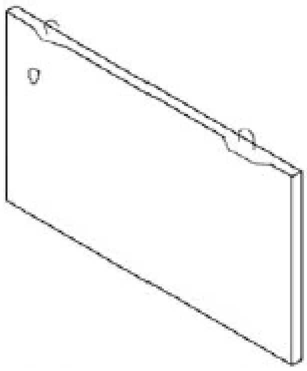
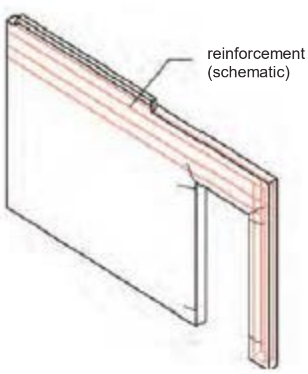
Possible manifestation/damage patterns after disassembly	Damage characteristics	Cause of damage	Real representation
	Chipping at corners and edges, front sides	separation process (chiselling work)	
	Concrete and mortar residue on side edges, Bursts on exposed lifting eyelets	Exposure of the lifting eyelets (chiselling work)	 

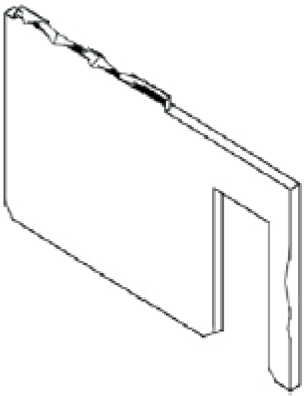
[83] extended according to Mettke, Angelika; Lassan, Bärbel; Britze, Mathias: Schadensbilder von demontierten Betonfertigteilen, Cottbus, 2004, p. 2

[84] Mettke, Angelika; Heyn, Sören; Asmus, Stefan, Evgeny Ivanov: Wiederverwendung von Plattenbauteilen in Osteuropa, final report processing phase I for the research project „Wissenschaftliche Vorbereitung und Planung des Rückbaus von Plattenbauten und der Wiederverwendung geeigneter Plattenbauteile in Tschechien“, Cottbus, 2008, p. 154 ff.

The edges of the ceiling panels had been primarily damaged during chiselling, especially during the use of mini-excavators with attachment chisels. When the lifting eyelets are being exposed, it can even happen that the panel is knocked through (cf. middle picture, real representation column, Tab. 4.8). Concrete bursts occurred if the joints or connecting bars had not been completely cut through.

Tab. 4.9: Possible damage patterns on disassembled inner wall elements

Possible manifestation/damage patterns after disassembly	Damage characteristics	Cause of damage	Real representation
	concrete spalling at corners and edges, exposed reinforcement; Damage occurs more frequently at the top edge of the wall element	Inappropriate separation process (chiselling work)	
	damage to lifting eyelets, drilled holes in the element (alternative strike) concrete bursts on exposed lifting eyelets	separation process, mechanical impacts	
	surface and bending cracks	external loads/tensions during disassembly	

	concrete spalling at corners and edges	separation process (chiselling work)	 

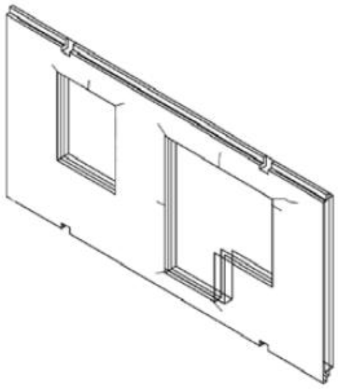
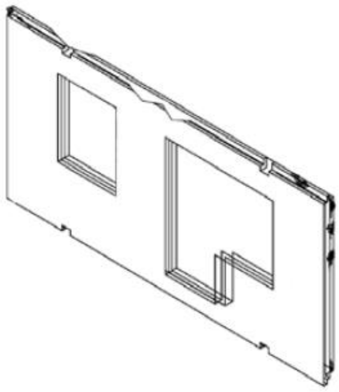
Concrete chipping and spalling at the edges of the inner walls is caused by the chiselling work performed in order to open the joints. Damage is more likely to occur during the use of machinery (mini-excavator with attachment chisel) than with hand-operated demolition hammers, just as was the case with the ceiling panels.

The boreholes made to provide for alternative attachment points prior to disassembly were partially fractured open. Obviously, neither support bolts nor pipe sleeves had been used to prevent such damage.

Inner walls with door openings displayed cracks in the corners in some cases, as illustrated in row 3 of Tab. 4.9. During disassembly, particular attention should be paid to the door shaft, which is a narrow structural component and a weak point.

Only minor concrete spalling has been observed on multi-layered outer walls (see Tab. 4.10): on the load-bearing layer in the area of the chiselled joints. Due to insufficient exposure of the joint, some cracks appear at the thresholds of balcony doors and in the area of window openings.

Tab. 4.10: Possible damage patterns on disassembled outer wall elements

Possible manifestation/damage patterns after disassembly	Damage characteristics	Cause of damage	Real representation
	Surface and bending cracks	external loads/tensions during disassembly	
	slight concrete spalling at corners and edges, mainly on the outside, concrete and mortar residue on side edges, partially exposed reinforcement, partially exposed connecting bars with incipient corrosion	separation process (chiselling work)	

Additionally, special attention must be paid to the transport, transshipment and storage processes (TUL) in order to prevent (further) damage to the concrete elements. The risk of additional damage to the elements increases with the number of transshipments. Therefore, transport, transshipment and interim storage processes in the context of reuse and/or further utilisation must be carried out with due care and efficiency.

It is important to ensure that the stacking timbers are arranged correctly during transportation and interim storage of the elements. This is because damage is almost exclusively due to improper handling and unqualified interim storage of the concrete elements.

Preventive measures – as applicable to new concrete elements – are essential to minimise or eliminate damage to concrete elements.

4.9.2 Preventive measures to minimise damage

All of the above mentioned damage caused by disassembly and transport, transshipment and storage processes can be avoided if:

- the work is carried out by qualified personnel in a proper and legally compliant manner,
- the joints are entirely open over the entire component length/width, and
- the elements are not torn loose from the bond.

In order to secure the door shaft against external impacts, it is recommended that a support is installed in the base area, in the same way as during the assembly with an iron bar. For example, a steel strip or flat steel bar could be attached, which can only be removed after the element has been finally installed. A screw connection proves to be a good choice here.

Furthermore, it is beneficial if the dismantling/disassembly team also carries out the reassembly. This ensures careful and professional handling of the existing building resources (building elements) right from the start. Mechanical damage should be reduced to a minimum in order to keep the work effort required for the preparation of the old concrete elements for their subsequent use as low as possible. This means that preparation work would primarily focus on closing the component openings for the alternative attachment points.

Results of the building condition analyses conducted throughout the entire dismantling process on a case study[85] revealed the following losses, which led to the components being sorted out:

- approx. 5-10% of ceiling panels (= 4 ceiling panels),
- approx. 10-15% of inner walls (= 5 inner walls),
- up to 5% of outer walls (= 2 outer walls)

in relation to the total number of dismantled elements.

This result (merely) supports the necessity to incorporate preventive measures for the prevention of additional damage.

4.10 Ecological assessment of the dismantling process as compared to demolition

4.10.1 Introduction

An ecological assessment of dismantling as compared to demolition was carried out 10 years ago in the context of research for the State Office for the Environment and Geology, Free State of Saxony, in terms of sustainable construction and dismantling[86]. Several assumptions had to be made due to insufficient expenditure data being available. As part of the BMBF research project "Dismantling industrial building fabric - large-format concrete elements in the ecological cycle", the energy expenditure and the resulting emission load for dismantling and demolition were recalculated on the basis of own measurement data and current data from literature.[87]

[85] Mettke, Angelika; Heyn, Sören: Ergebnisse der Untersuchungen zum Bauzustand der zwischengelagerten Elemente für den Bau des Vereinshauses Gröditz 1911 e.V., evaluation report, BTU Cottbus, 2005

[86] Mettke, Angelika, Thomas, Cynthia: Wiederverwendung von Gebäude und Gebäudeteilen, Materialien zur Abfallwirtschaft, 1999, p. 91 ff.

[87] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 1: Krangeführter Rückbau, 2008, p. 275 ff.

The investigations were based on a 6-storey prefabricated building of WBS 70 with 4 entrances, which had been partially deconstructed and demolished. The parameters of the residential building in the form of a building specification were as follows:

- 72 residential units,
- 2.720 m² of living space,
- 3.730 m² of enclosed space,
- 1.260 elements with a total weight of around 4,100 t.

The partial deconstruction comprised 1,5 entrances with around 1,180 t of concrete mass (elements), the demolition comprised 2,5 entrances with around 2,920 t of concrete mass (elements).

The aim of evaluating the dismantling and demolition efforts considered here from an ecological point of view is to demonstrate which procedures enable energy to be saved and emissions to be reduced. Evaluation was based on the energy consumption for the deployed machinery and equipment and the resulting air pollution from atmospheric emissions. In other words, the following calculation only captures the direct energy expenditure, including the environmental impact, resulting from preliminary measures (crane-independent expenditure) and direct disassembly (crane-dependent expenditure) or demolition. It does not consider any indirect environmental impacts resulting from dust and noise emissions or vibrations and their assessment with regard to compliance with the emission and immission values (see Chap. 8.2.4 and 8.2.5). Furthermore, the water consumption required, for example, for the containment of dust pollution during demolition is not taken into consideration. The impacts resulting from transport of the machines and equipment (cranes, excavators, etc.) to and from the site have not been defined either. In this respect, the identified ecological parameters are merely to be understood as initial orientation in the decision-making process for the removal of industrially constructed buildings.

4.10.2 Screening of the energy expenditure required for crane-based dismantling

The calculation of the energy consumption is based on the measurements of the operating times of the machines and equipment during dismantling. The operating times[88] are listed in detail in the final report. They are documented in a condensed form in Table 4.11 below.

In the case study evaluated here, a mobile crane (FZK) was deployed for the partial deconstruction. Alternatively, a tower crane (TDK) was included in the calculation in order to evaluate the deployment of large equipment within the measure (strategy). Extrapolation of the determined parameters - the machines and equipment used and their operating time – to the fictitious crane-guided dismantling or demolition of the entire building enables a comparison of the results.

The energy consumption results from:[89]

[88] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, 2008, p. 277

[89] Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, Materialien zur Abfallwirtschaft 1999, p. 94

$$E_G = \sum_{i=1}^{k} P_{M,i} \bullet t_{M,i} \bullet f_{M,i} \bullet V_{M,i} \bullet (PEI_i + H_{u,i}) \tag{4.3}$$

E_G	Total energy requirement for dismantling [MJ]
$P_{M,i}$	Performance of the deployed machines and equipment [kW]
$t_{M,i}$	Machine utilisation time [h]
$f_{M,i}$	Utilisation factor of machines and equipment per operation
$V_{M,i}$	specific energy consumption according to utilisation [l/kWh]
PEI_i	Primary energy content of specific energy source [MJ/l] or in case of electrical useful energy [MJ/kWh]
$H_{u,i}$	Calorific value of specific energy sources [MJ/ l] or useful electrical energy [MJ/ kWh]

Tab. 4.11: Energy expenditure for disassembly of a 6-storey apartment block of WBS 70 with 4 segments/4 entrances (values rounded)

	Device / Machine	Performance[1)] $P_{M,i}$ [kW]	Working hours $t_{M,i}$ [h]	Capacity[2)] $f_{M,i}$ [%]	Actual energy demand [kWh]	Energy source	spec. consumption capacity[3)] $V_{M,i}$ [l/kWh]	Demand [l] [kWh]	PEI_{ET} + $H_{u,i}$ [kW]	E_G [MJ]
	Row/Column	1	2	3	4	5	6	7	8	9
	Basis for investigation [see (4.3)]				1 x 2 x 3			4 x 6		7 x 8
1	Mobile crane (FZK)	149	596	75	66,491	Diesel	0.27[4)]	17,953	35.3[5)]	633,740
2	Tower crane (TDK)	149	595	75	66,491	Electricity	(1 kWh = 3.6 MJ)	239,369	1.21[6)]	289,636
3	Mini excavator	10.3	115	75	888	Diesel	0.27[4)]	240	35.3[5)]	8,472
4	Hammer drill	1.15	47	75	41	Electricity	(1 kWh = 3.6 MJ)	148	1.21[6)]	179
5	Cutting torch	22.9	24	100		Acetylene				550
	Total energy demand with FZK (Σ EG from row 1+3+4+5)									**642,941**
	Total energy demand with TDK (Σ EG from row 2+3+4+5)									**298,837**

1) Performance parameters according to device/machine manufacturer's specifications

2) Assumption

3) Expenditure considered for the provision of energy and energy content of the energy source according to GEMIS (Global Emission Model of Integrated Systems)[90]

4) Crane and mini-excavator are powered by diesel engines. Approx. 0.27 litres of diesel are used to generate the output of 1 kWh at a capacity utilisation of 75%[91]

[90] Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, Materialien zur Abfallwirtschaft 1999, p. 149
[91] ibidem, p. 150

5) Primary energy: 35 to 38 MJ/l for diesel, 32 MJ/l for petrol[92]

6) PEI = 0.21 MJ/MJuse: in order to utilise 1 MJ of energy, 0.21 MJ must be provided during production

Accordingly, the energy required for crane-guided dismantling of the entire block of flats would amount to approx. 643 GJ with FZK and only approx. 299 GJ with TDK. In terms of 1 tonne of concrete component to be dismantled, this results in ~ 157 MJ in case of FZK deployment and ~ 73 MJ in case of TDK deployment (cf. Fig. 4.22). The results show a clear advantage of TDK deployment. The energy consumption for FZK is more than twice as high as that of TDK.

4.10.3 Energy required for demolition

The demolition of 2.5 entrances to WBS 70 block of flats was completed in 176 hours by means of 2 excavators (30 t and 40 t load capacity). Extrapolating this to the demolition of 4 entrances to the entire block of flats results in approx. 290 deployment hours. The excavators are diesel-powered. Approx. 0.28 litres of diesel[93] are used to generate the output of 1 kWh at a capacity utilisation of 50 % (estimated) (cf. Table 4.12)

Tab. 4.12: Energy consumption for the demolition of a 6-storey block of flats of WBS 70 type[94]

Device	Performance* [kW]	Energy sources	Deployment time [h]	Capacity [%]	Actual energy demand [kWh]	spec. Consumption capacity [l/kWh]	Demand [l]	PEI_{ET} [MJ/l]	E_G [MJ]
Excavator (30 t)	130	Diesel	250	50%	16,250	0.27	4,550	35.3	160,615
Excavator (40 t)	220	Diesel	250	50%	27,500	0.27	7,700	35.3	271,810
								Total energy demand E_G	**432,425**

* Performance parameters according to machine manufacturer's specifications

The energy required for the complete demolition therefore amounts to approx. 433 GJ. This means that approximately 106 MJ of energy is required in order to generate 1 t of construction debris (see Fig. 4.22).

4.10.4 Emission assessment

A great deal of information on the environmental relevance of the processes involved in the manufacture of construction products is already available, yet there is relatively little knowledge of the direct environmental impacts of dismantling and demolition process of industrially constructed buildings.

The reduction of CO2 emissions is currently the main focus of general scientific and political discussions. Still, it is only a partial goal, as globally sustainable development requires careful use of all resources.

[92] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, 2008, p. 278, cf. www.bigdo.de/lexikon/64_heizwert.html; accessed on 14.12.2008

[93] Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, Materialien zur Abfallwirtschaft 1999, p. 150

[94] Mettke, Angelika, Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, Teil 1: Krangeführter Rückbau, 2008, p. 279

The emission analyses presented here are limited to the analysis of atmospherically relevant substances CO_2[95], SO_2 and NO_x, resulting from the energy expenditure of the equipment and machinery for dismantling and demolition and which have negative effects on the environment due to their released quantities (cf. Tab. 4.13).

Tab. 4.13: Sources, causes and effects of climate-relevant substances[96]

Hazardous substance	Source	Main causes	Impact
CO_2	Combustion of fossil fuels (crude oil, natural gas and coal)	Industry, manufacturing, transport, energy supply, small consumers	The greenhouse effect
SO_2	Combustion of sulphur-containing fossil fuels (coal, heating oil (heavy) and fuels)	Combustion systems of the energy sector, industry, and small consumers	Precursor substance of 'acid rain', new forms of forest damage
NO_x	Combustion of fossil fuels at high temperatures	Traffic	Precursor substance of tropospheric ozone, jointly responsible for acidification and eutrophication (over-fertilisation) of soil and water bodies

Energy-related emissions are calculated on the basis of emission data for the provision of electricity and diesel. Refer to Table 4.14 for the recording approach. The emission data refers to the year 2005.

Tab. 4.14: Emission data for electric energy mix and diesel, [GEMIS[97] 4.5, as of February 2009]

Energy sources	Emission factor [kg/TJ$_{final\ energy}$]		
	SO_2	**NO_x**	**CO_2**
Electric energy mix	107,037	175,766	178,885
Diesel	77,386	-	74,396

In the case of a 6-storey prefabricated building with 4 entrances that needs to be completely removed, the emissions based on the calculated energy consumption for disassembly by means of FZK or TDK and for demolition by means of an excavator are as follows:

[95] According to the latest alarming scientific findings on climate change, the WWF (World Wide Fund For Nature) is calling for a reduction in CO2 emissions throughout the EU by 2020 amounting to minimum 30 % in comparison to the values of 1990 [WWF: Gabriel must not torpedo the EU's 30 per cent CO2 reduction target; www.daylinet.de/energieumwelt/27860.pttp, accessed on 16.12.2008]

[96] extended according to Mettke, Angelika, Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, long version, 1999, p. 328; cf. www.umweltbundesamt.at/umweltschutz/luft/...; accessed on 15.12.2008

[97] GEMIS calculates not only the direct emissions from energy systems (power plants, electricity imports, oil, coal, gas supply, etc.) resulting from combustion, but also all upstream and downstream emissions (extraction, transport, processing)

Tab. 4.15: Emissions during disassembly and demolition of a WBS 70 apartment block (6-storey, 4 entrances) (values rounded)

	Total requirement* [TJ]	specific emissions** [kg/TJ]			Emissions [kg]		
		SO_2	NO_x	CO_2	SO_2	NO_x	CO_2
Disassembly by FZK							
Diesel	0.6422	77.386	-	74,396	49.697	-	47,778.111
Electricity	0.0002	107.037	175.766	178,885	0.021	0.035	35.778
Total					**49.718**	**0.035**	**47,813.889**
Disassembly by FZK							
Electricity	0.2899	107.037	175.766	178,885	31.030	50.955	51,858.762
Diesel	0.0085	77.386	-	74.396	0.658	-	632.366
Total					**31.688**	**50.955**	**52,491.128**
Demolition							
Diesel	0.4324	77.386	-	74,396	33.462	-	32,168/830

* see Tab. 4.11

** see Tab. 4.12 and 4.14;

Measurement unit Terra = 10^{12} (trillion)

4.10.5 Comparison of dismantling/demolition methods from an ecological perspective

A comparison of the total energy requirement calculated for the dismantling and demolition of the 6-storey WBS 70 with 4 entrances (approx. 4.100 t of concrete components installed) as an example gives the following picture in relation to 1 t of concrete component (Fig. 4.22):

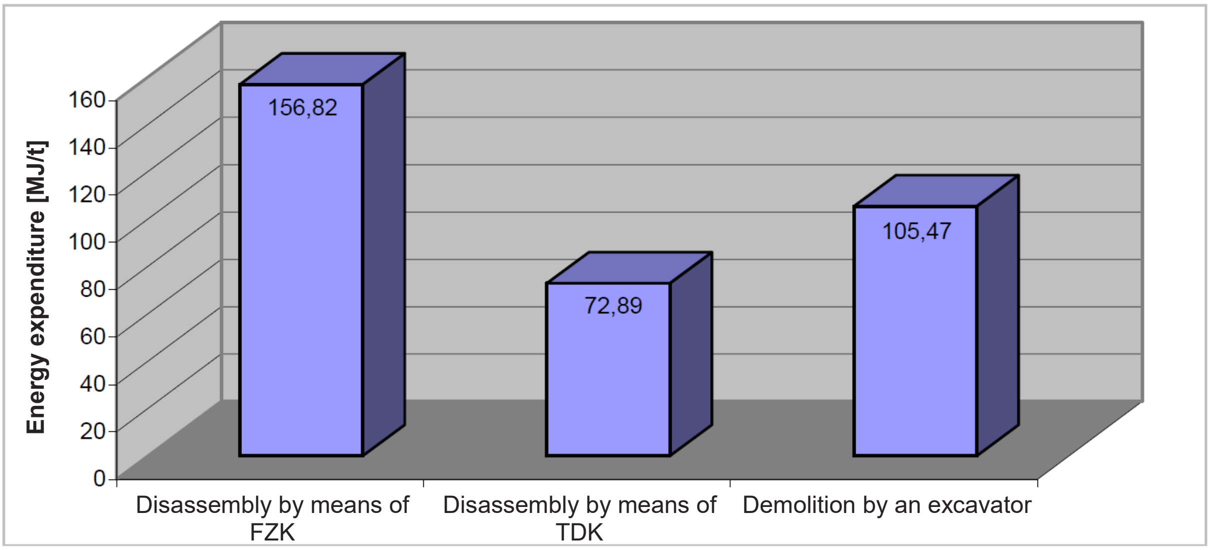


Fig. 4.22: Comparison of energy expenditure for disassembly and demolition of 1 t of concrete component

The graphic illustrates the energy advantage resulting from the deployment of a tower crane.

Fig. 4.23, energy-related CO2 emissions - in relation to 1 tonne of concrete component to be dismantled or demolished – compared in relation to the dismantling/demolition methods:

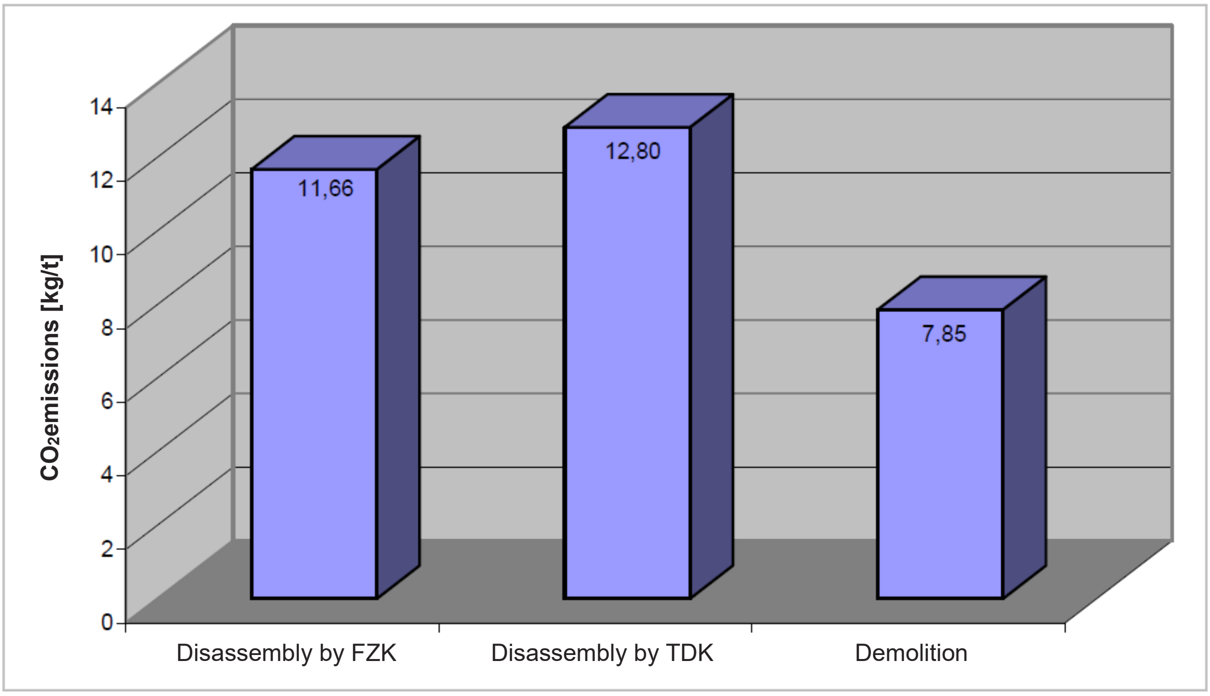


Fig. 4.23: Comparison of$_{CO2\ emissions}$during disassembly and demolition for 1 tonne of concrete component

Comparison of CO2 emissions of the analysed demolition method shows that demolition is lower in emissions than dismantling. The CO_2emission during demolition is only slightly greater than the CO_2emissions resulting from dismantling.

The comparison of SO_2 and NO_x emissions per 1 tonne of concrete component is presented graphically in Fig. 4.24.

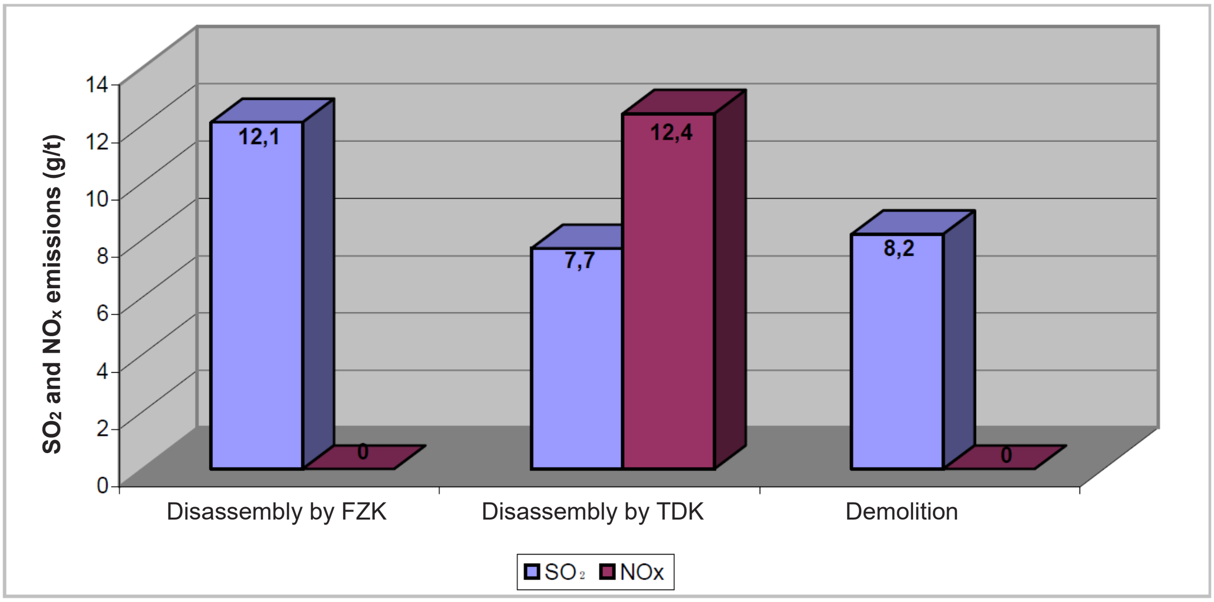


Fig. 4.24: Comparison of SO_2 and NO_xemissions for 1 tonne of concrete component during disassembly and demolition

The energy-related SO_2 emissions are minimally in favour of TDK deployment as compared to demolition and significantly in favour of disassembly by means of FZK. However, the deployment of TDK generates high levels of NO_x dust due to electricity as energy source.

Overall, it can be concluded that the energy required for disassembly by means of a TDK is cheaper by one-third in comparison with demolition and is almost 50% less expensive than disassembly by means of an FZK.

The$_{CO2\ emissions}$calculated for demolition are around 37% lower than in the case of disassembly. Demolition generates approx. 4.7 kg and 3.8 kg less CO_2 emissions per tonne of demolished material and produced construction waste respectively, which is better than the results for disassembly. There are no significant differences in the release of CO_2 between TDK and FZK deployment. In comparison to FZK, CO_2 emissions were higher by approx. 900 g in the case of the TDK use in relation to 1 tonne of dismantled prefabricated concrete element.

The SO_2 emissions are at the lowest level in the case of disassembly by means of TDK. At 0.6 g/t, the gains in comparison with demolition are only marginally more favourable, though still 4.5 g/t less in comparison wik the dismantling by means of FZK. However, the situation is reversed when it comes to nitrogen oxide emissions. The deployment of TDK generates 12.2 g of NO_x dust during the dismantling of 1 tonne of prefabricated concrete element due to electricity used as an energy source. According to the GEMIS 4.5 version of the emissions data, no more nitrogen oxides have been emitted from diesel as energy source since 2005. The GEMIS 4.2 version still reported NO_x emissions of 1.381 kg/TJ input for diesel.[98]

The implementation of technical measures in accordance with exhaust gas regulations has led to a reduction in air pollutant emissions, including nitrogen oxides, and this has been taken into account in the current GEMIS version.

Reduction rates for CO2 emissions are possible and necessary by utilising CO_2-free power generation.

[98] Due to the current data situation resulting from GEMIS 4.5, the emissions assessment is no longer entirely consistent with our own previous research work in some aspects.

5 Hazardous substances in prefabricated buildings and their specific disposal

6 Quality features of used concrete elements

In order to reuse and/or further use concrete elements that have been used previously, it is important to know their quality parameters. The final and interim results have been published continuously in [4], [5], [7], [25], [33], [35], [41], [43], [49], [50], [53], [55], [56], [58]. Particular reference is made to [55] below.

6.1 Analysed range of elements

The main range of elements installed in various design variants has been examined several times:

Ceiling panels (DP), load-bearing inner walls (IW) and outer walls (AW); as well as selected roof cassette panels and bathroom cells of the residential building types constructed by means of the wall construction method[198]

- WBS 70, P2, PN36-NO, WBR Erfurt (load level 5.0 t/6.3 t),
- IW 72 (strip construction method; 2.0 t),
- IW 64 (block construction method; 0.8 t).

Furthermore, ceilings, inner and outer walls, pillars, beams and frames of buildings erected using the mixed construction method were analysed:

- School building of the 'Dresden' type,
- Kindergartens in LGBW (light multi-storey construction; 3.0 t).

Due to the high proportion of WBS 70 (644,900 residential units) and P2 (363,600 residential units)[199] (see Chap. 2, Tab. 2.1), in the stock of industrially constructed residential buildings in the GDR, these are discussed below as an example. The basic geometric characteristics of the analysed main elements DP, IW and AW of the P2 and WBS 70 residential building series can be summarised as follows:

[198] Mettke, Angelika; Heyn, Sören; Thomas, Cynthia: Schlussbericht Forschungsvorhaben „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 1 Krangeführter Rückbau, 2008, p. 23 ff.

[199] Types of prefabricated buildings most frequently built in the GDR (as of 1990): WBS 70: 644,900 apartments; P2: 363,600 apartments [IEMB 1992]

Tab. 6.1: Geometric characteristics of outer wall elements of the WBS 70 and P2 residential building series

Outer walls (AW)	Length [m]	Height [m]	Thickness [mm]
WBS 70 Longitudinal walls and gable walls	1.460 1.975 3.580 5.115 5.845 5.980 etc.	2.865	230, 260, 300
P2 Longitudinal walls and gable walls	1.867	2.345	240
	3.585 3.750 3.887 5.985	2.845	290

The overview demonstrates that the outer walls of WBS 70 vary in length and thickness. The height of the outer walls is standardised at 2.865 m.

The geometric dimensions of the outer walls of the P2 type are also different. The thickness of the P2 outer walls varies between 240 and 290 mm. The height of the outer walls of the standard storeys is congruent at 2.845 m.

Tab. 6.2: Geometric characteristics of the inner wall elements in the WBS 70 and P2 residential building series

Inner walls (IW)	Length [m]	Height [m]	Thickness [mm]
WBS 70	3.580 4.610 5.810	2.630	150
	3.580 4.780 5.980	2.620	
P2	3.580 3.410 4.095	2.785	
	5.460 3.580	2.635	

The thickness of the inner walls of both building series is compliant and equals 150 mm. The parameters height and length of the inner walls in the standard storeys vary depending on the installation position.

Tab. 6.3: Geometric characteristics of the ceiling elements in the WBS 70 and P2 residential construction series

Ceilings (DP)	Length [m]	Width [m]	Thickness [mm]
WBS 70	5.980 5.970	2.980 1.785	140
P2	5.970 4.170 3.570 2.370	1.785	

The ceiling panels have identical thickness of 14 cm, irrespective of the large panel building type. Two different ceiling widths of 3.00 m and 1.80 m, of 6.00 m length (system dimensions) were installed in WBS 70. The ceiling panels in the P2 type have standardised widths of 1.80 m (system dimension). They vary in length; 6.00 m long ceilings are generally made of prestressed concrete.

Consequently, it is necessary to record the geometric parameters of the concrete elements on an object-specific basis for reuse and recycling.

It is beneficial to label and list the concrete elements intended for reuse or recycling while they are still installed. The element catalogues developed for the element ranges of type P2 and WBS 70[200], published by the author, serve as a working aid here.

Remark:

The range of elements in the 'Dresden' type school building, which was constructed using the mixed construction method differs in principle from that of the residential buildings constructed by means of the wall construction method. More than 70 different components are installed in this series. The ceiling panels are designed as cavity ceilings with L x W x H dimensions of e.g.: 7.20 m or 6.00 m x 0.60 m x 0.25 m (system dimensions) and the inner wall blocks with the dimensions L x D x H: 1.20 m x 0.32 m x 3.05 m.

6.2 Quality features of used concrete elements

6.2.1 Technical features of concrete

6.2.1.1 Concrete compressive strength classes, exposure classes

Concrete plays a significant role as load-bearing construction material due to its favourable strength performance, particularly under the compressive stress. Concrete is categorised into strength classes according to its compressive strength (see Tab. 6.4).[201]

[200] Mettke, Angelika (ed.) Element catalogue, overview: element range of type P2, 2003; Mettke, Angelika (ed.) Element catalogue, overview: Element range of type WBS 70 on the example of building type WBS 70/11, 2007

[201] DIN EN 206-1 and DIN 1045 as of 2001 introduced new concrete classes, among other things. In contrast to DIN 1045 from 1988 (determination of compressive strength on cubes with an edge length of 20 cm), the concretes are labelled with characteristic cylindrical compressive strength (first value) and characteristic cube compressive strength (second value). The cylinders are 150 mm in diameter and 300 mm high; the cubes have an edge length of 150 mm

Tab. 6.4: Overview of the concrete strength classes according to TGL, DIN and DIN EN[202]

	Rules and regulations	**Concrete quality/compressive strength classes for standard and heavy concrete**										
in FRG	DIN EN 206-1: 2001-07 / DIN 1045-2: 2001-07	C 8/10			C 8/10		C 12/15		C 16/20		C 20/25	C 25/30
	DIN 1045: 1977 / DIN 1045:1988-07	B 5			B 10		B 15				B 25	
in GDR	TGL 33412/01 after 1980	Bk 5	Bk 7.5		Bk 10		Bk 15		Bk 20		Bk 25	Bk 30
	TGL 0-1045 before 1980			B 80		B 120		B 160		B 225		B 300

	Rules and regulations	**Concrete quality/compressive strength classes for standard and heavy concrete**										
in FRG	DIN EN 206-1: 2001-07 / DIN 1045-2: 2001-07	C 30/37			C 35/45	C 40/50	C 45/55	C 50/60	C 55/67*		… C 100/115	
	DIN 1045: 1977 / DIN 1045:1988-07	B 35			B 45		B 55		B 65*			
in GDR	TGL 33412/01 after 1980	Bk 35		Bk 40	Bk 45	Bk 50	Bk 55	Bk 60				
	TGL 0-1045 before 1980				B 450			B 600				

Regulation for the transition period between the old and new DIN 1045 standard, *high-strength concrete

A total of around 1,200 concrete elements were tested by the Structural Recycling Group, primarily in a non-destructive manner by means of a Schmidt rebound hammer test (model N) in accordance with DIN EN 12504-2[203]. Using the drill cores, the obtained measurement results[204] were consistently demonstrated in a point-by-point comparison. The following results can be observed (see Tab. 6.5, Fig. 6.1).

[202] Extract from element catalogue; overview: Element range of type WBS 70 on the example of building type WBS 70/11, ed. Angelika Mettke, 2007

[203] DIN EN 12504-2: 2001-12 Testing of concrete in structures, Part 2: Non-destructive testing; determination of the rebound rate

[204] DIN EN 12504-1: 2000-09 Testing of concrete in structures, Part 1: Core samples; production, examination and testing under pressure; DIN 1048-2: 1991-06, Part 2: Test methods for concrete, solid concrete in structures and components

Tab. 6.5: Comparison of planned and actual concrete compressive strength classes of ceiling panels and inner walls of P2 and WBS 70 buildings

Requirements/measurement results	Concrete compressive strength class (underline means predominantly manufactured strength class)			
	Ceiling panels (DP)		Inner walls (IW)	
	P2	WBS 70	P2	WBS 70
Requirements: - According to project planning Concrete quality pursuant to TGL 0-1045: 1973-04 (former designation)	a) B 225 slack reinforced b) B 300 prestressed		B 160 / B 225B	
Concrete class BK (TGL 33403: 1980-10)		BK 25 prestressed		BK 25
according to strength class pursuant to DIN EN 206-1: 2001-07	a) C 16/20 slack reinforced b) C 25/30 prestressed	C 20/25	C 12/15 / C 16/20	C 20/25
- according to DIN 4227-1, section 3.1.2. strength class pursuant to DIN EN 206-1	B 35	B 35		
or according to DIN 1045-1: Section 6.2 (3)	C 30/37	C 30/37		
Test results: (statistical evaluation according to DIN 1048-2) in brackets ( ) Number of analysed elements	a) C 20/25 (77) slack reinforced b) C 30/37 (83) prestressed	C 50/60 (160) prestressed	C 20/25 (172)	C 20/25 (126)
Evaluation: achieved as compared to as compared to DIN 1045-1 (old DIN 4227-1)	project planning a) Increase by 1 class b) achieved	achieved Increase by 6 classes Increase by 4 classes	achieved Increase by 1 class	consistently achieved

TGL 0-1045: 1973-04 Reinforced concrete structures, design and execution
TGL 33403: 1980-10 Concrete construction; strength and deformation characteristics
DIN 4227-1: 1988-07 Prestressed concrete, components made of standard concrete with limited and full pre-tensioning
DIN EN 206-1: 2001-07 Concrete, Part 1: Specification, properties, production and conformity / DIN 1045-02: 2001-07 Application rules for DIN EN 206-1
DIN 1048-2: 1991-06 Test methods for concrete; hardened concrete in structures and components
DIN 1045-1: 2001-07 Concrete, reinforced concrete and prestressed concrete structures; dimensioning and construction

Discussion of the results for the compressive strength parameter (see Tab. 6.5)

It should generally be noted that the compressive strength of the concrete elements has improved with advancing age. This is valid without any restrictions for the results obtained on 172 measured inner walls of the P2 type, on 243 tested prestressed concrete ceilings of the WBS 70 and P2 type as well as on 77 controlled, slack reinforced ceiling panels of the P2 type. The tested 126 inner walls of WBS 70 confirm the projected concrete strength class.

- **WBS 70**

The statistical evaluation according to DIN 1048-2 of 160 series of measurements of the tested range of ceiling panels according to DIN EN 12504-1 and 2 proves that the compressive strengths are well above the requirements of the project planning documents. According to the project planning, the prestressed concrete ceiling panels had been manufactured as BK 25, B 25 or C 20/25. According to DIN 1045-1, section 6.2, replacement for 4227-1, section 3.1.2, prestressed concrete with immediate bond is required to be manufactured at least as C 30/37. The evaluation of the measurement data of the tested 15-30 year old WBS 70 ceiling range reveals a C 50/60. This corresponds to a 4-fold increase as compared to the minimum requirement according to the valid DIN. Random analyses of concrete compressive strength performed on drill cores confirm these results obtained by means of the rebound hammer testing.

The statistical evaluation of 126 series of measurements on load-bearing inner walls of WBS 70 confirm that strength class C 20/25 is achieved with certainty. The following graphical representation of the distribution of the measurement data in the frequency diagram (see Fig. 6.1) 6.1)[205] indicates normal distribution (Gaussian bell curve). The result for the tested range of elements ("presented in excerpts") can therefore be summarised as follows:

The strength class is as follows for

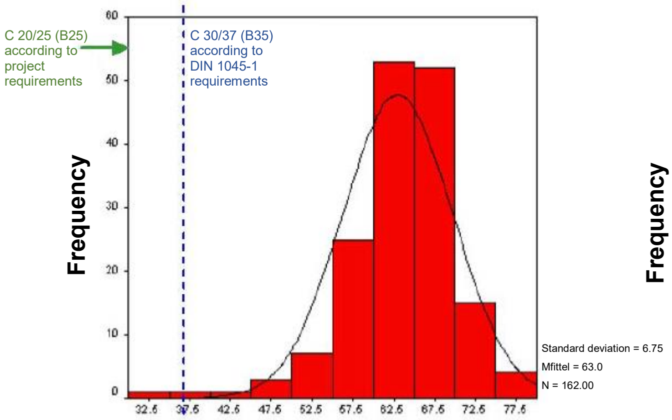
- Prestressed concrete ceilings C 50/60,
- load-bearing inner walls C 20/25.

- **P2**

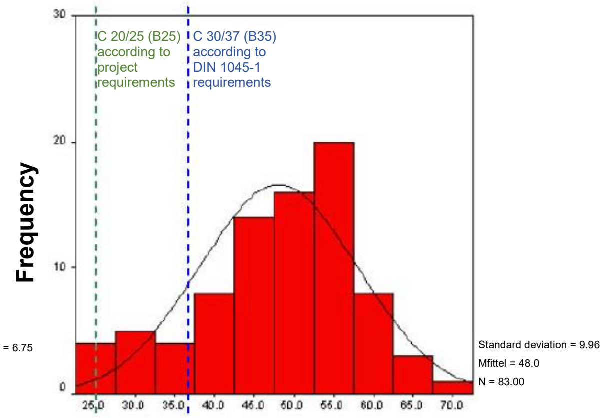
The measured values of the tested P2 concrete elements are somewhat scattered in comparison to the tested WBS 70 range. The investigations on a block of flats in Weißwasser are largely responsible for this. Such fluctuations have not been recorded at other investigation sites. However, normal distribution of the measured values has been calculated. 77 slack reinforced, 83 prestressed ceiling panels and 172 inner walls were examined. The tested range of elements - with the exception of the ceilings in the tested building in Weißwasser - complies with the following strength classes:

- slack reinforced ceilings C 20/25,
- Prestressed concrete ceilings C 30/37,
- load-bearing inner walls C 20/25 (cf Fig. 6.1).

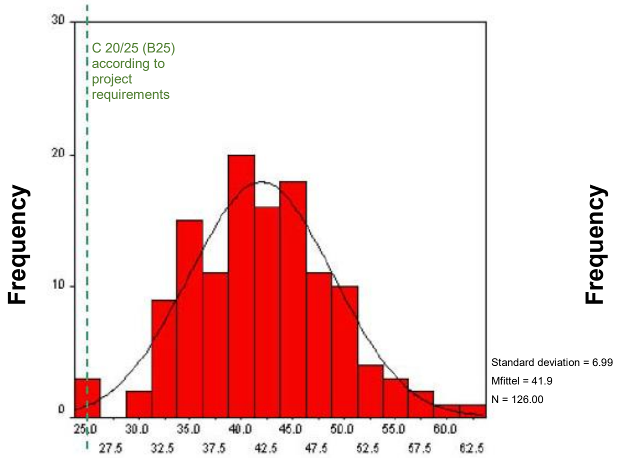
[205] According to the Kolmogorov-Smirnov adjustment test, the hypothesis "normal distribution is present" is not rejected in all cases.



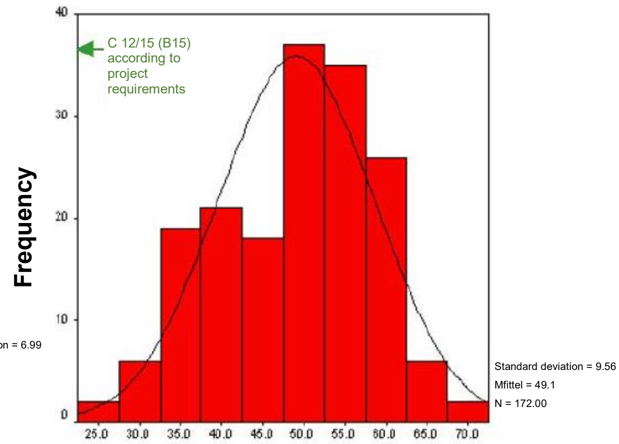
Concrete compressive strength WBS 70 DP



Concrete compressive strength P2 DP prestressed concrete



Concrete compressive strength WBS 70 IW



Concrete compressive strength P2 IW

Fig. 6.1: Comparison of the projected and determined concrete compressive strengths of ceiling panels and inner walls[206] (WBS 70: concrete age between 14-23 years, P2: concrete age between 21-27 years)

6.2.1.2 Exposure classes

The purpose of exposure classes is to ensure the durability of individual concrete components as well as the entire structure over the planned service life (usually > 50 years). A service life of 80 to 130 years is assumed for residential and public buildings.[207]

The installed concrete components are exposed to different environmental conditions during use, depending on where they are placed. Therefore, the main criterion for categorisation in the corresponding exposure class is the location where the building component is or will be installed. Exposure classes determine the type of impact on the concrete and the reinforcement.

Potential impacts on the reinforcement in the concrete are characterised by the following exposure classes:

- XC (carbonatation) - risk of corrosion due to carbonatation,
- XD (deicing) - risk of corrosion due to chlorides from deicing agents,

[206] Kania, Gregor: Statistische Auswertung der ermittelten Ergebnisse von Untersuchungen zur Betondruckfestigkeit, Karbonatisierungstiefe und Betondeckung an gebrauchten Betonfertigteilen, student research project, 2006
[207] cf. Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 20

- XS (Seawater) - risk of corrosion due to chlorides from seawater or salty sea air.

Potential impacts on the building material concrete are defined by exposure classes:

- XF (Freezing) exposure to frost with and without deicing agents,
- XA (Chemical Attack) exposure due to chemical attacks,
- XM (Mechanical Abrasion) exposure due to abrasion.

Level of influence is expressed on 1-4 scale with 1 meaning weak and 4 meaning strong. The specification of the exposure class has an effect on minimum concrete quality, minimum concrete cover (see Table 6.6) and limitation of crack widths.

Exposure class X0 (no risk of damage) only applies to non-reinforced concrete (e.g. non-reinforced foundations).

The following exposure classes, for example, apply simultaneously to the construction of a residential building:

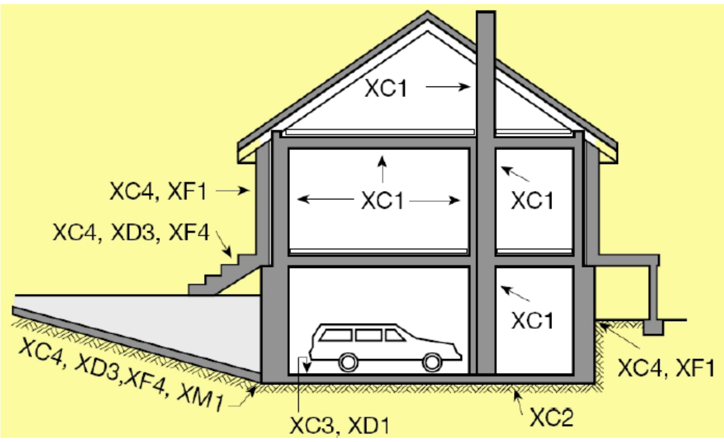


Fig. 6.2: Examples of several exposure classes that apply simultaneously to a residential building[208]

The results of the analysed concrete strength classes presented in Chapter 6.2.1.1 have been assigned to exposure classes (Tab. 6.6) to determine which specific environmental conditions are met in the absence of reconditioning measures.

The results demonstrate that the analysed ceiling panels and inner walls of the WBS 70 and P2 building type comply with the requirements of exposure classes XC1 to XC3. Accordingly, the prestressed ceiling panels of both building series allow the use of XC4 and higher.

[208] Concrete technology cement leaflet, B9

Tab. 6.6: Requirements in accordance with DIN EN 206-1/DIN 1045-1 for the concrete strength class and minimum concrete cover - Assessment of old concrete elements in preparation for their secondary use [excerpt from DIN 1045-1: 2001-07; Tab. 3, 4]

<table>
<tr><th colspan="2" rowspan="2">Relevant exposure class</th><th rowspan="2">Description of the surroundings</th><th rowspan="2">Examples of allocation</th><th colspan="2">Minimum concrete cover c_{min} [mm]</th><th rowspan="2">Minimum compressive strength class min f_{ck}</th><th rowspan="2">Evaluation
Utilisation of previously used
ceiling panels DP and inner walls IW without reconditioning</th></tr>
<tr><th>Concrete reconditioning steel</th><th>Tensioners</th></tr>
<tr><td rowspan="4">Carbonatation-induced reinforcement corrosion</td><td>XC1</td><td>dry or constantly wet</td><td>Components in interior spaces with the usual air humidity including kitchen, bathroom,</td><td>10</td><td>20</td><td>C 16/20</td><td rowspan="4">ceiling panels (DP) – prestressed and slack reinforced, inner walls (IW) from WBS 70 and P2</td></tr>
<tr><td>XC2</td><td>wet, rarely dry</td><td>Foundation components
Foundation slab</td><td>20</td><td>30</td><td>C 16/20</td></tr>
<tr><td>XC3</td><td>moderate humidity</td><td>Components that are frequently exposed to outside air; concrete protected from rain outdoors</td><td>20</td><td>30</td><td>C 20/25</td></tr>
<tr><td>XC4</td><td>alternately wet and dry</td><td>External components with direct exposure to rain</td><td>25</td><td>35</td><td>C 25/30</td></tr>
<tr><td rowspan="2">Chloride-induced reinforcement corrosion</td><td>XD1</td><td>moderate humidity</td><td>Concrete surfaces, exposed to spray mist; Garages</td><td>40</td><td>50</td><td>C 30/37</td><td rowspan="4">prestressed ceiling panels (DP) from WBS 70 and P2</td></tr>
<tr><td>XD3</td><td>alternately wet and dry</td><td>Components in splash water area, Road surfaces</td><td>40</td><td>50</td><td>C 35/45</td></tr>
<tr><td rowspan="2">Concrete exposure to frost with and without deicing agents</td><td>XF1</td><td>aqueous water saturation without deicing agents</td><td>vertical concrete surfaces, exposed to rain and frost; outer walls</td><td></td><td></td><td>C 25/30</td></tr>
<tr><td>XF 4</td><td>high water saturation,</td><td>in splash water area of traffic areas</td><td></td><td></td><td>C 30/37</td></tr>
</table>

		incl. deicing agents	treated with deicing agents	
Abrasion	XM 1	moderate exposure:	Exposure due to vehicles with pneumatic tyres	C 30/37

The minimum compressive strength class must be adhered to with regard to durability, unless higher requirements are placed on the compressive strength class from a structural point of view. As an example, the durability requirement for ceiling panels in buildings made of reinforced and prestressed concrete is f_{ck} ≥ C 16/20 (XC1). In contrast, from a structural point of view, prestressed concrete ceilings must be at least C 30/37 as per DIN 1045-1 (cf. Tab. 6.5).

Consequently, strength class C 30/37 is decisive for prestressed ceilings. In the case of concrete surfaces that are exposed to multiple environmental impacts, the exposure class with the highest applicable requirements is used. In the case of outer walls made of reinforced concrete in residential buildings (XC4, XF1), the durability requirement results in f_{ck} ≥ C 20/25.

As far as the reuse of dismantled prestressed concrete ceiling panels in house construction is concerned, this means that in relation to the ambient conditions the panels can be used both as storey ceiling and as floor panel or foundation slab in the garage. Reinforced concrete ceiling panels of the P2 type comply with the requirements of XC1 to XC3 in unprocessed condition. In terms of durability requirements, the use of dismantled inner walls indoors (XC1) and outdoors in rainproof conditions (XC3) is possible without restrictions. They can only be used as exterior components (XC4) if appropriate protection (thermal insulation and e.g. hydrophobic plaster layer) is provided.

Other areas of application, such as utilisation of used prestressed concrete ceilings in environmental protection structures, e.g. in dyke construction, allow for the following possibilities (Tab. 6.7):

Tab. 6.7: DIN EN 206-1/DIN 1045-1 requirements for the concrete strength class of old concrete elements used in dyke construction

Relevant exposure class	Place of installation	Minimum compressive strength class min f_{ck}	Old concrete elements that can be used without reconditioning
1	**2**	**3**	**4**
XC2	**Installation in the dyke body** (surface sealing, inner sealing), wet, rarely dry	C 16/20	DP and IW from WBS 70 and P2
XA1	**Installation in the dyke body** (surface sealing, inner sealing), environment of low chemical attack	C 25/30	prestressed ceiling panels (DP) from WBS 70 and P2
	Installation on the dyke surface		

XF1 XF3 XC4	(flooding, overflow sections) frost exposure without deicing agents: - moderate water saturation - high water saturation	C 25/30	
	Use in road construction		
XF4	Frost exposure with deicing agents in case of high water saturation	C 30/37	prestressed ceiling panels (DP) from WBS 70
XD3	Corrosion due to chlorides, except seawater; alternately wet and dry	C 35/45	

The initial assessment for use in dyke construction is as follows (cf. Chap. 9):

Provided there is no low-chemical attack environment, which must be verified by on-site tests, ceiling panels and inner walls from both building types can be used in the interior of the dyke body (mainly XC2). The use of prestressed concrete ceiling panels of building type WBS 70 and P2 is possible inside the dyke body even in the case of weak chemical attack of the environment (XA1) and on the dyke surface (XC4: reinforcement corrosion, XF1-3: frost attack with moderate and high water saturation).

Ceiling panels of WBS 70 and prestressed ceilings of P2 type (decisive XF4: frost attack with deicing agents and high water saturation) are suitable for use as top layers in road construction.

Since DIN 1045-1 stipulates requirements for ensuring durability that go beyond minimum concrete strength, further criteria must be complied with:

6.2.1.3 Concrete cover, carbonatation

- **Minimum concrete cover**

The minimum thickneess of concrete cover c_{min} must be preserved in order to ensure protection of the reinforcement against corrosion, safe transmission of bond forces and fire protection. Accordingly, concrete cover is subject to the following basic requirements:

- Minimum concrete cover depending on the exposure class (corrosion protection; see Table 6.6, 6.7, 6.8),
- Minimum concrete cover depending on the bar diameter of the concrete steel reinforcement for safe transmission of the bond forces.

Tab. 6.8: Requirements for the minimum concrete cover for protection against corrosion depending on the exposure class [excerpt from DIN 1045-1, Tab. 4]

Exposure class	Minimum concrete cover thickness cmin [mm]*	
	Reinforcing steel	Tensioners
XC1	10	20
XC2	20	30
XC3	20	30
XC4	25	35
XD1	40	50

XD2
XD3

*c_{min} may be reduced by 5 mm in case of components characterised by the concrete strength at least 2 strength classes higher than according to Tab. 6.1. Exception: this reduction is not permitted for XC1.

The minimum concrete cover thickness c_{min} must not be smaller than the bar diameter d_s of the steel reinforcement. The following applies: $c_{min} \geq d_S$.

The requirements for concrete cover in terms of fire protection result from the following:

- the applicable state building regulations (allocation of the components into fire-retardant and fire-resistant construction methods),
- DIN 4102 Fire behaviour of building materials and components (assignment to fire resistance classes)
    - Fire-retardant → F 30 - B
    - Fire-resistant → F 90 - A

and structural specifications:

- Adherence to minimum distances between the outer edge of the component and the axis of the load-bearing longitudinal reinforcement,
- Minimum thickness of the components,
- Minimum number of longitudinal reinforcement bars in reinforced concrete.

The test results for fire resistance are summarised in Chap. 6.2.4.3.

The actual concrete cover thickneess c_{vorh} was measured non-destructively on more than 500 elements using FS 10 Ferroscan system (magnetic reinforcement search) in order to examine the minimum concrete cover c_{min}. The statistical evaluation of the measured data was carried out according to the DBV data sheet "Concrete cover and reinforcement" of the German Concrete Association.[209] The distribution of the concrete cover was determined by measuring the concrete cover on several measuring lines. The c_{vorh} was derived from 10 measurements per element and compared with the minimum and average concrete cover thickness (c_{min} and $c_{i.M}$).

The following applies to the decision:

Tab. 6.9: Decision table to determine the quantile for quantitative detection[210]

Decision:	10% quantile for XC1	5% quantile for XC2-4
Rejection	$c_{min} > c$ (10%)	$c_{min} > c$ (5%)
Assumption	$c_{min} \leq c$ (10%)	$c_{min} \leq c$ (5%)

[209] DBV leaflet "Betondeckung und Bewehrung", version 07/2002, ed. German Concrete and Construction Technology Association, Berlin
[210] Kania, Gregor: Statistische Auswertung der ermittelten Ergebnisse von Untersuchungen zur Betondruckfestigkeit, Karbonatisierungstiefe und Betondeckung an gebrauchten Betonfertigteilen, student research project, 2006

With reference to the exposure classes, the measurement results are exemplified as follows[211]:

Tab. 6.10: Overview of the evaluation of the measurement results for the determined/existing concrete cover in relation to the exposure class

Element range	Type of building	Data records	Accomplishment			
			XC1		XC4	
			$c_{min, vorh}$	$c_{i.M., vorh}$	$c_{min, vorh}$	$c_{i.M., vorh}$
Prestressed concrete ceiling panels	WBS 70	32	not accomplished	V	not accomplished	not accomplished
	P2	52	V	V	not accomplished	not accomplished
Slack reinforced ceiling panels	P2	38	V	V	not accomplished	not accomplished
Inner walls	P2	50	V	V	not accomplished	not accomplished

V: accomplished, n.e.: not accomplished

Tests on concrete cover in XC1 (used inside the building) show that all elements of the P2 building series comply with the minimum concrete cover c_{min} according to Neville distribution. The prestressed concrete panels of WBS 70 do not comply with this requirement. However, if $c_{i.M.}$, vorh. is used as basis, then the condition is fulfilled.

The minimum concrete cover of the environmental class XC4 (use as external component with direct movement) is not complied with by any of the tested elements, as expected. However, this interim conclusion is only valid to a limited extent, as the carbonatation horizon must also be assessed in order to evaluate the actual risk of corrosion of the reinforcement.

- **Carbonatation**

The carbonatation rate depends mainly on:

- the type, concentration and intensity of exposure to attacking media (CO2, moisture, oxygen and other ions aggressive towards steel, such as acids, alkalis, salts),
- the porosity of concrete (especially capillary porosity),
- the moisture of concrete,
- the concrete compressive strength class,

[211] for details see: Mettke, Angelika; Heyn, Sören; Thomas, Cynthia: Schlussbericht Forschungsvorhaben „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 2: Wieder- und Weiterverwendung großformatiger Betonbauteile, 2008, p. 38 ff.

- the age of concrete,
- thickness of the concrete cover.[212]

The carbonatation rate is largely determined by the CO2 diffusion process and is calculated in construction practice according to the simplified formula t □Gesetz (cf. Fig. 6.3). The carbonatation depth was determined for fresh fracture surfaces on the basis of drill cores with the use of phenolphthalein. Concrete that has already been carbonatated remains uncoloured, while non-carbonated concrete turns purple.

Table 6.11 below summarises the key findings that had been determined in the course of analyses on reusability in our specialist group.

Tab. 6.11: Measured carbonation depths[213]

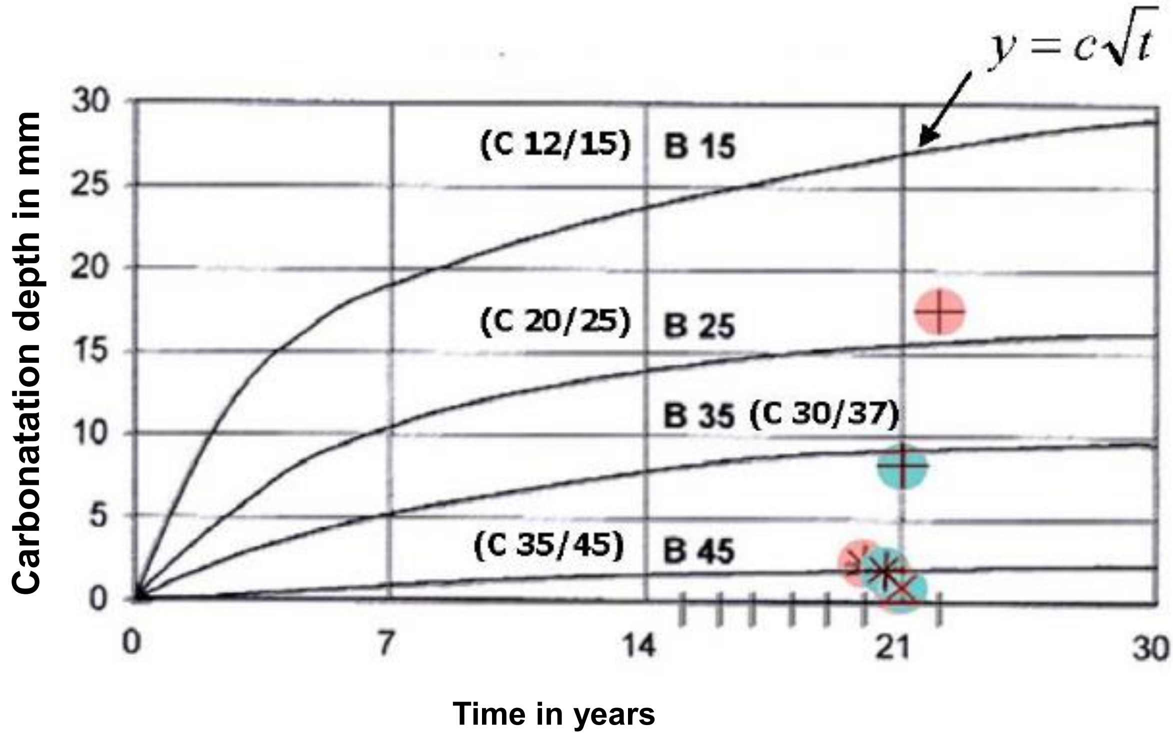
Element range		Concrete age (Years)	Number of measured values	Carbonisation depth [mm] measured		
				Minimum value	Average value	Maximum value
Prestressed concrete ceilings	WBS 70	20-22	26	0	2	18
	P2	23	14	0	0	0
Inner walls	WBS 70	21	13	0	2	8
	P2	23	9	0	0	0
Outer walls	WBS 70	18-21	5	0	5	10
	P2	23	21	0	12	30

This proved that no concrete transformation had taken place in the analysed prestressed concrete ceilings and inner walls of type P2, even at a construction age of 23 years. The analysed prestressed concrete ceilings of WBS 70 exhibited an average carbonatation depth of 2 mm.

The measured maximum value of 18 mm is to be regarded as a statistical outlier, since only one ceiling panel exhibited this value. The graphical representation of the carbonattaion depth is exemplary for the ceiling panels and inner walls of WBS 70 and is presented in the following Fig. 6.3.

[212] Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 100

[213] for details see: Mettke, Angelika; Heyn, Sören; Thomas, Cynthia: Schlussbericht Forschungsvorhaben „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 2: Wieder- und Weiterverwendung großformatiger Betonbauteile, 2008, p.32 ff.



Minimum value — y = carbonatation depth [mm]

Average — c = carbonation coefficient (material-specific)

Maximum value — t = age of building (years)

Concrete compressive strength class DP and IW according to project planning C20/25;
Measured DP C50/60, IW C20/25 (DP red, IW blue)

Fig. 6.3: Determined carbonatation depth on 26 prestressed concrete ceilings and 13 inner walls of WBS 70

The 23-year-old outer walls of the P2 series exhibit an average carbonatation depth of 12 mm and are thus significantly below the predicted carbonatation horizons according to $\sqrt{t - Gesetz}$ and depending on the projected concrete compressive strength class (approx. 27 mm).

Summing up the carbonatation issue, it can be stated that the reinforcement is protected against corrosion in all 78 examined components that were 18 to 23 year old, with the exception of one storey ceiling. It can be assumed that there is sufficient corrosion protection in secondary use as compared to primary use if the environmental conditions remain the same because carbonatation only progresses imperceptibly with increasing construction age and practically reaches a final value (see Fig. 6.3).

The high density of old prestressed concrete ceiling panels (see Table 6.5 – verified concrete compressive strength classes as well as determined low porosity, Section 6.2.1.4) coupled with the increasing compaction of the concrete itself due to the carbonatation process means that no further carbonatation progress can be expected. The progress of carbonatation into the interior of the component has practically come to a standstill. With reference to the interim conclusion regarding the measured concrete cover values, it is worth noting that the following can be relativised for prestressed concrete ceiling panels of the WBS 70 series: based on the maximum value of the measured carbonatation depth of 18 mm, the reinforcing steel is still embedded in a corrosion-resistant manner with an average minimum concrete cover of 2.3 cm. A treatment of the concrete surface is necessary if

c_{min} is only 13 to 17 mm (determined on 6 of 32 measured prestressed concrete ceilings of WBS 70) and if the carbonation depth is 18 mm in extreme cases.

If inner and outer walls are used secondarily in housing construction as exterior building components (XC4; see Chap. 6.2.1.2), then they generally need to be upgraded in terms of structural physics. As a result, the supply of CO2 to the concrete component is impeded or stopped.

6.2.1.4 Permeability, total porosity, water penetration depth[214]

The examined 22-year-old prestressed concrete ceilings and 19-year-old inner walls of the WBS 70 type surprisingly exhibit permeability values of k_f = 10^{-10} to 10^{-11} m/s[215] (comparable to clay characterised by k_f=10^{-8} to 10^{-12} m/s). Consequently, these panels formerly used in residential buildings can be categorised as impermeable.

The total porosity (proportion of the total pore volume) varies between 6.5% and 15.6%; the average is 12.5%. These values are also indicative of durable concrete characterised by solid concrete porosity < 16%.[216] Furthermore, these results correlate with the determined concrete compressive strengths and the results on acid resistance.

The water penetration depth is between 1.3 cm and 2.4 cm. Thus, pursuant to ZTV-W in accordance with DIN EN 12390-8: 2001-021,[217] the specified water penetration depth does not exceed maximum value of 3 cm.

6.2.1.5 Frost resistance with and without the impact of deicing agents[218]

The secondary use of old concrete elements outdoors, for example in overflow sections in dyke construction, is subject to the frost attack. If used as a top layer in road construction, the impact of deicing salts must also be taken into account. According to DIN 1045-1, concrete compressive strengths of C 30/37 are required for such applications (exposure class XF4 for frost attack with deicing salts on horizontal surfaces). This requirement is complied with (cf. Chap. 6.2.1.2).

In order to determine the frost resistance, 12 drill cores were taken from WBS 70 ceiling panels (construction age: 20 years) and tested by means of the CIF or CF method. [219] The average weathering after 28 freeze-thaw cycles is 147.5 g/m² (acceptable 1,500 g/m², minimum test surface 800 cm²).

The change in the dynamic modulus of elasticity after 56 freeze-thaw cycles is 72.9%. Extensive cracks were found in these samples, which are attributable to internal damage. In terms of the damage level , the tested concrete is categorised as "very severely damaged".

[214] Investigations carried out by Mettke, Angelika as part of the research project "Pro Altbeton im Hochwasserschutz", funded by the BMBF; publication of the final report Mettke, Angelika; Heyn, Sören: "Pro Altbeton im Hochwasserschutz", April 2009

[215] IBeWa Wilsnack & Partner, Freiberg: Bestimmung der Flüssigkeitspermeabilität von Betonelementen, Inspection report on behalf of the Expert Group on Structural Recycling as of December 2004

[216] Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 92

[217] DIN EN 12390-8: 2001-02: Prüfung von Festbeton, Teil 8: Wassereindringtiefe unter Druck und ZTV-W LB 215 - Wasserbauwerke aus Beton und Stahlbeton, Anlage 1 Eignungsprüfungen Pkt. 3.2 Wassereindringwiderstand, edition 2004

[218] the parameters were determined by Mettke, Angelika as part of the research project "Pro Altbeton im Hochwasserschutz"; see final report Mettke, Angelika; Heyn, Sören: "Pro Altbeton im Hochwasserschutz", April 2009

[219] Research and Materials Testing Institute, Concrete Technology Group at the BTUC: Testing of freeze-thaw resistance by means of the CF and CIF methods, test report on behalf of the Construction Recycling Group, November 2005; CF test: determination of weathering on the concrete surface; CIF test: determination of internal damage by means of ultrasonic transit time

The damage increases with simultaneous deicing salt attacks. In total, 8 out of 12 test specimens disintegrated after 14 freeze-thaw cycles. The concrete failed the CDF test[220], thus it does not comply with the requirements for concrete with high freeze-thaw resistance.

The behaviour of old concrete towards various acid solutions is discussed in Chap. 7.5.2.

6.2.2 Investigations into load-bearing capacity

6.2.2.1 Evaluation of reinforced and prestressed concrete ceiling panels

The repeated utilisation of storey ceilings requires a reliable assessment of their load-bearing capacity. Therefore, the mathematical verifications of load-bearing and utilisation capacity were supplemented in part by experimental load tests.

The following old concrete panels were tested:

Tab. 6.12: Overview of the tested old concrete panels - mathematical and experimental verifications of load-bearing and utilisation capacity

	Dimensions L x W (H) x D [m] (axial dimensions)	Location/year of construction	Element no.
from the P2 housing series:			
Prestressed concrete ceiling elements	6.00 x 1.80 x 0.14	Hoyerswerda and Cottbus 1971, Weißwasser 1973, Cottbus 1976	22000 21000 22006
	4.20 x 1.80 x 0.14		21118 21120 21119 21121
Slack reinforced ceiling panels	3.60 x 1.80 x 0.14	Cottbus 1968 to 1976	23630 21200 23632 23631 23633
	2.40 x 1.80 x 0.14		21300
Load-bearing inner wall panels	3.745 x 2.635 x 0.15	Cottbus 1970	51707 and 10 more
from the WBS 70 housing series:			
Prestressed concrete ceiling elements	6.00 x 1.80 x 0.14	Dresden-Gorbitz 1980	D 410 D 413
from the PN 36-NO residential building series:			
Slack reinforced ceiling panels	3.60 x 2.40 x 0.14	Eggesin 1972 or 1976	G 62 b/A, G 6 A
	3.60 x 2.40 x 0.10		G 81 A
Roof panels	3.60 x 2.00 x 0.10		D 56 A
Load-bearing inner walls	4.81 x 2.635 x 0.15		I 77 A, I 78 A

[220] Research and Materials Testing Institute, Concrete Technology Group at the BTUC: Testing of freeze-thaw resistance by means of the CF and CIF methods, test report on behalf of the Construction Recycling Group, November 2005; CF test: Determination of weathering on the concrete surface; CIF test: Determination of internal damage by means of ultrasonic transit time, test report on behalf of the Construction Recycling Group, July 2005

Initial values for the verifications

The prestressed concrete ceiling panels of the P2 and WBS 70 series had been planned for "partial pre-tensioning" (prestressed concrete status II). The mathematical verification was carried out by SCHMIEDEHAUSEN[221] in accordance with DIN 4227-1: 1988-07, components made of standard concrete with limited and full pre-tensioning, in order to investigate the extent to which it is also possible to classify the ceiling panels for "limited pre-tensioning" (prestressed concrete as per condition I). This enables categorisation into a higher utility value class.

The experimental verifications are used for checking the load-bearing and deformation behaviour of components. Experimental tests are particularly advantageous for reinforced concrete and prestressed concrete components in addition to mathematical verifications, as the onset and distribution of cracks in the concrete tension zone and the onset of steel yielding can be evaluated more effectively in relation to the deformation behaviour of the component.

The following were loaded:

- **in dismantled condition/offside:**

Quantity	Ceiling panel	Building age [years]	Element no.	Number of tension wires [pcs.]	Tensioning steel cross-section [mm²]	Concrete compressive strength determined at drill cores
in the FMPA Cottbus						
3	Prestressed concrete ceilings P2	28	22000 2-sided storage	20 St 140/160	40	C 35/45
2	Prestressed concrete ceilings P2	30	22006 2-sided storage	17 St 140/160	40	C 35/45
4	Reinforced concrete ceilings P2	30	21120 resp. 21121 stored on 2-sides	St A - I Ø 18, a = 18 cm or St A - III Ø 10, a = 10 cm		C 40/50
in the Otto Mohr Laboratory of the Dresden Technical University						
2	Prestressed concrete ceiling WBS 70	23	D 410 Standard plate stored on 2 sides	18 St 140/160	40	C 60/75
1	Prestressed concrete ceiling WBS 70	23	D 413 Edge plate stored on 3 sides	14 St 140/160	40	C 55/67

[221] Schmiedehausen, Rudolf, Ingenieurbüro Tragwerksplanung Cottbus

- **in installed condition/in situ:**

Quantity	Ceiling panel	Building age [years]	Element no.	Number of tension wires [pcs.]	Tensioning steel cross-section [mm²]	Concrete compressive strength determined at drill cores
3	Prestressed concrete ceilings P2	29	21000	16 St 140/160 stored on 2 sides	40	C 25/30

At the time of production of the tested prestressed concrete ceiling panels, concrete of B 300 quality according to TGL 11422: 1964-03[222] was used; this corresponds to a B 25 according to DIN 1045: 1988-07 and a strength class C 20/25 according to DIN 1045-1 or DIN EN 206-1: 2001-07. According to DIN 4227-1: 1988-07[223], a minimum of B 35 (C 30/37) must be used for prestressed concrete components with immediate bonding. This requirement also needs to be complied with in accordance with the new DIN 1045.

After the load-bearing tests, drill cores with a diameter of approx. 100 mm were extracted and analysed in accordance with DIN 1048-2: 1999-061 to determine the existing concrete strength in undisturbed areas close to the support [224].

The compressive strength tests, for example, of ceiling panels 22000/1-3 resulted in a concrete of strength class B 45 (C 35/45), the ceiling panels D 410/1-3 exhibited strengths of 73.0 to 83.2 N/mm², those of element number 413/1-3 from 60.0 to 66.9 N/mm² (corresponding to C 60/75 or C 55/67).

The mathematical verification carried out by SCHMIEDEHAUSEN[225] resulted in B 35 or C 30/37 due to the reason described above and the previous tests (sufficient concrete strengths were achieved in all cases).

The prestressed concrete panels had been pre-tensioned electrothermally and anchored in the prestressing mould by means of shrink sleeve end anchoring, and from the 1980s by means of a compression head. A permissible value of 800 N/mm² < 1,040 N/mm² was calculated for the steel stress (= prestressing bed stress) arising after the prestressing wires have cooled. The calculated stress drop due to creep and shrinkage is entered as $t = \infty$. Details of the calculations can be found in the conference proceedings "Alte Platte - Neues Design - Die Platte lebt"[226] .

The mathematical verification on slack reinforced ceiling panels of the PN 36-NO residential building series constructed in 1972 and 1976 was carried out on storey ceiling G 62 b/A, G 6 A and jamb ceiling G 81 A (for dimensions, see Tab. 6.12). The elements had been planned for the concrete quality class B 160 and reinforced steel class St A-I. B 15/BSt I was used for recalculation.[227] Furthermore, slack

[222] TGL 11422: 1964-03 Bauwerke und Fertigteile aus Beton und Stahlbeton; Berechnungsgrundlagen, Traglastverfahren
[223] DIN 4227-1; 1988-07 replaced by DIN 1045-1: 2001-07 (binding since 01.01.2005). The requirements for concrete components with immediate bonding in terms of minimum concrete compressive strength remain unchanged.
[224] DIN 1048-2: 1999-06 Prüfverfahren für Beton; Festbeton in Bauwerken und Bauteilen
[225] Schmiedehausen, Rudolf; Ingenieurbüro Tragwerksplanung, Cottbus
[226] Schmiedehausen, Rudolf: Was sind gebrauchte Betonfertigteile eigentlich heute noch wert?, in conference proceedings „Alte Platte – Neues Design – Die Platte lebt“, ed. Angelika Mettke, 2005, p. 145 ff. and expert report: Rechnerische und experimentelle Untersuchungen für P2-Spannbetondeckenplatten 22006 und P2-Stahlbetondeckenplatten 21120 und 21121, Aug./Oct. 2006
[227] Schmiedehausen, Rudolf: Rechnerische Nachweise für ausgewählte Dachplatten, Deckenplatten und Wandfertigteile von Wohngebäuden des Typs PN 36-NO, test report on behalf of FG Bauliches Recycling, BTU Cottbus, 2001

reinforced ceiling panels from the P2 type series were analysed (see Tab. 6.12). Depending on the year of construction, either A-I reinforced steel, smooth round steel, or A-III, ribbed round steel, was used. According to project planning, they were manufactured in B 225 (~ C20/25). Analysis of the drill cores revealed the compressive strength test of DP 21121 equal to C 40/50.

The load results from:

Tab. 6.13: Load assumptions

Load assumptions	22000	21000, 22006, D 410, D 413	21120, 21121	G 6 A G 62 b/A	G 81 A
Dead load g					
14 cm prestressed concrete 0.14 m x 25 kN/m³	3.50 kN/m²	3.50 kN/m²			
14 cm reinforced concrete 0.14 m x 25 kN/m³			3.50 kN/m²	3.50 kN/m²	
10 cm reinforced concrete 0.10m x 25 kN/m³					2.50 kN/m²
additional dead load g1					
Insulation layer, foil, screed, covering	1.00 kN/m²	1.00 kN/m²		1.60 kN/m² (incl. screed)	
Insulation layer, covering, tiles in kitchen/bathroom area			2.00 kN/m²		0.10 kN/m²
Total g	4.50 kN/m²	4.50 kN/m²	5.50 kN/m²	5.10 kN/m²	2.60 kN/m²
Live load p					
[DIN 1055-3: 1971-06] for living spaces with sufficient lateral load distribution	1.50 kN/m²	1.50 kN/m²	1.50 kN/m²	1.50 kN/m²	1.00 kN/m² < (jamb can be crawled on)
Surcharge ∆ p for unloaded lightweight partition walls					
incl.					
g ≤ 150 kg/m²	1.25 kN/m²			1.25 kN/m²	
g ≤ 100 kg/m²		0.75 kN/m²		0.75 kN/m²	
G_w (wall transverse to the load-bearing direction)			4.66 kN/m		
Total p	2.75 kN/m²	2.25 kN/m²			1.00 kN/m²
Total q	**7.25 kN/m²**	**6.75 kN/m²**	**10.00 kN/m²**		**3.60 kN/m²**

The measurement was carried out on the basis of the TGL 11422 load-bearing capacity method (Oct. 1961 or Mar. 1964); new DIN 1045-1: 2001-07

6.2.2.2 Results of the mathematical verifications The results are summarised as follows[228]:

- **Prestressed concrete ceiling panels**

Tab. 6.14: Prestressed concrete ceiling panels – results of the mathematical verifications of load-bearing capacity

	Element no.	**21000**	**22000**	**22006**	**D 410**	**$\delta_{b,zul.}$**
	Number of prestressed steels	16	20	17	18	
1	**Concrete stresses due to g + V + KS + g_1 + p [N/mm²]**					
	in the middle of the panel					
	Compression (top):	7.2	6.9	7.12	7.11	14
	Tension (bottom)	3.69	2.6	3.25	3.2	3.5
2	**Concrete stresses due to g + V + KS +$_{g1}$ + p + Δp [N/mm²]**					
	in the middle of the panel					
	Compression (top):	8.2	8.7	8.12	8.1	14
	Tension (bottom)	4.7	4.4	4.23	4.17	3.5
3	**Concrete stresses due to g + V [N/mm²]**					
	at the support					
	Compression (bottom)	4.9	6.1	5.16	5.46	17
	Tension (top)	0.9	1.1	0.95	1.0	3.5
4	**Steel stresses due to total load incl. KS [N/mm²]**					
		681	671	729	684 calc. 625 measured	< 880; 800

The permissible concrete stresses apply to B 35 (C 30/37) as verified by measurement.

The permissible concrete stresses according to the verification for 'limited prestressing' are slightly exceeded in the case of the prestressed concrete panels analysed here under full load (see Tab. 6.14, row 2). The steel stresses are within the permissible range (see Tab. 6.14, row 4). Slack round steel reinforcement provided in addition to prestressed steel reinforcement for limiting crack widths complies with the requirements concerning the serviceability and durability of the panels.

[228] Summary of several expert reports by Schmiedehausen, Rudolf; Ingenieurbüro Tragwerksplanung, Cottbus

The slight overshoot of the permissible concrete tensile stresses is not considered to be of concern, as reuse of the ceiling panels inside buildings practically rules out the risk of corrosion.

As per SCHMIEDEHAUSEN's[229] verification of the calculated fracture safety, it was also determined that the existing reinforcement is sufficient due to the 1.75-fold sum of all external loads (without partition wall surcharge). However, if the partition surcharge is included in the calculation, then the existing reinforcement is not entirely sufficient. The plate D 413 is an exception. It meets all requirements, including that of mathematical fracture resistance. Supplementary verifications for principal stress, calculated crack width limitation, tendon bond, splitting tensile effect in the force application area, anchorage of prestressing wires and tensile force coverage, verification of freedom from bending tension and shear cracks, splitting tension and end tension reinforcement and panel deflection resulted in no restrictions for their reuse.

This evaluation also applies to the following ceiling panels:

Tab. 6.15: Examined ceiling panels

Element number	Prestressed steel A_S [cm²]	perm. Bending moment M_q [kNm/panel]
21000	6.4	49.0
22000	8.0	58.0
22001	8.0	58.0
22003	8.0	58.0
22031	8.0	58.0
22006	6.8	52.0
21009	10.0	72.0
21018	10.0	72.0
21019	10.0	72.0
21039	10.0	72.0
22007	9.2	66.0
22008	9.2	66.0
D 410	7.2	55.0

A follow-up test must be arranged for other less reinforced ceiling panels.

- **Slack reinforced ceiling panels[230]**

Tests on the ceiling panels of element no. 21118, 21119, 21300, 23630, 23632, 23631, 23633 revealed that the existing load-bearing reinforcement meets the requirements of DIN 1045-1 in all cases. The ceiling panels of elements no. 21120, 21121 and 21200 also comply with all requirements of DIN 1045-

[229] cf. Schmiedehausen, Rudolf: Was sind gebrauchte Betonfertigteile eigentlich heute noch wert? In: conference proceedings „Alte Platte – Neues Design – Die Platte lebt“, ed. Angelika Mettke, 2005, p. 147
[230] cf. Schmiedehausen, Rudolf: Was sind gebrauchte Betonfertigteile eigentlich heute noch wert? In: conference proceedings „Alte Platte – Neues Design – Die Platte lebt“, ed. Angelika Mettke, 2005, p. 150 f.

1 when using StA-III. Only in the case of panels reinforced with StA-I reinforcing steel there is a shortfall of 4% for the load-bearing reinforcement for elements no. 21120 and 21121. The panel of element no. 21200 has a shortfall of 10%. However, this only applies to the unfavourable case of бs=220 N/mm². If the yield strength бs=240 N/mm² is used for STA-I, the existing load-bearing reinforcement is sufficient. The results are summarised in the table below (Tab. 6.16).

Tab. 6.16: Synopsis of the load-bearing capacity of selected reinforced concrete ceiling panels in accordance with TGL 11422 and DIN 1045-1

Ceiling panel of element no.	Sufficient load-bearing reinforcement		Insufficient load-bearing reinforcement	
	StA-III	StA-I	StA-III	StA-I
21118	X	X		
21119	X	X		
23630	X	X		
23632	X	X		
21120	X			X
21121	X			X
21200	X			
21300	X	X		X
23631	X	X		
23 633	X	X		

According to DIN 1045-1, the transverse reinforcement (= distribution reinforcement) should amount to 20% of the cross-section of the load-bearing reinforcement. However, TGL 11422: 1961-10, which was valid at the time of construction, states that 10% was sufficient.

In the present case, since the panels are uniaxially reinforced, the transverse reinforcement primarily fulfils structural functions. Therefore, no restrictions should be imposed on the reuse of the ceiling panels due to the lower transverse reinforcement.

6.2.2.3 Results of the experimental verification of load-bearing behaviour

The tests were carried out as part of the research project "Dismantling of industrial buildings - large-format concrete elements in the ecological cycle" - funded by the BMBF. In cooperation with Dr. Schmiedehausen, an authorised advisory and construction project engineer, Mr Petke, Research and Materials Testing Institute (FMPA) of the BTU Cottbus and Dr Jonigkeit, an advisory test engineer, the most recently completed load-bearing tests are explained here by way of example.

In the period from June to September 2006, two prestressed concrete panels and four slack reinforced ceiling panels of building type P2 were examined in the presence of other approved test engineers as well as authorised construction project structural engineers, expert colleagues and interested parties. The elements originated from an 11-storey donor building erected in 1976 in the Sachsendorf-Madlow district of Cottbus. Following two to five months of interim storage in the outdoor area of the FMPA (see

Fig. 6.4), the load tests were carried out in the technical centre. The experimental testing of the load-bearing behaviour was carried out in accordance with DIN EN 1356: 1997-2. A 1,000 kN test cylinder system with electronic control of accuracy class 1 was available (see Fig. 6.6).

- **Prestressed concrete ceiling panels**

The key data for the 22006 prestressed concrete ceiling panel is presented in the following Tab. 6.12 and Fig. 6.5. The panel exhibited no damage, with the exception of minor chipping at the edges due to disassembly (see Fig. 6.4).

Fig. 6.4: Interim stored ceiling panels in the outdoor area

The load arrangement is presented in the following Fig. 6.5:

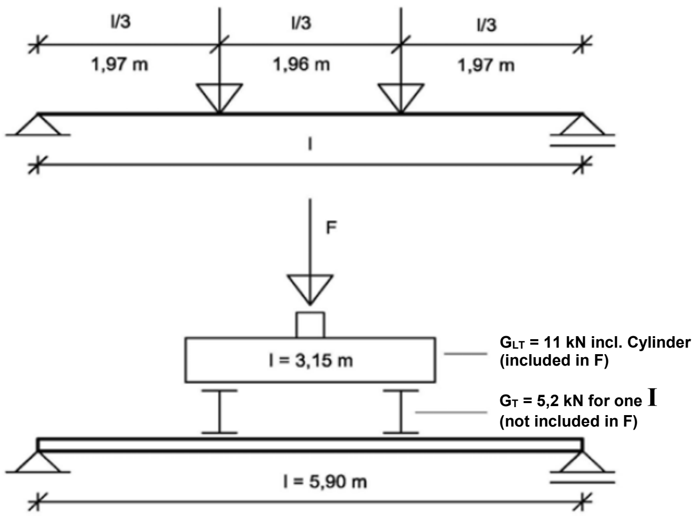


Fig. 6.5: Load arrangement and installation of prestressed concrete ceiling panel 22006

Fig. 6.6: Test facility

The permissible bending moment for the prestressed concrete ceiling panel 22 006 according to the catalogue is

M_q= 52 kNm/Panel

Bending moments M_g = 3.5 kN/m² 1.8 m * $\frac{(5{,}9m)^2}{8}$ = 27.41 kNm/panel

This results in

M_p= 52 kNm/panel – 27.41kNm/panel = 24.59 kNm/panel ≈ 24.6 kNm/panel

Each F/2 = 24.59 kNm/panel / $\frac{5{,}9m}{3}$ =12.5 kN

Res. force F = 2 * $(\frac{F}{2} - G_T)$

F = 2 * (12.5 kN - 5.2 kN) = 14.6 kN

If the load application points are at a distance of 1/3 from the supports, the two individual loads of 12.5 kN for the application of the bending moment result from the live load Mp=24.6 kNm/panel. The dead load of the two load transfer beams of GT=5.2 kN each is included here. The resulting force F=2* $(\frac{F}{2} - G_T)$ is therefore applied via the test cylinder system. The permissible bending moment from live load Mp=24.6 kNm is reached at F=14.6 kN.[231]

[231] Schmiedehausen, Rudolf: Rechnerische und experimentelle Untersuchungen für Spannbetondeckenplatten des P2-Wohnungsbaus, Elemente-Nr. 22006, test report on behalf of FG Bauliches Recycling, BTU Cottbus, 08.08.2006

The load transfer is simulated by transferring the force via a crossbeam and two rigid steel profiles. These extend over the entire width of the ceiling panel. The position of the force application lines and measuring points for investigating the load-bearing behaviour is illustrated in Fig. 6.7.

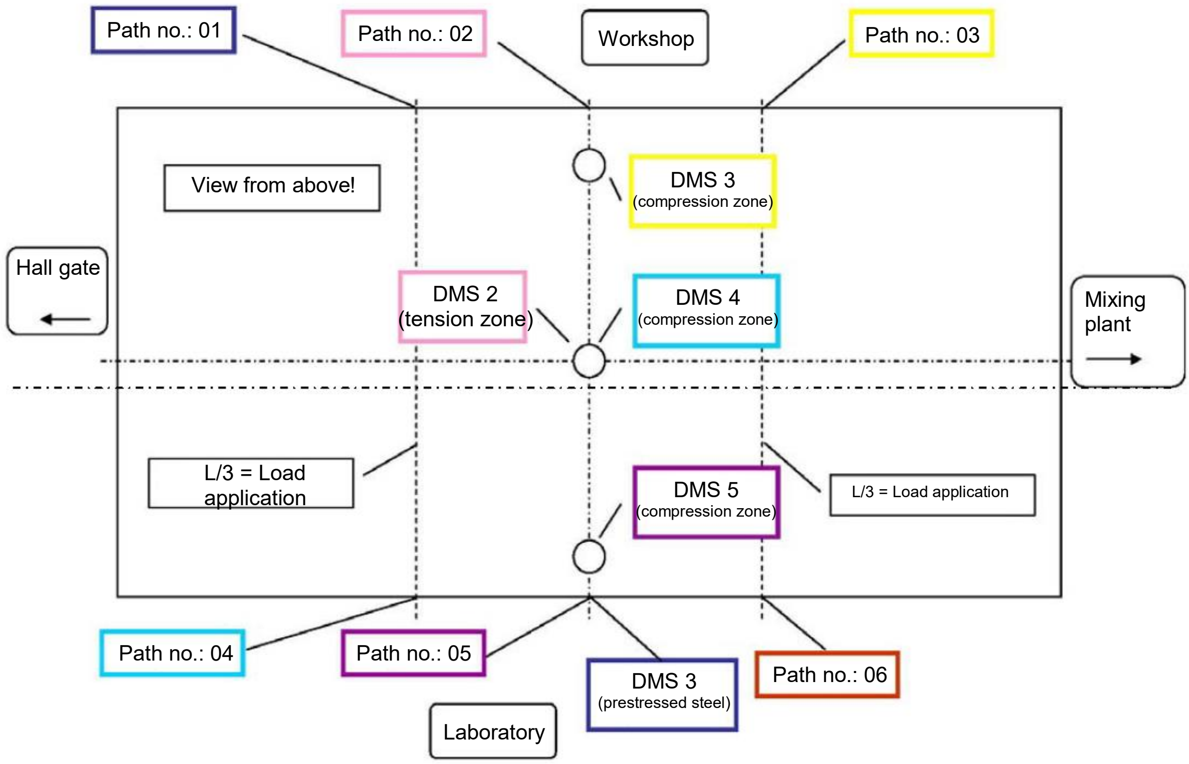


Fig. 6.7: Position of the force application lines and measuring points for the examination of the load-bearing behaviour

The deflection of the panel was measured at three points per longitudinal edge of the panel (path no. 01 - 03 and 04 - 06). The concrete compression was determined at three measuring points in the middle of the field (DMS 3 - 5). DMS 2 strain gauges were installed in the tension zone to measure the concrete strain (Fig. 6.8). The elongation of the prestressed steel (strain gauge 1) under load was recorded approximately in the middle of the field. For this purpose, it was necessary to pry open the longitudinal edge of the panel (Fig. 6.9).

Fig. 6.8: Strain gauges in the tension zone

Fig. 6.9: Exposed area for determining the elongation of the prestressed steel under load

For the examination of possible shear force stresses, strain gauges in the form of a rosette were glued in the support area of the longitudinal sides of the ceiling (Fig. 6.10).

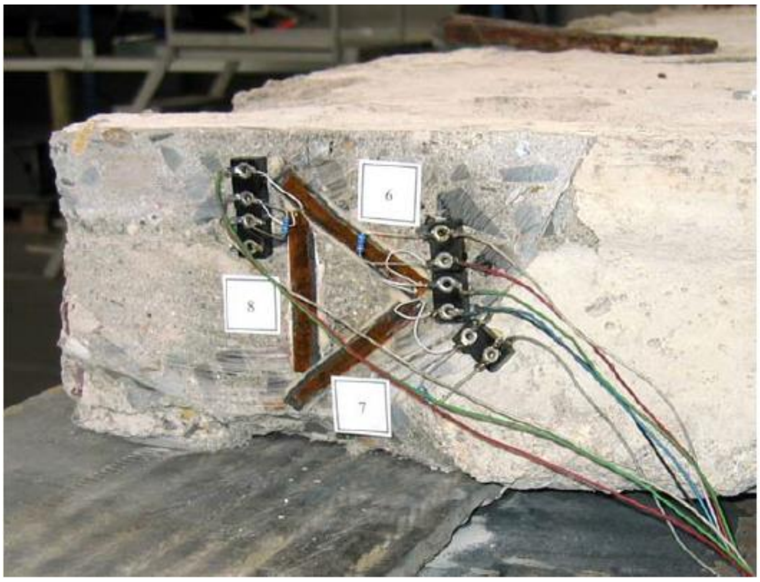


Fig. 6.10: Measurement of the shear force tension

Execution of the examination

The load-time diagram (see Fig. 6.11) shows that no intermediate unloading of any kind was applied. It has been proven in previous own investigations that, due to their particularly favourable elastic behaviour, prestressed concrete ceiling panels spring back to their original position when the load is removed, provided that the previously applied load does not exceed the service load by more than 1.5 to 1.7 times.[232]

[232] cf. Mettke, Angelika: Rückbau von Plattenbauten – Wieder- und Weiterverwendbarkeit gebrauchter Betonbauteile, in: Holschemacher (ed.) Stahlbetonplatten, 2005, p. 74 ff.;
Schmiedehausen, Rudolf: Rechnerische und experimentelle Untersuchungen für Spannbetondeckenplatten des P2-Wohnungbaus, Elemente-Nr. 22006, test report on behalf of FG Bauliches Recycling, BTU Cottbus, 08.08.2006

The following time intervals were defined for each load level:

- Application of the load for 120 seconds,
- Keeping the load constant for 180 seconds.

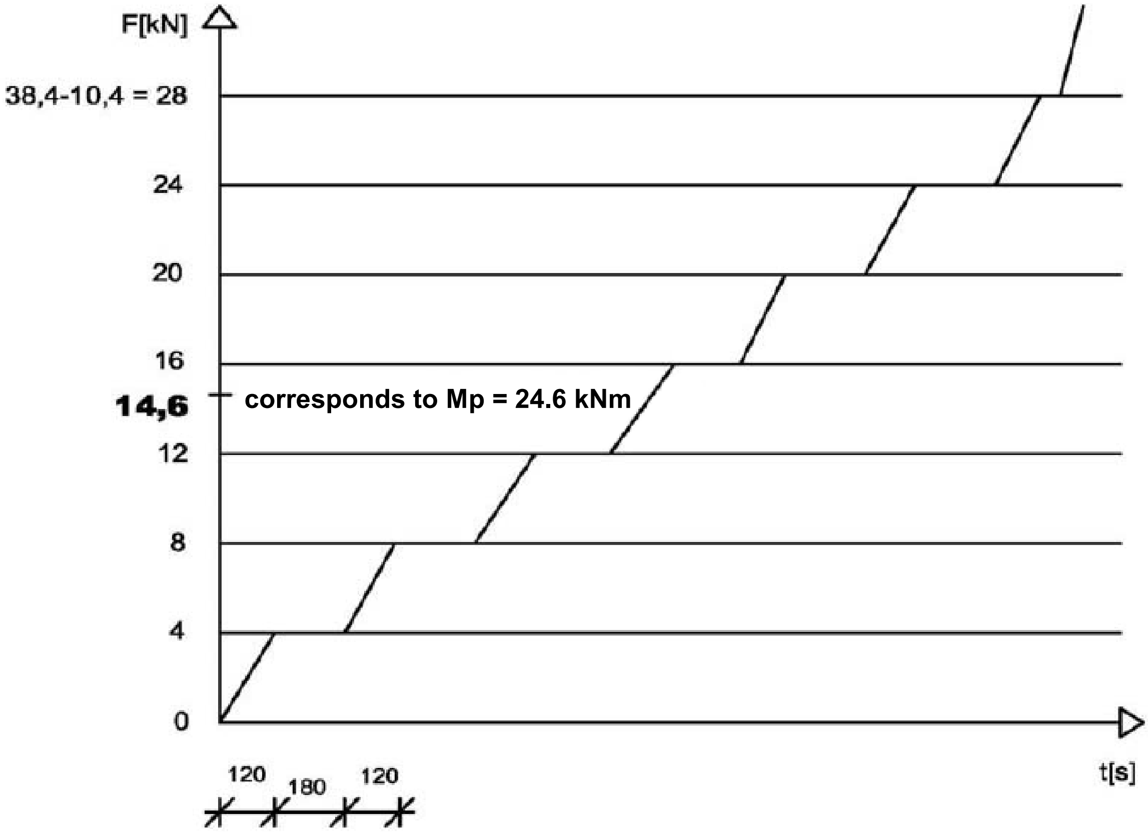


Fig. 6.11: Load-time diagram, based on DIN EN 1356: 1997-2

Trial results

Two of the examined ceiling panels provided the following key results:

- **Deflection**

In the load tests, the deflection development revealed an almost linear correlation between load and deformation. In the case of prestressed concrete panel 1, this proportionality was maintained with load increases of up to 1.5 times the service load (see Fig. 6.12), and in the case of prestressed concrete panel 2 at least up to 2 times the service load. The deformations only increased disproportionately with further load increases.

The calculated deflection determined by SCHMIEDEHAUSEN as a result of service load is approximately f ≈ 6 mm in the middle of the field. The reduction in pre-tension due to creep and shrinkage is included here. However, the experimentally determined value is only f ≈ 4 mm.

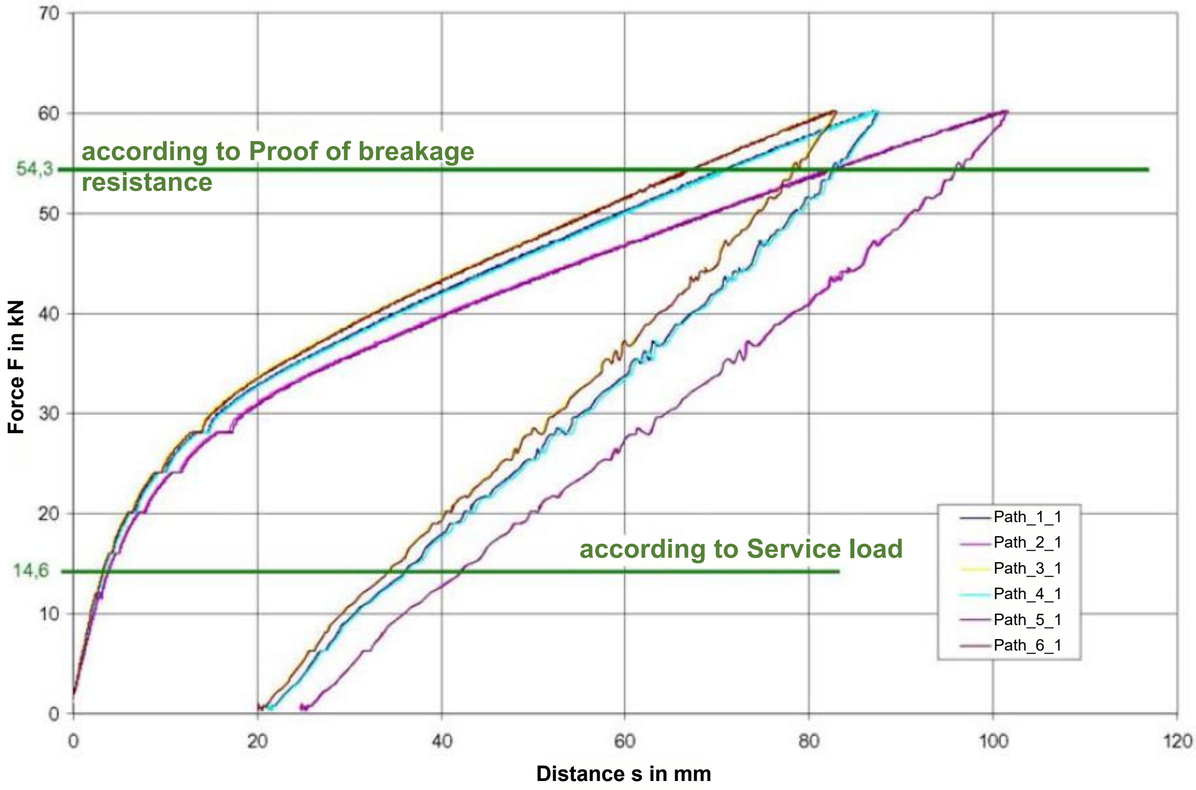


Fig. 6.12: Force-path diagram of prestressed concrete ceiling panel 1, element no. 22006

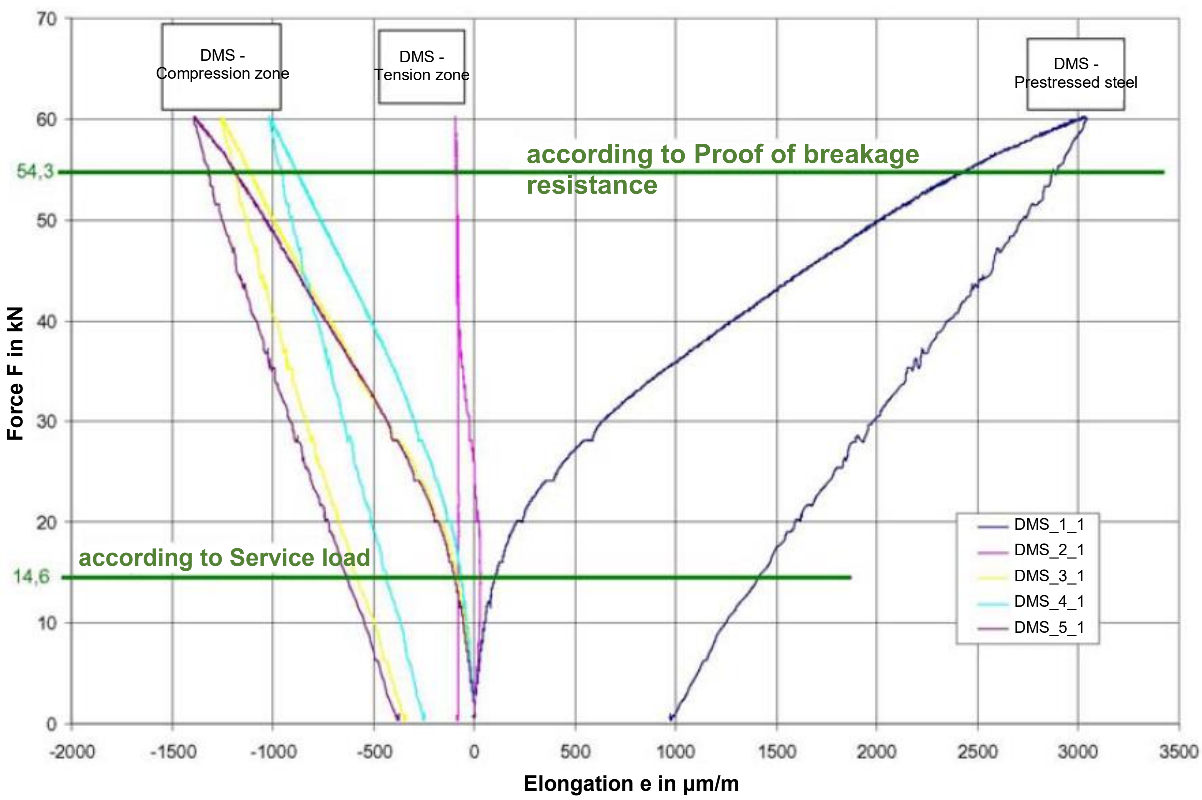


Fig. 6.13: Force-elongation diagram of prestressed concrete ceiling 1, element no. 22006

A failure of the panels was not observed neither in the concrete compression zone nor as a result of the steel flow. This is documented by the test load F = 54.3 kN, which replaces the calculated breaking moment. After unloading, the deflections occurring at F = 54.3 kN were reduced to around 25%. This finding is also proof of the high elasticity of prestressed steel and the excellent adhesive bond between steel and concrete.

- **Concrete compression and steel elongation**

The concrete deformations in the compression zone also exhibit an almost linear dependence on the load:

- for prestressed concrete ceiling 1: approx. up to 1.5 times the service load (see Fig. 6.13),
- for prestressed concrete ceiling 2: at least up to 2 times the service load.

In the case of F = 54.3 kN load, which corresponds to the calculated fracture safety proof, the measured concrete compression is a maximum of 1.2‰ and is therefore significantly smaller than 3.5‰. Therefore, failure of the concrete compression zone is excluded.

The concrete deformations of the concrete tension zone (= elongations) in service load condition (test load F=14.6 kN) are very low for both prestressed concrete panels with max. 0.1‰ (corresponding to concrete tensile stress of ~ 3 N/mm²). Consequently, the concrete tension zone remains crack-free in service load condition.

The prestressed steel elongation was measured under the impact of F = 54.3 kN test load with max. = 2.5‰, which replaced the mathematical proof of fracture safety. If the calculated prestressed steel elongation after creep and shrinkage of 3.56‰ is included, the total prestressed steel elongation is ~ 6.1‰. The yield strength of St 1.400/1.600 prestressed steel used is therefore not fully exploited.

Conclusion: According to these and previous own investigations, there is no restriction of utility value. There are no objections to the reuse of the prestressed concrete ceiling panels.[233]

- Slack reinforced ceiling panels

The load arrangement is presented in the following Fig. 5.14):

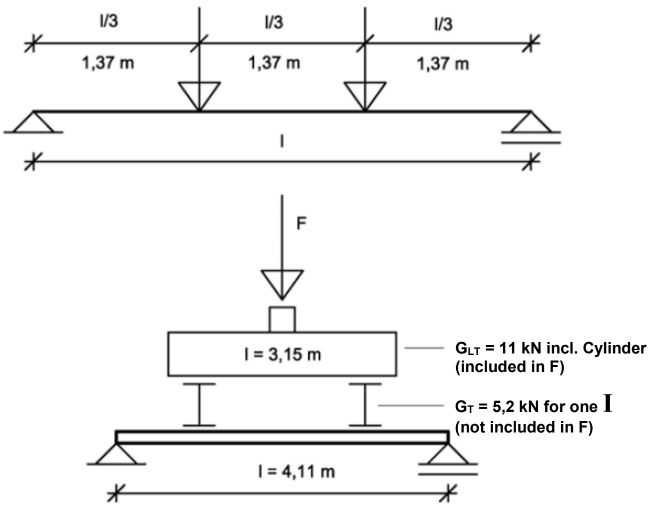


Fig. 6.14: Load arrangement and installation of reinforced concrete ceiling panel 21120

[233] Note: The load tests have been documented in the form of a video.

$$\mathrm{M_q} = \frac{10 \cdot 4{,}11^2}{8} \cdot 1{,}8 = 38{,}0\ \mathrm{kNm/Platte}$$

$$\mathrm{M_q} = 21{,}12\ \mathrm{kNm/m}$$

Dead load	= 0.14 · 25	= 3.50 kN/m2
Flooring		= 1.50 kN/m2
Live load		= 5.00 kN/m2
	q	= 10.00 kN/m2

$$\mathrm{M_g} = \frac{3{,}5 \cdot 4{,}11^2}{8} \cdot 1{,}8 = 13{,}30\ \mathrm{kNm/Platte}$$

consequently

$$\mathrm{M_p} = 38{,}0 - 13{,}3 = 24{,}7\ \mathrm{kNm/Platte}$$

It works depending on

$$\mathrm{F/2} = 24{,}7/\ \frac{4{,}11}{3} = 18{,}03\ \mathrm{kN}$$

res. force

$$\mathrm{F} = 2\cdot\left(\frac{F}{2} - G_T\right)$$

$$\mathrm{F} = 2\cdot(18{,}03 - 5{,}2) = 25{,}66\ kN$$

consequently

$$\mathrm{M_p} = \frac{4{,}11}{3} \cdot (12{,}83 + 5{,}2) = 24{,}70\ \mathrm{kNm/Platte}$$

The two individual loads are determined by the distance of the load application points at 1/3 from the supports for the application of the bending moment from live load Mp = 24.7 kNm/panel.

per F/2 = 24.7 / 1.37 = 18.03 kN

The dead load of the two load transfer beams of$_{GT}$ = 5.2 kN each is included here.

The resulting force F = 2 · (F/2 - GT) is therefore applied by the test cylinder system.

The permissible bending moment from live load

Mp = 24.7 kNm is achieved at F = 25.66 kN.

Mp = (25.66 + 10.4) · 0.5 · 4.11/3 = 24.7 kNm

The load was applied according to the load-time diagram below (Fig. 6.15). The position of the force application and measuring points is analogous to the prestressed concrete ceiling panel (cf Fig. 6.7).

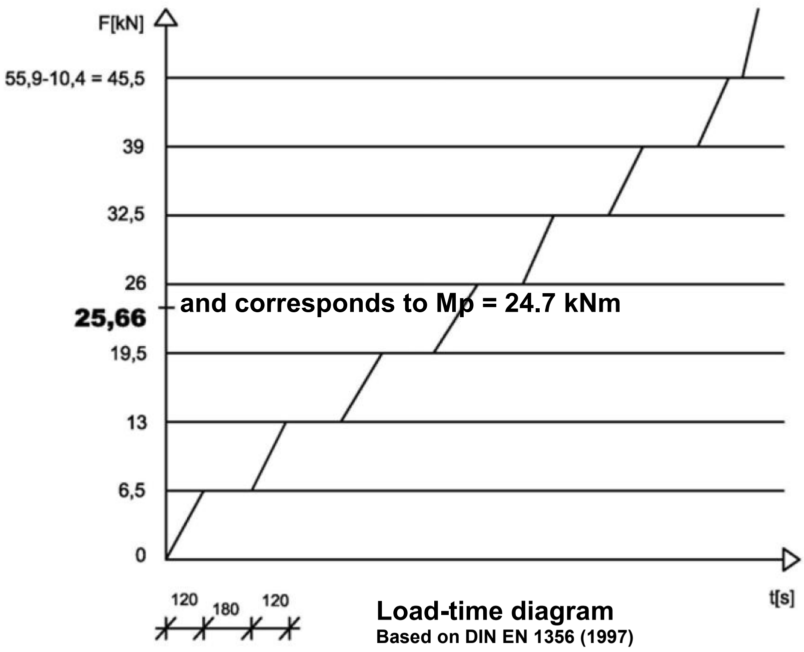


Fig. 6.15: Load-time diagram based on DIN EN 1356: 1997-02

Test results[234]

The results are as follows:

- **Deflection**

The measured deflections are very low at max. 6 mm under the load of F = 25.66 kN replacing the service load condition.

The permissible deflection of l/250 = 411/250 = 1.64 cm or

l/500 = 411/500 = 0.82 cm (with regard to partition walls)

is therefore not exceeded.

In the case of DP 1 and 2 0.82 cm was reached only with double service load,

in the case of DP 3, only with 1.4 times the service load (= 36 kN),

in the case of DP 4 only with 1.5 times the service load (= 39 kN).

Furthermore, the test results again demonstrate a linear correlation between load and deflection, which is maintained at least up to 2.5 times the service load (see Fig. 6.16). The same applies to steel elongations and concrete deformations in the compression and tension zone (see Fig. 6.17).

[234] Schmiedehausen, Rudolf: Rechnerische und experimentelle Untersuchungen für Stahlbetondeckenplatten des P2-Wohnungsbaus, El.-Nr. 21120 und 21121, test report on behalf of FG Bauliches Recycling, BTU Cottbus, 02.10.2006

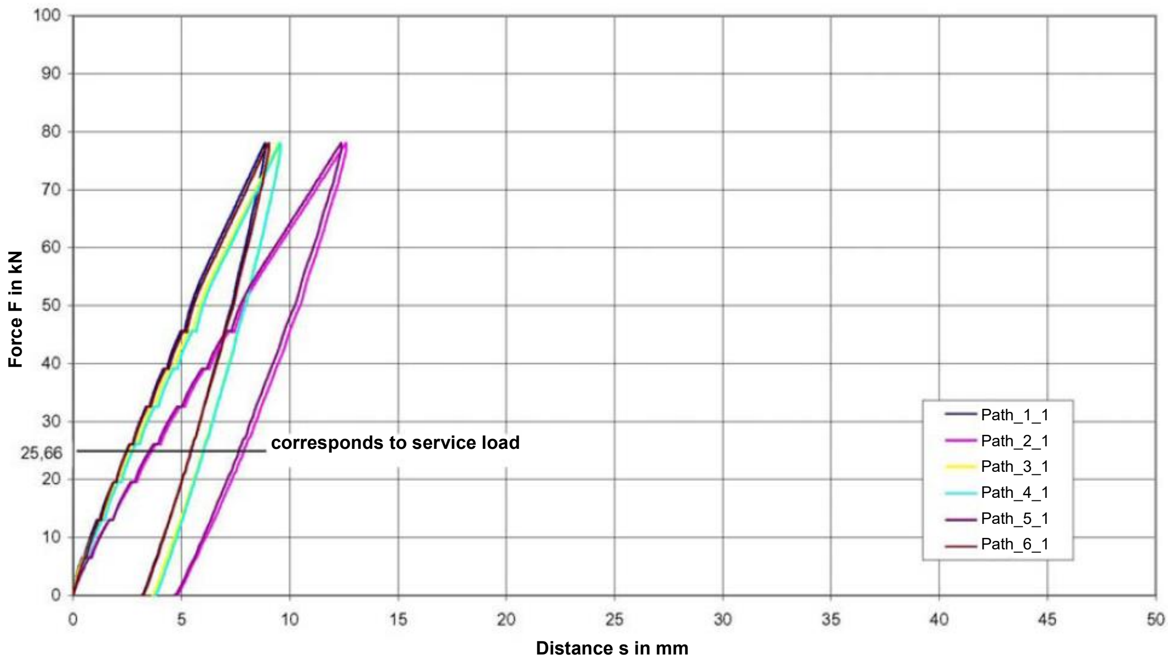


Fig. 6.16: Force-path diagram of reinforced concrete ceiling 2, element no. 21120

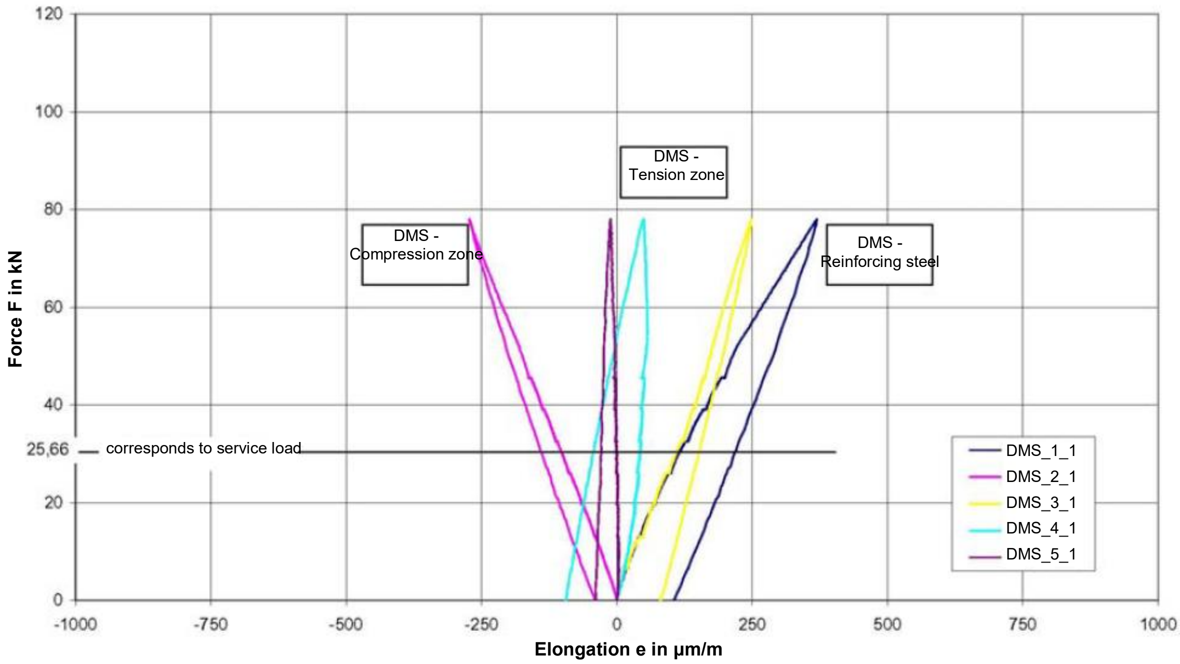


Fig. 6.17: Force-elongation diagram reinforced concrete ceiling 2, element no. 21120

In the case of DP3, the load was increased to over F = 125 kN (corresponds to approximately 6 times the service load). A disproportionate increase in deflection was only observed from F = 75kN upwards (see Fig. 6.18). At the same time, a disproportionate increase in steel elongation occurred just now (see Fig. 6.19). Coupled with the pronounced steel flow, a deflection of around 130 mm was achieved at F ≈ 135 kN. After unloading, a permanent deflection of 100 mm was measured.

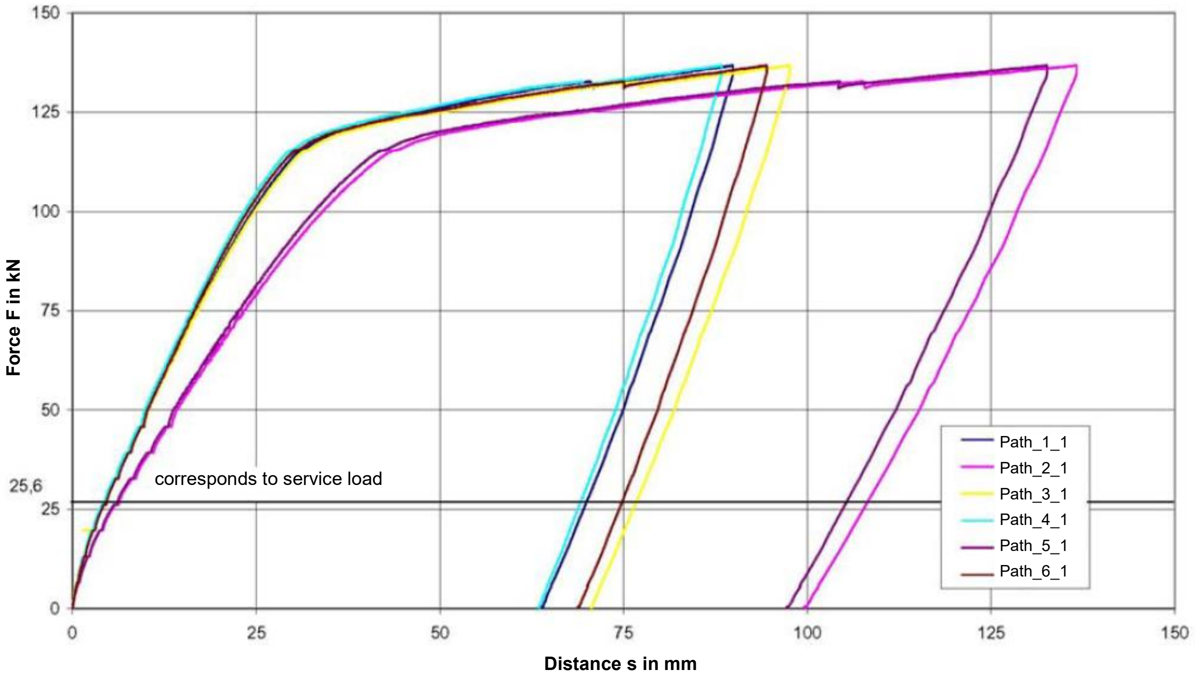


Fig. 6.16: Force-path diagram of reinforced concrete ceiling 3, element no. 21120

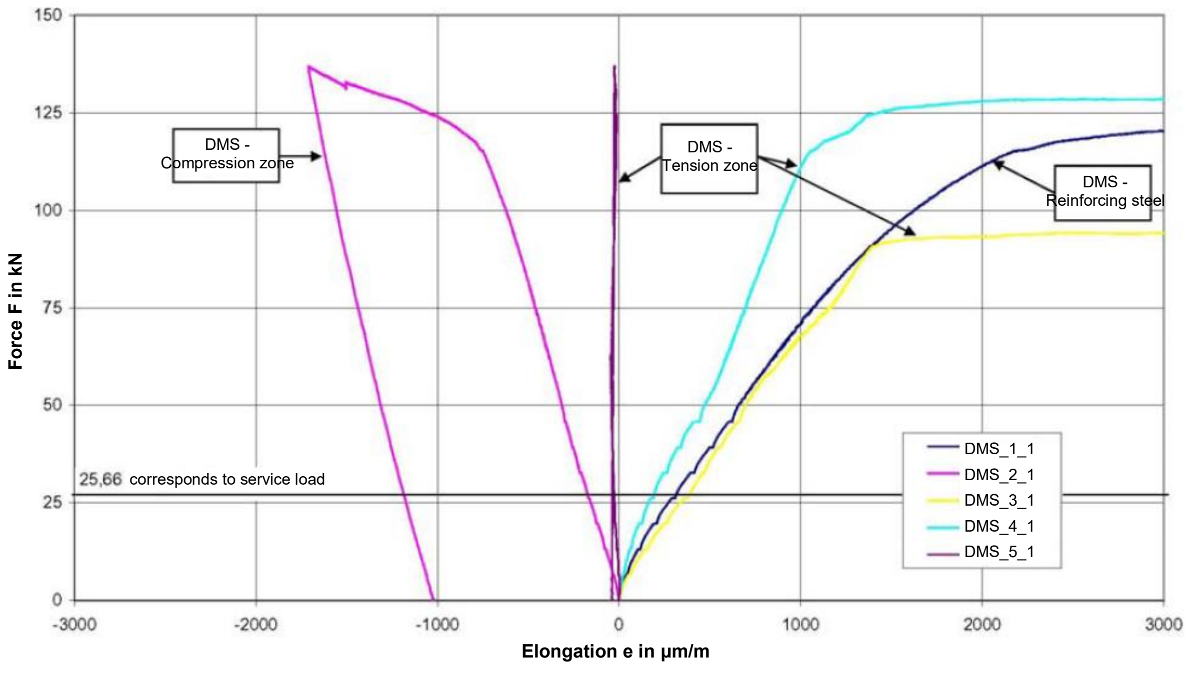


Fig. 6.17: Force-elongation diagram of reinforced concrete ceiling 3, element no. 21120

The DPs did not fail neither in the concrete compression zone nor as a result of the steel flow. A typical flexural crack pattern developed in the concrete tension zone with an uniform crack distribution at close intervals. The crack depth was about 2/3 of the panel thickness.

- **Deformation in the support area**

The measured deflections or elongations were max. ± 0.1‰ and therefore below the evaluation limit due to the very small size. Consequently, deformations (shear cracks) due to shear stresses cannot occur. The same conclusion can also be drawn from the shear force analysis.

Conclusion: The test results show that there are no restrictions in terms of utility value. Therefore, there are no objections against reuse.

6.2.2.4 Evaluation of the inner walls[235]

At the time of construction, it was necessary to observe not only TGL 11422 but also the regulation "Buildings in assembly construction"[236] for the calculation or determination of the permissible wall load. The results of the inner wall panel 51707 of the P2 type are presented as an example. The inner wall was constructed in B 160 (~ C12/15) and is considered as non-reinforced. Only the structural load-bearing and transport reinforcement is present.

Since the assumption was made that three-storey residential buildings would be built, in contrast to the original multi-storey design,

the actual load for 3 storeys N_{actual} = 155 kN/m was compared with

the permissible load N_{perm} .= 161 kN/m

in the verification in accordance with DIN 1045. Therefore, from a structural point of view, there are no objections to the reuse of the inner wall panels for this particular case.

6.2.2.5 Conclusion

The following can essentially be stated and concluded:

- The tested concrete elements have high performance characteristics, i.e. there are no objections to reuse or further utilisation.
- The existing load-bearing reinforcement of the tested ceiling elements is sufficient for live loads in living spaces (1.50 kN/m²).
- The slack reinforced ceiling panels of P2 type can even be used in offices (live load 5 kN/m²).
- The compressive strength of the concrete elements has increased in comparison to the requirements from project planning. The minimum concrete class C 30/37 in question has been verified for the tested prestressed concrete ceiling elements.
- All of the concrete elements tested comply with exposure class XC1. Components from the interior of the building can easily be reinstalled inside. If exposure to environmental conditions (exposure classes) increases, e.g., concrete components that were previously installed inside are to be used secondarily outside, corresponding measures for strengthening have to be included in the planning.

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[235] Schmiedehausen, Rudolf: Prüfbericht – Rechnerische Nachweise zur Trag- und Nutzungsfähigkeit ausgewählter Deckenplatten und Wände von Wohngebäuden der Typenserie P2, test report on behalf of FG Bauliches Recycling, BTU Cottbus, September 2001

[236] WBS 70 Bauten in Wandkonstruktion in Montagebauweise, Vorschrift (1977), Schriftenreihe der Bauforschung, Reihe Wohn- und Gesellschaftsbauten, Heft 34, Berlin

6.3 Building physics characteristics

Buildings are subject to certain building physics requirements, such as[237]:

- sound insulation against noise and acoustic pollution (external noise, noise from utilisation areas),
- fire protection in order to exclude risks to health and life; personal protection (risk of fire from outside and inside utilisation areas),
- thermal insulation to guarantee comfort and living hygiene (protection against extreme temperature changes). Thermal insulation has an impact on energy consumption and directly influences the service life (the same applies to moisture protection); energy-saving thermal insulation of buildings means improved environmental protection and reduced energy costs,
- moisture protection (protection against driving rain, removal of living moisture); prevention of damage to the building fabric.

Individual building components are often required to comply with the aforementioned building physics requirements simultaneously. Building physics requirements are primarily concerned with:

- DIN 4109 – Sound insulation in building construction
- DIN 4108 – Thermal insulation and energy saving in buildings
- EnEV[238] – Energy Saving Ordinance
- DIN 4102 – Fire behaviour of construction materials and components

The following chapters focus primarily on the results of own investigations into sound insulation, thermal insulation and fire protection.

6.3.1 Sound insulation

Sound insulation refers to all measures that counteract irritating and health-damaging noise. These include not only the generation of sound but also measures against the transmission of the airborne and impact sound as a special form of a structure-borne sound[239].

Building acoustics requirements in residential buildings are defined by means of a weighted sound reduction index R'W for airborne sound insulation and a weighted standardised impact sound level $L'_{n,W}$ for impact sound insulation. Both parameters describe the sound insulation for typical residential noise situations.

[237] cf. Reuschel, Mathias: Gebäudediagnose aus bauphysikalischer Sicht. Energieeffiziente Gebäudesanierung, in: conference proceedings Alte Platte – Neues Design – die Platte lebt, ed. Angelika Mettke, Cottbus, 2005, p. 111.

[238] valid since 1. February 2002; serves to reduce energy consumption in new and existing buildings and thus also to reduce energy-related CO2 emissions. The EnEV stipulates requirements and measures for existing buildings

- in the case of structural alterations (if the installation, replacement or renewal of individual components exceeds 20 % of the respective component surface area for the first time),
- in terms of plant engineering and structural retrofitting obligations,
- for maintaining energetic quality

[For more information, see the Munich Research Institute for Thermal Insulation at www.fiw-muenchen.de]

[239] Verbesserung des Schallschutzes von Wohngebäuden im Bestand: www.insurance-and-finance.de/download/Leitfaden-Bauen16-4.pdf accessed on 02.11.2007.

When it comes to the requirements, a distinction is made between minimum requirements and increased requirements. The former are defined with the aim of protecting people in rooms from unreasonable noise exposure. The following explanations refer to this level of protection[240]. Walls and ceilings of the P2 building series were evaluated:

- Apartment partition walls, stairwell walls

  Thickness of the walls: 15 cm reinforced concrete; positioned on the bare ceiling and supporting the ceiling; the joints are sealed by mortar lock

- Apartment partition ceilings

consisting of:	14 cm	reinforced concrete
		Separating layer
	5 cm	Anhydrite screed
	0.6 cm	Tensioned matt with felt inlay

- Staircases

  are manufactured in the form of castellated prefabricated elements. Main landings are integrated into the stairwell walls on both sides. The secondary landings are part of a bent staircase element and are also structurally integrated into the staircase wall on one side.

  The longitudinal joint between the main and secondary landings is intended to be structurally open to the staircase wall. In practice, a closed joint is regularly constructed between the main landing and the stairwell wall on the long side.

  The flights of stairs are separated from the stairwell walls by a joint. The stair flights and landings are rigidly connected to each other.

  All stair elements have a terrazzo surface.

The standard TGL 10687/03 "Sound insulation of building components" had been introduced at the time the buildings were constructed. These requirements are generally adhered to in industrially constructed buildings (block, strip and prefabricated construction) if they are constructed properly. By contrast, the requirements set out in the currently valid DIN 4109-1: 1989-11 and in VDI 4100: 1994-09 are largely not complied with.

Table 6.17 below compares the results of measurements of acoustically relevant building components in the standard construction of the P2 building type with the calculation results for sound insulation, the TGL requirements in force back then and today's DIN requirements.

[240] Mettke, Angelika: Wieder- und Weiterverwendung von gebrauchten Betonfertigteilen, in: Beton+Fertigteil-Jahrbuch 2003, p.70 ff.

Tab. 6.17: Requirements and actual values for airborne and impact sound insulation for components of the P2 type (standard construction)[241]

Component	TGL 10687 / 03 (Issued 09.86)		DIN 4109 (Issued 11.89)		VDI 4100 (Issued 09.94) Sound insulation level 1		Calculated values [dB]		Measured values [dB]	
	erf. R'_w	erf. $L'_{n,w}$	erf. R'_w	erf. $L'_{n,w}$	erf. R'_w	erf. $L'_{n,w}$	R'_w	$L'_{n,w}$	R'_w	$L'_{n,w}$
Apartment partition walls	51		53		53		51		47	
Staircase room walls	51		52		52		51			
Apartment partition ceilings	51	59	54	53[1]	54	53[1]	53	72[2] 48[3] 55[4]	48[3]	77 50[3] 55[4]
Staircase installations: Staircase flights and landings		59		58		58		59[5] 65[6]		68[7] 56[8] 58[9]
Apartment entrance doors	22		27		27		not accomp lished		not accomp lished	

[1] Soft-sprung floor coverings may not be taken into account in the verification of the requirements
[2] for the ceiling with screed
[3] for the ceiling with tensioned matt
[4] for the sanitary unit
[5] with open joint to the stairwell wall
[6] with closed joint to the staircase wall
[7] Landing
[8] Side landing
[9] Flights of stairs
not accomplished

The following evaluation of the situation is based on measurements carried out in the existing building stock to determine the level of sound insulation achieved in practice[242]:

Apartment partition walls

The weighted sound reduction index R'_W = 47 dB (average) is surprisingly low. The determined value is 4 dB below the calculated value and even 4 dB below the required value according to TGL. The achieved level of protection can therefore be described as extremely poor. The minimum requirements currently applicable in accordance with DIN 4109 are not achieved by 6 dB of the average calculated value.

The reasons for poor airborne sound insulation are to be found in the joint connections and the inadequate construction of these. Joint connections have cracked due to movements of the structural

[241] summarised from: Jackisch, Reinhard: Rechnerischer und messtechnischer Nachweis der Luft- und Trittschalldämmung von Standardkonstruktionen des Typs P2, test report on behalf of FG Bauliches Recycling, 2002 and comparison with Baasch, Helga; Paap, Helga; Rietz, Andreas: Sanierungsgrundlagen Plattenbau, 1999 Abschn. 4.3.3.
[242] Jackisch, Reinhard: Rechnerischer und messtechnischer Nachweis der Luft- und Trittschalldämmung von Standardkonstruktionen der Wohnungsbauweise P2, test report on behalf of FG Bauliches Recycling, BTU Cottbus, 2002, p. 22 ff.

elements, the joint fillings show considerable differences in compaction, in some cases interspersed with cavities.

From a subjective point of view, raised speech can be heard from room to room via the connecting joints.

Performed simulation calculations and structure-borne sound measurements on the building proved that the existing flanking components exhibited sufficient longitudinal sound insulation dimensions.

In order to achieve the desired level of sound insulation in accordance with DIN 4109, renovation measures are required both in the joint area and in the direct apartment partition wall area.

Apartment partition ceilings, living space

The airborne sound insulation of the apartment partition ceilings was measured at an average of R'W = 48 dB. This means that the measured mean value of the airborne sound insulation is 5 dB below the calculated value, 3 dB below the requirement value according to TGL and 5 dB below the currently applicable DIN specifications.

The average value of the established impact sound insulation of $L'_{n,W}$ = 50 dB for ceilings with tensioned matt is due to the ageing behaviour of the covering. The impact sound insulation requirements of the TGL are exceeded by 9 dB and the DIN requirements by 3 dB, i.e., they are achieved with a high degree of certainty.

$L'_{n,W}$ = 77 dB (average) in the case of a bare ceiling with screed. This is 5 dB worse than the calculated or theoretically expected impact sound insulation. The reason for this is the separation layer installed between the screed and the bare ceiling and the resulting acoustically unfavourable resonance system. Simultaneously, the screed layer becomes more stimulated by the energy input and can transfer the energy to the adjoining walls. This is because the bond between the screed and the wall is relatively strong.

Apartment partition ceilings, sanitary unit cell

An average value of L'n,W = 55 dB was determined for diagonal impact sound transmission in apartment partition ceilings with sanitary unit cells. This corresponds to the theoretical expected value.

The requirement value according to TGL is achieved to a good extent with $L'_{n,W}$ = 59 dB. The current requirement value according to DIN 4109 in the amount of $L'_{n,W}$ = 53 dB is not achieved. Therefore, the impact sound protection level is not good.

The reason for the unsatisfactory impact sound insulation is seen in structure-borne sound bridges in the floor connection area and in the vertical connection area of the shaft panelling to the apartment partition wall.

Staircase walls

Measurements were not performed. Airborne noise protection values of around 51 dB are expected (corresponding to the calculated R'_W) due to the structural conditions. The required airborne sound insulation level according to TGL is thus achieved, although it is 1 dB below the DIN standard.

Staircases, main and side landings

The average impact sound insulation of side landings was determined on average with $L'_{n,W}$ = 56 dB, which is of comparable value as for the flights of stairs.

The main landings have an average impact sound insulation of $L'_{n,W}$ = 68 dB and are therefore considerably worse than the side landings and flights of stairs. All impact sound requirements are significantly exceeded. The level of sound insulation is considered unacceptably low.

The reason for this is the joint between the main landing and the long side of the staircase wall. In contrast to the flights of stairs and the side landings, this joint had been closed in the disassembly process. The measured value corresponds approximately to the calculated value of $L'_{n,W}$ = 65 dB.

Summary of the sound insulation results

The comparison of the values according to TGL 10687/03: 1986-09 with the current sound insulation requirements according to DIN 4109: 1989-11 and VDI 4100: 1994-09 shows that the P2 type of prefabricated construction does not fulfil today's sound insulation requirements. An exception is the apartment partition ceiling with tensioned matt. It also fulfils today's requirements for impact sound insulation.

However, in some cases the measurement results[243] of approx. 30 individual measurements deviate considerably from the calculated values. This applies in particular to the airborne sound insulation of apartment partition ceilings and walls (cf Tab. 6.17). The cause was found to be construction and processing defects as well as structure-related issues.

6.3.2 Thermal insulation

Thermal insulation requirements are divided into minimum requirements and requirements for energy-saving thermal insulation. Adherence to the minimum thermal insulation is intended to ensure that the building components are free of condensation and mould and thus guarantee a hygienic indoor climate. The requirements for energy-saving thermal insulation involve stricter requirements that ensure the energy-saving design of components and buildings. Component requirements are specified either via thermal resistance R or via thermal transmittance U (formerly k).

The following analyses include calculations of thermal transmittance coefficients and thermal resistance of three-layered outer walls (17 cm load-bearing layer, 5 cm expanded polystyrene, 7 cm weather shell), staircase walls (15 cm reinforced concrete) and ceilings: Storey ceiling, basement ceiling (14 cm bare ceiling, separating layer, 5 cm flowing anhydrite screed, 0.6 cm tensioned matt with felt inlay[244]), ceiling to ventilated roof with standard structure (14 cm bare ceiling, 1 layer of roofing felt laid loose, 4.5 cm mineral wool mats) of the P2 building series. The calculation results were compared with the requirements of TGL 35424/03(12/85) "Constructional Thermal Insulation" and the current requirements of DIN 4108-2: 2003-07 (unchanged since the 2001-03 edition). The results for thermal resistance are presented in Tab. 6.18 below.

[243] Basics: DIN EN ISO 140 „Messung der Schalldämmung in Gebäuden und von Bauteilen"; DIN EN ISO 717 „Bewertung der Schalldämmung in Gebäuden und Bauteilen, Bauakustische Auswertungssoftware NOR-SIC, Version 3.0.18

[244] Apartment partition ceilings were constructed by VEB WBK Cottbus generally without additional insulation layers in the flooring structure. Basement ceilings were partially constructed without thermal insulation, however, most were thermally insulated. The worst-case scenario is assumed here, i.e., an uninsulated flooring structure.

Tab. 6.18: Thermal insulation – assessment of the actual stock situation[245]

	Minimum values for thermal resistance R of building components according to DIN 4108-2:2003-07 [m²K/W]		Minimum thermal insulation requirements in accordance with TGL 35424/03(12/85) [m²K/W]		Minimum requirement for evaluation		Remarks
	R	R_{vorh}	R_{min}	$R_{m,vorh}$	accomplished	not accomplished	
Outer walls (longitudinal outer walls and gable panels)	1.2	≈ 1.0 (-14%)[3]	0.60[1] 1.15[2]	1.28 (-11%)[3]		x	Increased risk of condensation and mould formation (corners of rooms and window jambs are particularly at risk)
Staircase walls							
θ_i > 10 °C	0.07	0.10	No requirements, as radiators are present in the staircases		x		
θ_i ≤ 10 °C	0.25	0.10				x	
Apartment partition walls	0.07	0.10	No special requirements		x		
Apartment partition ceilings	0.35	0.27	No requirements			x	no additional insulation layer
Basement ceilings	0.9	0.27	0.5			x	no additional insulation layer
		0.4 – 0.7				x	with insulating layer
top storey ceilings	0.9	1.07	1.3		x according to DIN	x according to TGL	Complies with insulation layer thickness of 4 cm or more

[1] of rooms with an outer wall

[2] as second and further outer wall of the room

[3] when thermal bridges at the edges of the panels and window reveals are taken into account

$R_{m,prev}$ - Calculation of thermal resistance on average

R_{min} - Minimum thermal resistance

In terms of thermal insulation, the existing structure of the building stock is assessed as follows[246]:

Outer walls

The three-layered longitudinal outer wall panels and gable wall panels exhibit an average thermal resistance of $R_{m,vorh}$ of 1.28 m²K/W, calculated in accordance with TGL. This means that the requirements of TGL 35424/03 of R_{min} = 0.60 or 1.15 m²K/W valid during the construction period are adhered to.

[245] summarised according to: Grosch, Volker; Pöthig, Steffen: Wärmeschutz von Standardkonstruktionen des Wohnbautyps P2, test report on behalf of FG Bauliches Recycling, BTU Cottbus, 2002
[246] ibidem, p. 30 f.

A comparison with the currently valid minimum requirements according to DIN 4108-2 demonstrates that the thermal resistance of the outer wall elements with R ≈ 1.00 m²·K/W, determined according to DIN EN ISO 6946, is below the limit value of R = 1.2 m²·K/W. The minimum thermal insulation is not complied with.

Thus, there is a fundamental increased risk of condensation and mould formation. The corners of rooms, window jambs and the connections between the outer wall and the basement ceiling are particularly at risk.

Staircase walls

The staircase area can be regarded as low-heated space with an inside temperature of θ_i > 10 °C due to the presence of radiators in the staircases of the P2 housing series.

According to TGL, there were no requirements regarding the minimum thermal insulation of the staircase walls. According to DIN 4108-2, the requirements for staircase walls of θ_i > 10 °C of R ≥ 0.07m²·K/W are fulfilled by the existing staircase walls.

The more stringent requirements of R = 0.25 m²·K/W for stairwells that are only heated indirectly or only up to temperatures of θ_i ≤ 10 °C (but are frost-free) are not fulfilled by the existing walls.

Apartment partition walls

There were no special requirements after TGL.

In accordance with DIN 4108-2, the minimum requirements for apartment partition walls or walls between rooms used by third parties of R ≥ 0.07 m²·K/W are complied with.

Apartment partition ceilings

After TGL, there were no thermal insulation requirements for apartment partition ceilings in centrally heated buildings. The requirements of DIN 4108-2 for the minimum thermal insulation of apartment partition ceilings of R ≥ 0.35 m²·K/W are not fulfilled by the considered ceiling structure without additional insulation layers with R = 0.27 m²·K/W.

However, from a building physics perspective, there is no increased risk with regard to thermal and condensation protection if this requirement is not adhered to, provided the living spaces are heated to θ_i > 10 °C.

Basement ceiling

In the most unfavourable case, no additional insulation layers are installed in the floor structure of the basement ceiling or in the apartment partition ceilings. In this scenario, the minimum requirements according to TGL of R_{min} = 0.95 or 0.50 m²·K/W or according to DIN 4108-2 of R ≥ 0.90 m²·K/W are not complied with.

If insulation layers have been installed, it can be assumed that thermal resistance of R = 0.40 ... 0.70 m²·K/W is achieved. The currently valid minimum requirements are still not complied with.

Ceiling to the ventilated roof space

The thermal insulation properties of the ceiling to the ventilated roof space are secured by an insulating material layer. During the construction of the buildings, the installed insulation thickness was generally adapted to the applicable minimum requirements of TGL. Insulation thicknesses of 45, 60 and 75 mm were used and thermal resistances of approx. R = 1.1 to 1.9 m²·K/W were achieved.

According to DIN 4108-2, the minimum thermal insulation of R ≥ 0.90 m²·K/W is already achieved at an insulation thickness of approx. 4 cm.

Summary of the results for thermal insulation

Ultimately, it was determined that the tested apartment partition walls and the top storey ceiling of the P2 type fulfil the minimum requirements according to DIN 4108-02 due to the thickness of the insulation layer. The outer walls and basement ceilings do not fulfil these requirements. In the case of staircase walls, fulfilment of the minimum requirements depends on the staircase temperature. The requirements are fulfilled at inside temperatures above 10°C , but not at ≤ 10°C .

This means that the P2 prefabricated construction method does not meet today's thermal insulation requirements if no additional measures are taken, what is caused by the poorly dimensioned thermal insulation layers.

Further reference is made to the publication by REUSCHEL[247], where e.g., components of WBS 70 of different construction variants are evaluated.

Inadequate thermal insulation of industrially constructed residential buildings is a common feature of all types of residential buildings. However, this deficiency has not only been identified in eastern Germany, but also in the industrial residential buildings, particularly in countries of Central and Eastern Europe. Basically, the same problems are encountered there, though usually in an aggravated form.[248]

6.3.3 Fire protection

The requirements in terms of fire protection are set out in the respective state construction regulations. These compliance rules include are requirements in terms of the

- location on the property and in relation to adjacent buildings,
- fire behaviour of building materials and components,
- size and protection of fire compartments, and
- location and design of

escape routes.

DIN 4102 defines, among other things, the fire resistance of building components and the fire protection class. As a classic building material without combustible components, concrete is assigned to class A1 (non-combustible). The minimum requirements for structural fire protection must be complied with

[247] Reuschel, Mathias: Gebäudediagnose aus bauphysikalischer Sicht. Energieeffiziente Gebäudesanierung, in: Alte Platte – Neues Design – Die Platte lebt, ed. Angelika Mettke, Cottbus, 2005, p. 111 ff.
[248] see Kerschberger, Alfred: energetischer Umbau von Plattenbauten – Deutschland, Osteuropa, Russland, China [Toblacher Gespräche 2005: Bauen für die Zukunft, 22.09. – 24.09.2005].

depending on the height of the building and the number of flats (corresponding fire resistance classification[249]). Compliant with the Model Construction Code (MBO, as amended in November 2002), most federal states differentiate between 4 building classes below the high-rise limit of 22 metres. In the case of other buildings with heights between 22 m ≥ OFF > 7 m[250] (corresponding to building class 5 as per MBO; 5 and 6-storey prefabricated buildings with storey heights of 2.80 m can be classified as such), for example, walls as per Section 27 MBO and ceilings as per Section 31 MBO are required to be fire-resistant. This means that fire resistance class F 90 is required.

The following is an outline of the test results for the fire behaviour of reinforced concrete and prestressed concrete ceilings. The assessment of fire resistance duration was carried out on two reinforced concrete and two prestressed concrete ceiling panels. The tests were carried out at MFPA Leipzig[251]. Subjects under examination were elements 21000 (prestressed concrete ceiling panel), 21119 and 21120 (reinforced concrete panel) of the P2 building type with a construction age of 28 years. They were installed in a 5-storey building on Turower Straße in Cottbus. The disassembled concrete elements were transported approx. 180 km to Laue (near Delitzsch) by low-loader for the purpose of investigating their fire protection behaviour.

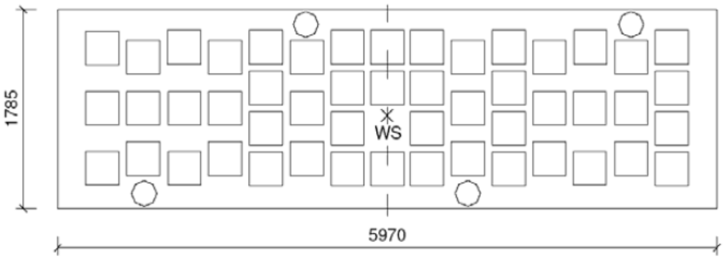
According to DIN 4102-4: 2004-11, the elements of the P 2 type series analysed as part of the research project achieve at least the fire resistance classes F30-A[252]. This has also been confirmed by fire tests. Each ceiling panel was tested individually, installed as horizontal room closure of a ceiling test furnace. The load on the elements was 3.25 kN/m² (cf Chap. 6.2.2.1, Tab. 6.13; consisting of additional dead load g1 = 1.00 kN/m², live load p= 1.50 kN/m², suplus for lightweight partition walls Δp= 0.75 kN/m²) and was simulated by means of dead loads in the form of concrete and steel weights (see Fig. 6.20, 6.21). In order to measure the deformation, a potentiometric path sensor (WS) was installed in the middle of the panel. The position of the measuring points in the fire test room is illustrated in Fig. 6.22.

[249] Fire resistance class designation by construction authorities:
- Fire-retardant F30, F60; the component fulfils its function for at least 30 resp. 60 minutes in the event of fire
- Fire-resistant F90; the component fulfils its function for at least 90 minutes in the event of fire
- Highly fire-resistant F120, F180; the component fulfils its function for at least 120 resp. 180 minutes in the event of fire

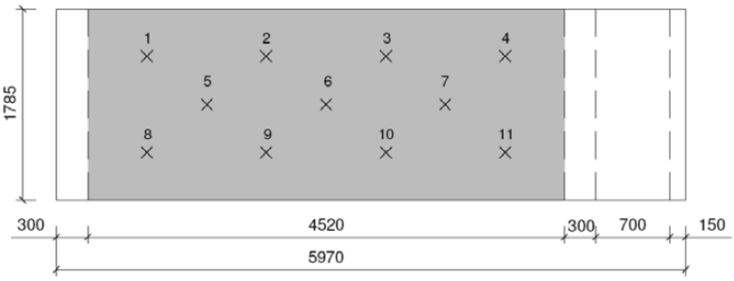
[250] cf. e.g. Brandenburgische Bauordnung (BbgBO) as of 01.06.1994, §2 Abs. 3: Buildings of medium height are buildings where the floor of the top storey is higher than 7 metres but no higher than 22 metres above ground level.

[251] Gesellschaft für Materialforschung und Prüfungsanstalt für Bauwesen (MFPA) Leipzig GmbH, Prüf-, Überwachungs- und Zertifizierungsstelle nach Landesbauordnung, Bereich III Bauphysik, Baulicher Brandschutz.

[252] see Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Ivanow, Evgeny: Endbericht “Wiederverwendung von Plattenbauteilen in Osteuropa”, May 2008, p. 140



□ Concrete cube (62.1 kg) Not represented: other small weights,
○ Cylinder (80 kg) Total weight: 40 kg
× Path sensor (WS)



× Surface measuring points 1 to 11
▒ Flamed area

Fig. 6.20: Exemplary representation of the measuring points and the load plan for the examination of fire resistance - prestressed concrete ceiling panel 21000

Fig. 6.21: Fire test room (left) and simulation load (right)

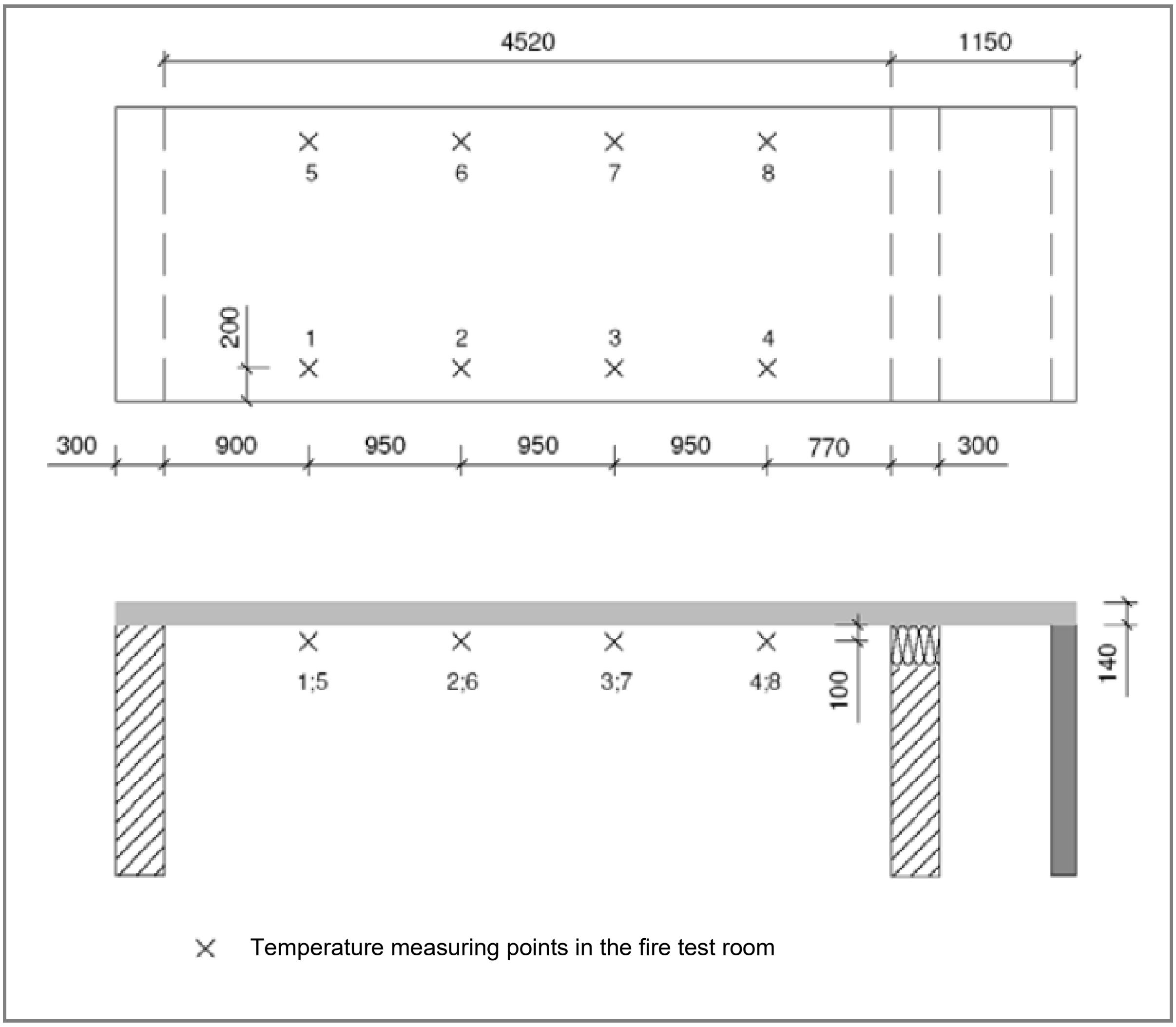


Fig. 6.22: Test arrangement / position of the fire test room measuring points – prestressed concrete ceiling panel 21000

The fire test room was heated according to the standardised temperature-time curve (ETK) in accordance with DIN 4102-2: 1977-09.

Key test results[253]:

During fire tests, observations on all 4 ceiling panels revealed that the panels deformed slowly (see Fig. 6.23, 6.24). After aborted testing of prestressed concrete ceiling panel I or after completed testing of prestressed concrete ceiling panel II, the panels have more or less returned to the horizontal position. Important test results are presented in Table 6.19 below.

[253] Hertel, Claudia: Prüfung des Brandverhaltens von Spann- und Stahlbetondeckenplatten zur Ermittlung der Deckenunterseite, excerpt from test report on behalf of FG Bauliches Recycling, BTU Cottbus, MFPA Leipzig GmbH, April 2003; Mettke, Angelika: Nachnutzungsmöglichkeiten gebrauchter Betonbauteile, in: Alte Platte – Neues Design – Die Platte lebt, ed. Angelika Mettke, 2005, p. 136 f.

Tab. 6.19: Results of the fire tests

Prestressed concrete ceiling panel 21000			
Standard reference according to DIN 4102-2:1977-09, section	**Requirements**	**Sample panel**	
		I	**II**
5.2.4 Load-bearing capacity	Maintaining the load-bearing capacity under load	The load-bearing capacity was maintained for 30 minutes	
5.2.6 Deflection speed	Compliance with the permissible deflection speed $\Delta f/\Delta t = 570^2/(9.000 \times 13) = 2.8$ cm/min	max. available deflection speed	
		approx. 1 cm/min between 25. and 27. test minute	approx. 0.8 cm/min between 19. and 20. test minute
8.7	other details	max. deflection 30. test minute in the middle of the panel	
		> 100 mm	104 mm
Fire resistance duration		**> 30 minutes**	
Reinforced concrete ceiling panels			
Standard reference according to DIN 4102-2:1977-09, section	**Requirements**	**Reinforced concrete ceiling panel**	
		21120	**21119**
5.2.4 Load-bearing capacity	Maintaining the load-bearing capacity under load	The load-bearing capacity was maintained	
		> 90 minutes	> 85 minutes
5.2.6 Deflection speed	Compliance with the permissible deflection speed $\Delta f/\Delta t = 390^2/(9.000 \times 13) = 1.3$ cm/min	max. available deflection speed	
		approx. 4.0 cm/min between 80. and 90. test minute	> 1.3 cm/min between 80. and 86. test minute
8.7	other details	max. deflection in the middle of the panel	
		90. test minute approx. 600 mm	86. test minute abrupt failure
Fire resistance duration		**approx. 80 minutes**	

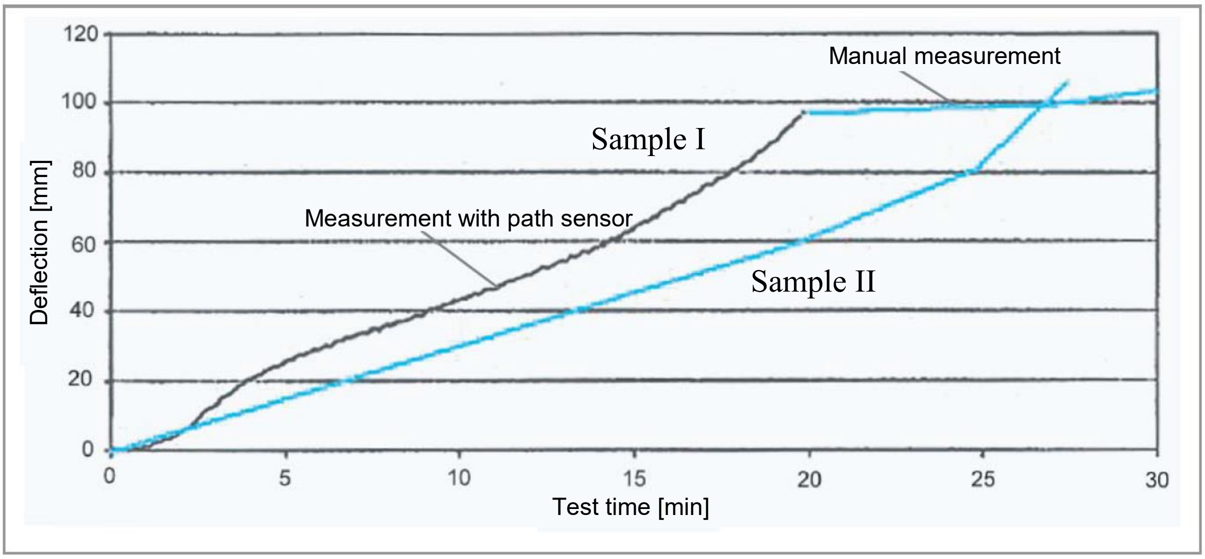


Fig. 6.23: Deflection in the direction of the fire test room - prestressed concrete ceiling panels 21000 (P2 type)

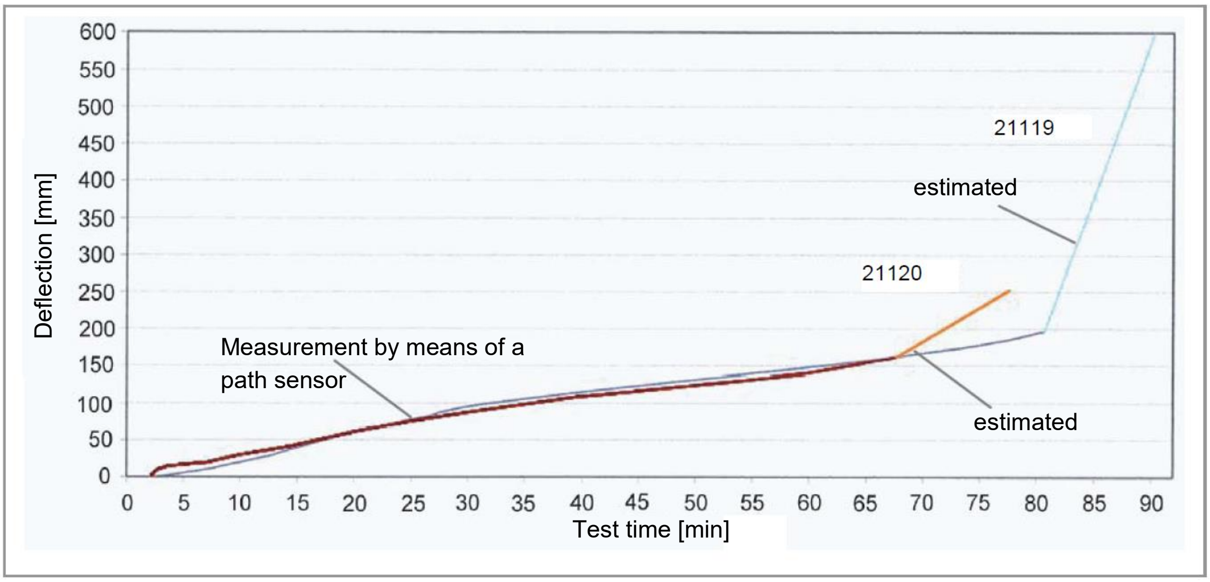


Fig. 6.24: Deflection in the direction of the fire test room - reinforced concrete floor panels 21119, 21120 (P2 type)

Overall, it can be summarised as follows:

- **Prestressed concrete panels:**

The requirements for F 30 have been fulfilled in the case of fire resistance duration of > 30 min. In the 30. test minute, the maximum deflection in the middle of the panel was > 100 mm for sample I or 104 mm for sample II. The load-bearing capacity under load was maintained for over 30 minutes.

- **Reinforced concrete panels**

The fire resistance duration for both ceiling panels is approx. 80 min. The maximum deflection of approx. 600 mm was recorded for element 21120 in the 90. test minute. In the case of element 21119, an increased degree of deflection was observed from the 80. test minute onwards, and the panel failed abruptly in the 86. test minute.

Summary of the test results on fire behaviour

In conclusion, it can be stated that the calculations for fire resistance duration correspond to the values obtained in the test. This means that the elements can only be reinstalled in residential buildings with a height of up to 7 metres, unless they are upgraded. This is due to the fact that building class 3 requires utilisation of fire-retardant fire resistance classes for ceilings and walls on standard storey in accordance with § 27 and 31 MBO. If ceilings and walls are used as secondary elements in the basement, this is possible up to building class 2 (residential buildings with a height of up to 7 m and no more than two utilisation units of no more than 400 m² total floor area) without processing.

7 Options for subsequent utilisation of used concrete elements from prefabricated buildings

Possible secondary areas of application for previously utilised concrete components are discussed below. Interim results were published on a regular and timely basis in accordance with the obtained research results in [5], [7] - [12], [16], [20], [23] - [25], [27], [30], [38], [39], [41], [43], [45], [50], [51], [53], [57], [58], [61] - [65]. Further reference is made to this in the following; with regard to the further use of concrete elements in dyke construction in particular to [53].

7.1 Introduction

Dismantled concrete elements (see Chap. 4 and 6) can either be used as a component in their entirety (cf. def. Chapter 2.1) or if necessary, reprocessed or treated in RC plants as secondary raw material or recyclate (cf. Chap. 9). Both recycling options are in line with the overriding objective of the sustainability policy of conserving natural resources (cf. Chap. 2.2). However, prefabricated buildings should not only be regarded as potential donor buildings for RC building materials or concrete chippings (cf. Chap. 9), but primarily as adaptable shell structure and donor objects for RC concrete elements.

Partial deconstructions carried out in many places in the recent past, usually coupled with modernisation and refurbishment measures for the remaining stock, prove that prefabricated buildings are reformable. The user catalogues published by the author and the exemplary solutions presented in the conference proceedings "Alte Platte - Neues Design "[254] provide information, suggestions and answers for sustainable urban redevelopment.

The combination of partial deconstruction and conversion of the remaining building stock. in accordance with current structural and, above all, energy requirements, with consideration of today's living preferences, including measures to improve the living surroundings in the context of utilising dismantled precast concrete elements, offers approaches that cannot be achieved with traditional refurbishment and modernisation or demolition measures. Consequently, all those involved in construction are forced to invert and ward off the idea of combating vacancy problems solely by demolishing buildings and constructing new buildings or structures only with new building materials and products. It is therefore not only a question of construction in the existing building stock, but also of construction with the existing building stock (product recycling).

Product recycling is of exceptional importance since added value is retained and the materials used (construction materials and energy) can be completely or at least extensively utilised. As described in Chapters 6 and 2.3, these are high-quality, young precast concrete elements with a construction age of approx. 10 to 40 years.

Furthermore, the recycling of building components is in line with the prevention of construction waste in accordance with § 4 (1) sentence 1 KrW-/AbfG and is optimally aligned with the hierarchy specified in the European Waste Framework Directive.

Apart from maintaining added value, component recycling also facilitates an increase in value, as illustrated by the demonstration projects that have already been implemented.

[254] Mettke, Angelika (ed.): Plattenumbauten, Wieder- und Weiterverwendungen – Anwenderkatalog I und II, BTU Cottbus, 2001 und 2003; Mettke, Angelika (ed.): Alte Platte – Neues Design – Die Platte lebt, Tagungsband, Fachtagung 16./17.02.2005, BTU Cottbus, 2005; Mettke, Angelika (ed.): Alte Platte – Neues Design, Teil 2, Die Platte – wrapped – verpackt, Tagungsband 01./02.03.2007, BTU Cottbus, 2008

Notwithstanding the considerable efforts made by progressive planners and builders in numerous places, the scientific basis created for the serviceability of the dismantled concrete components and the public relations work carried out by the author, the implementation of construction with used precast concrete components is still confronted with scepticism. There are individual solutions and several pilot projects, however, industrial implementation is still a long way off. Therefore, the following fundamental issues need to be discussed for construction with recycled concrete components:[255]

- "Panel or large panel = image problem?"

  Is there a justified image problem with panel construction?

- "Construction in the system – construction with the system"

  In what ways are modifications to the design and execution different from construction with new concrete components? Is the planner's creativity restricted by the use of (old) RC elements?

- "Added value instead of unit value"

  What are the opportunities for product recycling from a holistic perspective (economic, technological, logistical, ecological, social, legal)? Currently, the predominant question is how much the owner/client can save on costs.

Throughout the history of architecture and urban planning, it has been proven that the reuse of construction components is an age-old principle. Examples include church buildings or entire city complexes such as that of Troy, which served as source of raw materials for new buildings.

In the process of reconstructing towns and villages, especially after the Second World War, bricks, beams and other building components were salvaged from the rubble and reused. Commercial activity was affected by the shortage of construction materials and reuse and recycling measures had not been questioned. The concept of sustainable development has evolved in modern times, particularly in the wake of the Brundtland Report[256], the Meadows study[257] and the Enquete Commission of the 12th German Bundestag on the "Protection of Man and the Environment", and is now being applied in the construction sector with regard to the use of construction materials and construction technologies and also in the property industry.

This is precisely where the considerations for the subsequent utilisation of dismantled/disassembled concrete elements come in. The following section outlines potential applications, measures that have been implemented or are about to be implemented or have already been tested. The accompanying scientific analyses of case studies allow the questions above to be answered and any remaining hindrances to be identified.

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[255] Uhl, Markus: Bauen in und mit dem Bestand „Vereinshaus Fußballverein Gröditz – Metamorphose der Platte“, in: conference proceedings „Alte Platte – Neues Design – Die Platte lebt“, ed. Angelika Mettke, 2005, p. 161 f.

[256] Brundtland-Report (1987): „Unsere gemeinsame Zukunft“ („Our common Future“); relevant for the international debate on development and environmental policy, coining the concept of sustainable development "that meets the needs of the present without compromising the ability of future generations to meet their own needs". "Sustainable development is a process of change where utilisation of resources ... is made consistent with future and current needs."

[257] On behalf of the Club of Rome, Dennis L. Meadows and his colleagues carried out a system analysis with various levels of natural raw material reserves on earth and identified "Limits of Development" (1972).

7.2 Decision-making on suitability for reuse and/or further use

The assessment of suitability for reuse (product recycling) is a multi-stage decision-making process that requires a specific sequence in its execution (see Fig. 7.1). The basic procedure is characterised by a multi-level problem-solving process.

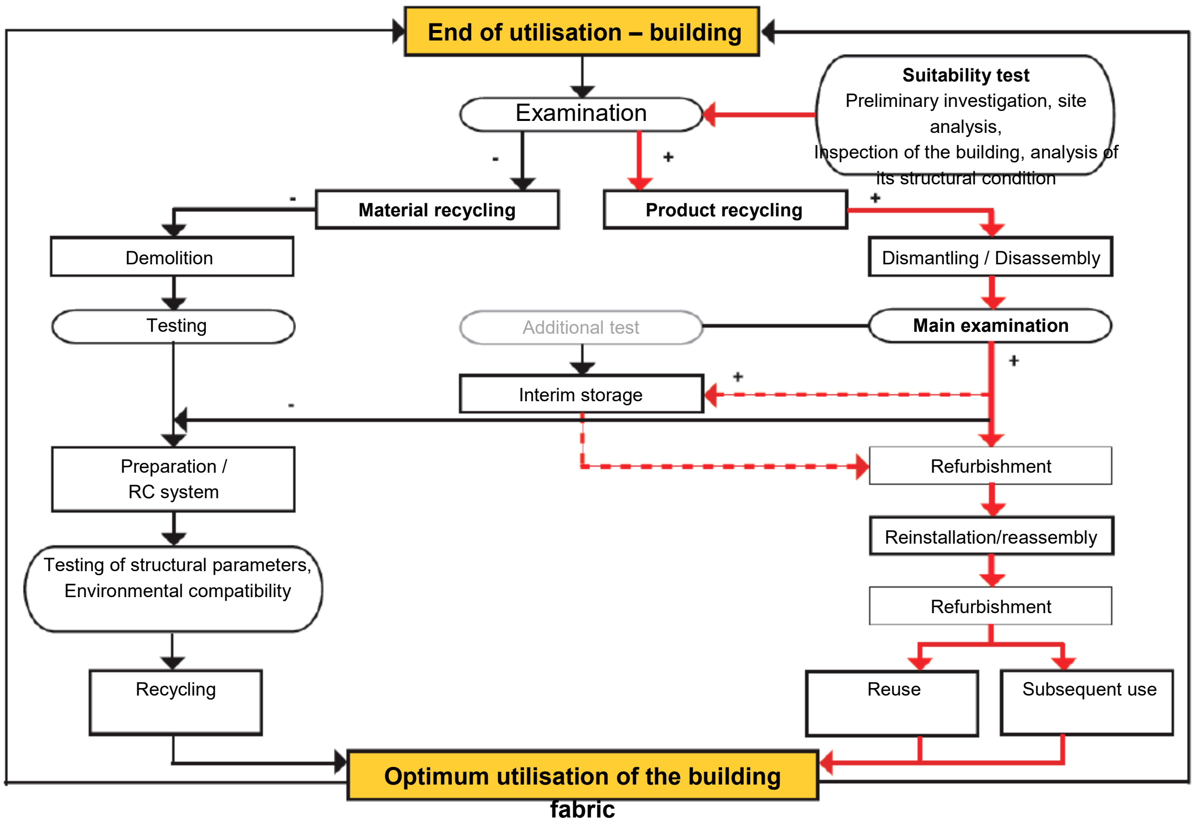

Fig. 7.1: Options for optimising the subsequent use of buildings and structures[258]

This methodological approach has proven itself and proven to be appropriate in own research work for more than 10 years. The practicability of the model for decision-making concerning reusability and/or suitability for further use was demonstrated on a large number of examples.

The suitability test includes examinations of the object as well as examinations of the structural components and elements. This means that the structural condition of the concrete elements and the potential for reuse and / or further utilisation (broken down by product range) is assessed in the installed state.

The main and the additional test are performed on the disassembled component. The impacts of disassembly are taken into account in the main test. The designation was chosen appropriately, as the quality of the dismantling technology has significant influence on the structural condition of the construction elements.

Since subsequent utilisation of the dismantled concrete elements should immediately follow-up the dismantling only in the very best case, an additional test is usually required. The additional test on the

[258] Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 155

concrete elements should be carried out directly before their (re)installation/reassembly in the interim storage area and/or on the reassembly construction site.

A summarising overview of the decision-making levels for assessment of the suitability for reuse of concrete components that have already been in use is provided in Tab. 7.1

Tab. 7.1: Decision-making levels for reusability of concrete elements[259]

INVESTIGATIONS	in installed condition; prior to disassembly:	1. Zero stage (as upstream stage): Preliminary investigation Determination of the possibility of disassembly of the building (accessibility, type of construction, etc.)
		2. Decision stage I: Suitability test Assessment of the structural condition of the concrete elements (visual and structural diagnostic analysis); preliminary assessment of reusability; appropriate labelling of the concrete elements is recommended
	in dismantled condition; after disassembly:	3. Decision stage II: Main inspection Recording of any damage and/or damage resulting from the disassembly process (cracks, broken edges, fasteners, lifting eyelets, etc.); preliminary assessment of reusability if transport of the components to the reassembly site is necessary, otherwise final assessment of reusability if the disassembly site is the same as the reassembly site (ideal case); final assessment immediately before reassembly in each case
		4. Decision stage III: Additional test Recording of any damage and/or deterioration as a result of further transport, transshipment and storage processes and/or longer interim storage of the concrete components prior to their secondary utilisation; final assessment of reusability

The prerequisite in order to access the next stage is always the fulfilment of the parameters of the previous stages.

Fig. 7.2 identifies the assessment and test criteria for structural diagnostic investigations that are generally applicable in order to define the performance characteristics of the concrete elements (see Chap. 6).

[259] Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 154 ff.

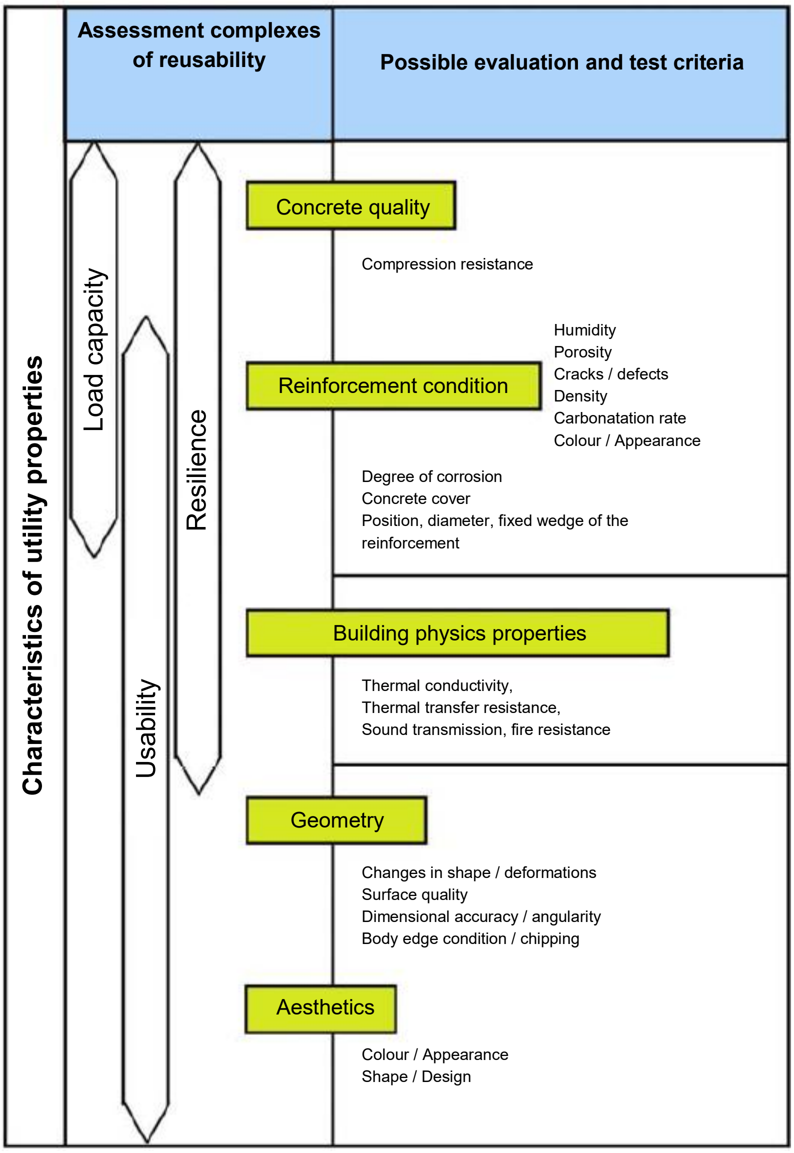

Fig. 7.2: Investigation programme for the structural condition of concrete elements[260]

The visual assessment for determination of the structural condition with the help of the structural condition level catalogue provided initial information. It can be used as reference for the selection of relevant test criteria depending on the requirements for secondary use. The investigation programme needs to be specified according to the secondary use, especially for reasons of cost-effectiveness. Building physics properties or aesthetics, for example, are irrelevant for the further use of concrete panels in dyke construction (cf. Chap. 7.5).

7.3 Consequences for reusability

The author's own investigations into construction materials and technology conducted 10 years ago on old precast concrete elements in the P2 range revealed that the load-bearing inner walls and ceiling panels of standard storeys are particularly suitable for reuse.[261] These findings are currently regarded as confirmed – also for other types of prefabricated buildings (see Tab. 7.2). with the exception of

[260] Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 117
[261] Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, Materialien zur Abfallwirtschaft, 1999, p. 29 ff.

partition walls and those outer wall panels where mineral wool (Kamilit) was used as insulating material, the entire range of the installed concrete elements can in principle be reused (see Tab. 7.3). Due to their geometry and shape, the subsequent use of e.g., staircase elements, bathroom cells and roof cassette panels will be limited to special areas of application.

Tab. 7.2: Suitability of the components for secondary use

Concrete elements – Assortment	Suitability for reuse	Reasons/remarks
Ceiling panels	suitable	- manufactured in reinforced or prestressed concrete - can also be used for ceiling panels with openings
Inner walls	suitable	- without load-bearing reinforcement - can also be used for the inner walls with openings
Roof cassettes	partially suitable	- Unfavourable structural design for use in HWS, for example - Possible exposure to contaminants (PAK)
Jamb walls	partially suitable	- Insufficient quantity in donor buildings
Outer walls	suitable to partially suitable and not suitable	- Unfavourable structural design (large openings) - Possible exposure to contaminants (mineral wool - Kamilit)
Partition walls	not suitable	- Usually damaged in the course of dismantling (component thickness too low) - Non-reinforced, low concrete strength class
Loggia	partially suitable	- Suitable as floor panel - Possible exposure to asbestos in parapet and side walls
Basement walls	partially suitable	- limited quantity

The conducted investigations prove beyond doubt that dismantled concrete elements from prefabricated buildings exhibit high utility value properties and can be reinstalled ready for use in shell constructions or otherwise reused if properly dismantled, transported and temporarily stored. The current legal framework is discussed in the following Chapter 7.4.

Analysis of the potential for subsequent use is provided in Chapter 7.5.2.

7.4 Legal aspects of reuse or subsequent use of utilised concrete elements

At present, there are no generally recognised regulations of technology for the use of utilised concrete elements/RC concrete elements. Therefore, they require either

- a general building authority approval or

- a general building authority test certificate or
- approval in individual cases.

Accordingly, it can be assumed at this point in time, that the authorisation effort for the reuse or continued use is high and is time-consuming as compared to approvals for conventional new buildings.

Legal reports[262] prove that concrete elements generated by dismantling are not waste, but products and therefore economic assets. Apart from the legal waste inspection, it was also examined whether the concrete panels meet the requirements of the building code regulations. For instance, Section 20 of the Brandenburg Construction Code (BgbBO) stipulates that certain objects may be used as construction products under certain conditions. Reference is made in particular to Directive 89/106/EEC (Construction Products Directive). This means that construction products can be divided into five groups:

a) *Regulated construction products (Building Rules List A Part 1)*

These are construction products for which there are generally recognised technical rules that have been published in the Building Rules List and that do not deviate significantly from these.

b) *Non-regulated building products (Building Rules List A Part 2)*

These construction products deviate significantly from the technical rules published in Building Rules List A, Part 1. In terms of regulated construction products, a distinction needs be made as to whether and to what extent a proof of usability is required.

c) *Non-regulated construction types (Building Rules List A Part 3)*

d) *Marketable and freely tradable construction products (Building Rules List B, Part 1 and 2)*

These are construction products that may be placed on the market and traded in accordance with the regulations of the EU member states and the contracting states to the Agreement on the European Economic Area. This is confirmed by the CE mark.

e) *Other construction products (Building Rules List C)*

Includes construction products for which there are neither technical regulations nor generally recognised technical rules and which are only of secondary importance for the fulfilment of building code requirements.

In terms of reuse, the decisive question is whether the utilised concrete components are construction products, as they are only generated when buildings are dismantled and are not primarily manufactured for their new use. This question can be answered in favour of reuse, as the crane-based dismantling process is designed in such a way that the concrete panels are preserved as reusable construction elements. Alternatively, it is possible to organise the dismantling process, including disposal, in such a way that the panels cannot be reused.

Furthermore, it must be clarified whether the declaration of conformity required from the manufacturer can be submitted. This in turn requires that a factory inspection is carried out.

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[262] Leitzke, Claus: Rechtliche Betrachtung von Rückbauprojekten, expert report on behalf of Fachgruppe Bauliches Recycling, BTU Cottbus, 2001; Ehlers, Benjamin: Rechtliche Aspekte der Wiederverwendung, in: conference proceedings „Alte Platte – Neues De-sign" Teil 2, ed. Angelika Mettke, 2007, p. 203 ff.

EHLERS[263] emphasises that although it is unusual to classify the dismantling site as a production facility, there are no arguments against it.

In this respect:[264]

1. The fact that dismantled precast concrete elements can also be approved as regulated construction products (in accordance with Section 20 (1) No. 1 BgbBO) is a priori not ruled out. This applies in particular to ceiling panels and former load-bearing inner walls, as they can generally be assigned to section 1.6.1 of the Building Rules List. However, the required certificate of conformity presupposes compliance with the relevant technical regulations, self-inspection and external monitoring.

    - Compliance with the relevant technical regulations has been tested for ceiling panels of several building types (cf. Chapter 6) on the basis of current DIN regulations. It still needs to be clarified as to what extent the results obtained are sufficiently representative and whether they are readily transferable to the entire range of ceilings.

    - In terms of external monitoring, the required expertise in this area needs to be demonstrated. There is still no clarification as to whether the certification and monitoring bodies in accordance with Section 28 BgbBO and any other comparable regulations of the federal states have these. In this respect, it can initially be assumed that monitoring centres require further training.

    - Self-inspection or the so-called in-house production control assumes special measures at the dismantling site (cf. decision-making stages for reuse, Chap. 7.2), which have not yet been regulated in a binding manner. In this respect, an amendment to Annex 0.3 of Building Rules List A is recommended in order to standardise production control for dismantled components on the construction site.

2. No conclusive statements can yet be made with regard to other prefabricated concrete parts that are mainly generated during dismantling (mainly outer walls, roof cassette panels). Further research is required here.

3. Otherwise, in individual cases, proof of usability (according to § 23 BgbBO) may be considered for other prefabricated concrete elements.

4. In some cases, there is no obligation to provide evidence if the utilised concrete elements can be classified with a corresponding purpose within the meaning of Section 4.1 of the Building Rules List C.

It can therefore be concluded that utilised concrete elements are basically construction products.

It is therefore a technical issue to check whether the utilised concrete elements comply with the technical regulations of the Building Rules List. It is therefore important to summarise all the investigations

carried out in this regard in order to determine whether it is possible to draw conclusions about similarly produced old or RC prefabricated concrete elements and their load-bearing behaviour / safety /

[263] Ehlers, Benjamin: Rechtliche Aspekte der Wiederverwendung, in: Tagungsband „Alte Platte – Neues Design – Teil 2“, ed. Angelika Mettke, 2007, p. 205

[264] according to Leitzke, Claus: Rechtliche Betrachtung von Rückbauprojekten, expert report on behalf of FG Bauliches Recycling, BTU Cottbus, 2001

durability. However, in the case of compliance with the provisions specified in the Building Rules List A, proof of compliance would then have to be provided again.

The fundamental question therefore arises as to how it is possible to provide proof of conformity for utilised concrete elements on the basis of technical building regulations established by the building authorities.

In 2001, the Saxon State Ministry of the Interior presented a corresponding draft guideline "Component cycle of prefabricated components made of concrete, reinforced concrete and prestressed concrete", which was repeatedly discussed by the expert commission of the German Institute for Construction Technology with the conclusion that the reuse of concrete components should generally be resolved by approval granted in the individual cases.

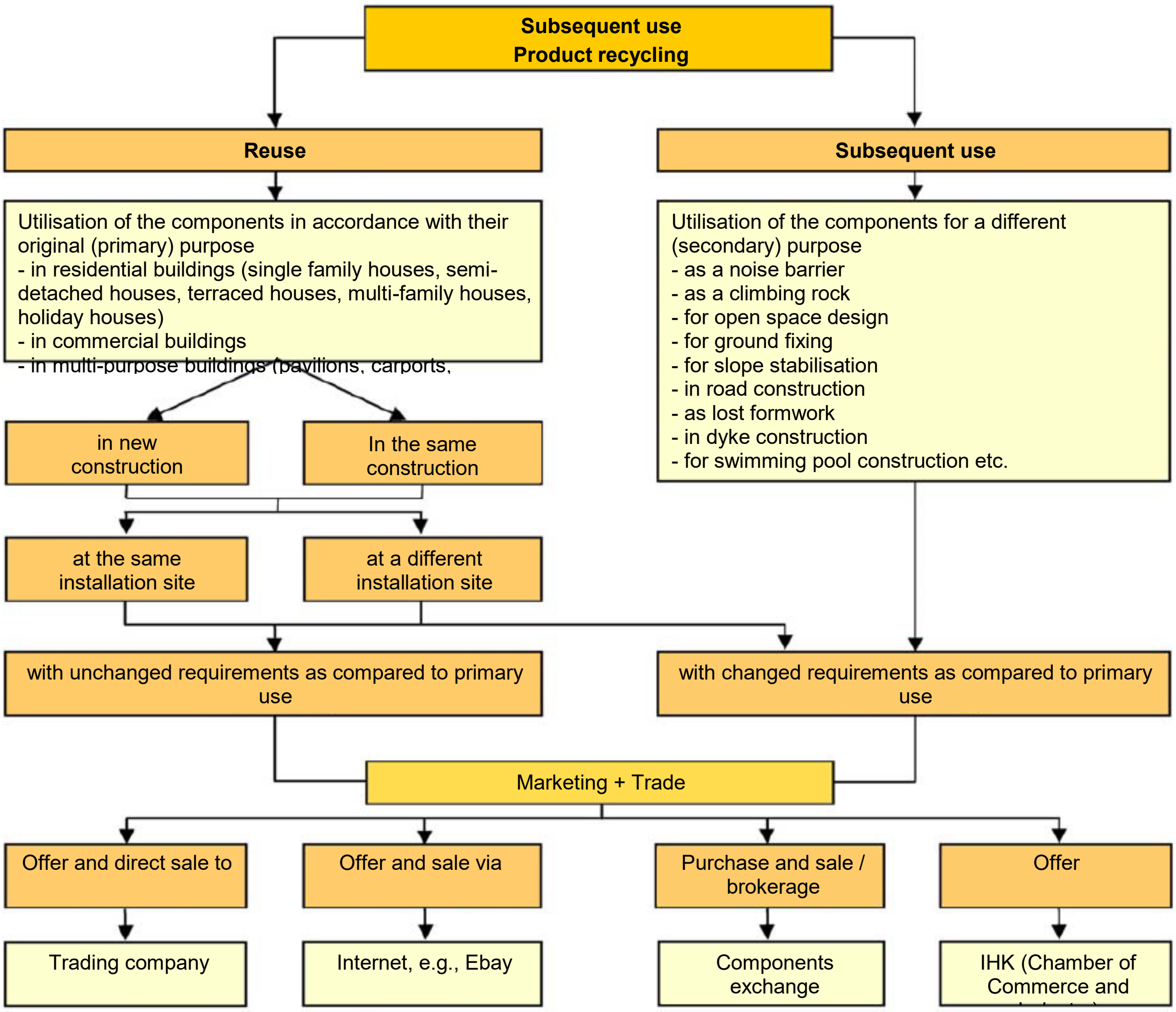
Ultimately, the Free State of Saxony did not introduce this directive since it was insufficient for the assessment of usability, even with regard to the required proof of conformity.

Similarly, own activities to develop a test standard in this regard could not be successfully completed as part of the BMBF-funded research project "Demolition of industrial buildings - large-format concrete elements in the ecological cycle". Further research in this area is absolutely essential, as the high level of effort required for obtaining authorisation in individual cases is forcing the majority of developers to abandon their planned reuse projects.

7.5 Areas of application for reutilisation of used concrete elements – case studies, evaluation

Dismantled concrete elements can be applied in a variety of areas, such as

- in the house construction (detached, semi-detached, terraced, chain, multi-family and holiday houses),
- in multi-purpose buildings (pavilions, garages, bunkers),
- for landscape and park design as well as in residential surroundings (stairs, boundary elements, design elements),
- for environmental protection measures (noise barriers, dyke construction),
- in agricultural construction (silos, ground stabilisation) etc. (see Fig. 7.3).



EFH	Single-family house	RH	Terraced house
DH	Semi-detached house	MFH	Multi-family dwelling or apartment house

Fig. 7.3: Partially tested and conceivable areas of application for the subsequent use of utilised concrete elements with marketing possibilities

Pilot, sample and demonstration projects have proven that used concrete components can be reused and further utilised. These include the construction of

- Residential buildings in various forms of housing such as
  - the semi-detached (two-family) house in Eggesin (Mecklenburg-Vorpommern),
  - the semi-detached (two-family) house in Bröthen (Saxony),
  - the city villas in Cottbus (Brandenburg),
  - the single-family house in Leinefelde (Thuringia),
  - the single-family house in Plauen (Thuringia),

    - the single-family house in Werneuchen (Brandenburg),
    - the single-family house estate in Brielow (Brandenburg),

- Multi-purpose buildings
    - the mourning hall in Mellingen (Thuringia),
    - the garage in Mellingen (Thuringia),
    - the carports in Waltershausen (Thuringia),
    - the garage in Weißwasser (Saxony),
    - the community house in Plauen (Thuringia),
    - the community house in Gröditz (Saxony),
    - the community house in Kolkwitz (Brandenburg),
- as well as the use of decorative elements in open spaces
    - the outdoor area of the youth centre in Leinefelde (Thuringia),
    - construction of climbing rocks and boulder walls (nationwide),
    - in Gröditz leisure park (Saxony),
    - in the kindergarten in Leinefelde (Thuringia).

The implemented pilot projects speak for themselves and prove, among other things, that they are ecologically and economically viable in comparison to conventional new buildings. The costs (KG 300 - structure, structural design) were reduced by more than 10% to approx. 30%.

Selected examples of (re) new constructions are summarised in the form of profiles in Tab. 7.3. Moreover, several projects initiated by the author are currently in the planning phase, such as the "Santa Fe" project (camping site) on Lake Gräbendorf as well as the cross-border projects. There are plans to erect multi-storey apartment blocks in the suburbs of St. Petersburg and Kaliningrad as part of the 'affordable construction' programme.

Nevertheless, the list of successful implementations should not disguise the fact that a number of reutilisation projects that have been initiated have not managed to progress beyond the planning phase. Since the housing associations and cooperatives are generally in a precarious economic situation, partial deconstruction measures and subsequent use concepts have been discarded and demolitions, which are comparatively more cost-efficient, were performed instead.

Tab. 7.3: Examples of reuse/subsequent use measures

	Measure	Project / Location	Year of construction / Planner	Donor building	Transport distance [km]	Reuse/ subsequent use	Characteristics	Costs
House construction		Semi-detached house Eggesin	1999 / Domizil Bauregie GmbH Greifswald	WBS 70, IW 64 , Eggesin	approx. 2 km	16 wall elements	DH per residential unit: 172.90 m^2/living space	Reassembly of the shell construction: 284 €/m^2 living space
		Two-family house Bröthen	2001 / Bauingenieurbüro Haidan, Wittichenau	P2, Hoyerswerda	approx. 6 km	26 wall elements, 50 ceiling panels	Living space 274.2 m^2 (137.1 m^2 per residential unit)	€ 1,279/m^2 living space (turnkey)
		City villas Cottbus	2000/2001 / Architekturbüro Zimmermann und Partner, Cottbus	P2, Cottbus	Disassembly site = Reassembly site	274 Precast concrete parts	1.050 m^2 (13 residential units)	Reassembly of the shell construction: € 84/m^2 living space; € 1,149/m^2 living space (turnkey)
		Detached house Mehrow	2005 / CONCLUS Architekten, Berlin	WBS 70, Berlin-Marzahn	approx. 17 km	22 wall elements, 27 ceiling panels	Living space: 212 m^2 (2 storeys)	€ 840/m^2 living space (calculated, turnkey)
		Detached house Werneuchen	since 2005 / MWM objects freie Architekten , Dipl.-Ing. (FH) David Seidl, Erfurt	WBS 70, Berlin-Marzahn	ca. 15 km	2 outer walls, 7 inner walls, 6 ceiling panels, 3 roof cassette panels	Living space: 145 m^2 (2 storeys)	Reassembly of the shell construction: approx. € 33.000 (calculated)
		Single-family house Plauen	2006 / Prof. Dr.-Ing. habil. W.R. Eisentraut, Berlin	IW 73, Plauen	approx. 2 km	17 wall elements, 15 ceiling panels, 1 staircase element	Living space: 122 m^2; GNF: 160 m^2	~€ 1,043/m^2 living space (turnkey)
		Single-family house Leinefelde	2006 / AG wbk 21, MWM objects freie Architekten, Dipl.-Ing.(FH) David Seidl, Erfurt	WBR Erfurt 82, Leinefelde	approx. 0.5 km	19 wall elements, 26 ceiling panels	Living space: 106 m^2	Shell construction: € 50,000; € 472/m^2 living space
		Multi-family dwelling Mühlhausen	2007 / AG wbk 21, MWM objects freie Architekten, Dipl.-Ing. (FH) David Seidl, Erfurt	WBS 70, Leinefelde	approx. 28 km	28 wall elements, 23 ceiling panels, 7 staircase elements	Living space: 248 m^2 (2 storeys)	Reassembly of the shell construction: € 452/m^2 living space
		Single-family housing estate Brielow	2007 / Projektentwicklung Mischker und Projektteam GmbH, Brandenburg	WBS 70, Berlin-Marzahn	approx. 100 km	Inner walls (cut), Ceiling elements	Living space: 98 m^2 (1-storey); living space: 177 m^2 (two-storey)	from € 59.000, starter house ~€ 620/m^2 living space (€ 855/m^2 living space turnkey)

	Measure	Project / Location	Year of construction / Planner	Donor building	Transport distance [km]	Reuse/ subsequent use	Characteristics	Costs
Multi-purpose buildings		Mourning Hall Mellingen	2004/2005 /iff Weimar	WBR 80-E, Leinefelde	approx. 125 km	8 gable walls	Total area: 68.45 m²	30 % cost savings in the shell construction
		Garage Mellingen	2004/2005 / iff Weimar	WBR 80-E, Leinefelde	approx. 125 km	6 outer walls, 1 of which is cut, 4 ceiling panels	experimental construction (weather, humidity, temperature, ventilation)	
		Carports Walters-hausen	2006/2007/Planungsgruppe Mitte GmbH (PGM), Dipl.-Ing. Arch. Norbert Sprinz, Gotha	WBR 80-E, 6.3 t series, Waltershausen	Disassembly site = Reassembly site	21 inner walls, 16 ceiling panels	16 parking spaces	per parking space: € 2.400
		Garage Weißwasser	2007/Dr. Rudolf Schmiedehausen, Cottbus Fa. Wolff Weißwasser	P2, 11-storey, Weißwasser	approx. 3 km	5 outer walls, 8 ceiling panels, 4 of which as floor panels	Gross floor area: approx. 43 m² Reassembly time: 3 h Roof designed as a gable roof, 3 parking spaces	Foundation and crane costs: € 800
		Community house VFC Plauen e.V.	2006/2007/Bauplanung Plauen GmbH	IW 73/6, Plauen	approx. 7 km	49 outer walls, 14 inner walls, 11 basement walls, 145 ceiling panels	GFA: 400 m²	approx. € 600,000
		Community house Sportverein 1911 Gröditz e.V.	2007/2008/Architekturbüro Markus Uhl, Berlin	WBS 70 type Dresden, Gröditz and school type 2MP, type Dresden Gröditz	approx. 2.5 km	13 outer walls, 25 inner walls, 35 ceiling panels; 46 ceiling panels	GFA: 1,090 m²	Shell construction: € 298,224 turnkey: € 850/m²
		Community house Kolkwitzer Sportverein 1896 e.V.	2008/2009 / (under construction) Ingenieurbüro P. Jähne, Cottbus	P2, 8 and 11 storeys, Cottbus	approx. 10 km	20 outer walls, 20 inner walls, 40 ceiling panels	GFA: 463 m² (NF: 410 m²)	€ 350,000
Environmental constructions	 	Experimental dyke body open-cast mine Welzow Süd	2006–2008/BTU Cottbus, FG Bauliches Recycling	WBS 70, Dresden	approx. 90 km	21 ceiling panels (cut)	Base area of the dyke: 40 x 40 m; used for: Surface and inner sealing, overflow sections	s. Chap. 7.6.4

Open space and landscape planning

Measure	Project / Location	Year of construction / Planner	Donor building	Transport distance [km]	Reuse/ subsequent use	Characteristics	Costs
	Open dancing space Sportverein Wacker 09 e.V., Cottbus-Ströbitz	2003/BTU Cottbus, FG Bauliches Recycling; Ingenieurbüro Jähne & Göpfert GmbH, Cottbus	P2, Cottbus	approx. 8 km	10 ceiling panels	GF: 100 m² (10 x 10 m)	
 	Leisure and Youth Park Gröditz	2005-2008/Schwarz & Partner, Landschaftsarchitekten, Berlin	School type 2MP, type Dresden, Gröditz	Disassembly site = Reassembly site	11 outer wall blocks, 11 plinth panels, 44 inner wall blocks, 9 interior wall frames, 42 ceiling panels	Total area approx. 16.000 m²	
 	Open space design for the "Sonnen-schein" kindergarten in Leinefelde	2006/2007/Dipl.-Ing. Ottmar Stadermann, Hausen, in collaboration with the Kunstverein	WBR Erfurt, Leinefelde	Disassembly site = Reassembly site	Various inner walls		
	Leinefelde Youth and Leisure Park	2002 Büro für Landschaftsplanung birkigtquentin, Adelebsen	Leinefelde	Disassembly site = Reassembly site	Ceiling panels, partially cut	as boundary elements, stair elements, etc.	
	Climbing rocks and bouldering walls Freie Waldorfschule Cottbus	2003 Brand-Rock Felsenbau	P2, Cottbus	Disassembly site = Reassembly site	Balcony ceiling panels		
	Climbing rocks for sport climbers Leipzig Grünau	2002 Architekturbüro Skirl+Heinrich Stollberg	Leipzig-Grünau	Disassembly site = Reassembly site	Loggia parapet panels, ceiling panels		260.0 €

7.6 Deployment of used concrete elements in dyke construction – a contribution to flood protection

7.6.1 Introduction

A reasonable secondary area of application for RC concrete elements is seen in dyke construction.

The approach present in this research[265] addresses the large number of vacant prefabricated buildings in the eastern Germany as well as concrete elements generated by partial deconstruction measures and interlinks this situation with the urgent need for action in terms of disaster protection to both upgrade the existing dykes and construct new ones.

The flood events of the past have repeatedly led to devastating damage running into billions due to flooding and have claimed numerous lives.

It is worth remembering:

- the Oder flood in July 1997 caused total damage of ~DM 10 billion, 54 deaths in Poland, 60 deaths in the Czech Republic, evacuation of approx. 195,500 people and
- the flood disaster in the summer of 2002 on the Elbe, Mulde and Danube rivers, with over € 9 billion in direct property damage and 21 deaths in Germany alone.[266]

Therefore, it is particularly important for dyke construction to be characterizzed by a sufficient impermeability and stability. The following benefits are associated with the use of concrete elements from prefabricated buildings as an alternative to traditional materials and products, e.g., in comparison to sheet piling:

- connecting two tasks mentioned above: flood prevention on the one hand and reasonable utilisation of disassembled prefabricated concrete elements on the other,
- improved protection against moisture ingress and the resulting improved stability of the dykes,
- improved utilisation of the lifespan of the concrete components,
- substitution of new products,
- economic advantage as compared to traditional dyke constructions.

At the same time, the image problem of the panel is being addressed. Although the installation in the ground is not visible, it fulfils an important function - insofar as mathematical and experimental proof is provided.

Furthermore, the state subsidies from the "Urban Redevelopment East" programme or other programmes claimed for dismantling are more efficient.

Three basic variants for the utilisation of used concrete elements in dyke construction have been developed and tested:

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[265] Research project: Deichbau – Nutzung ausgebauter großformatiger Betonelemente aus dem Wohnungsbau für den Hochwasserschutz, short title: Pro Altbeton im Hochwasserschutz, Project management: Mettke, Angelika, BTU Cottbus, LS Altlasten, FG Bauliches Recycling

[266] www.umweltdaten.de/publikationen/fpdf-l/3019.pdf, p. 37; accessed on 24.06.2008

- the waterside support of the concrete elements according to slope inclination (surface sealing)
- the vertical installation of the elements as a core or inner sealing and
- overflow/flooding sections.

Potential structural applications of concrete elements in dyke construction have been tested in various laboratory tests supported by large-scale tests/in the field tests on a 1:1 scale prototype. That is the only reliable way to determine material behaviour under real conditions.

7.6.2 Available and suitable range of RC concrete elements

- **General suitability**

In general, ceiling panels (DP) and former load-bearing inner walls (IW) from the range of concrete elements installed in prefabricated buildings are suitable for reuse and further utilisation measures (cf. Chap. 6, 7.3). Due to the scope of application of the P2 and WBS 70 building series (644,900 flats were built in WBS 70 and 363,600 flats in P2 (as of 1996); cf. Tab. 2.1), it is assumed that most RC concrete elements will originate from these series.

The share of ceiling panels and inner walls in the total number of concrete elements installed in the building is, for example, approx. 37 % for P2/5 and approx. 30 % for WBS 70/11. In the case of WBS 70, 3.00 m wide ceiling panels were predominantly used. Therefore, the percentage of WBS 70 in relation to the number of concrete elements is reduced as compared to the P2 type.

- **Geometry**

From a geometric point of view, the advantage of the concrete panels, which are preferably intended for further use, is that the thickness of all ceiling panels is 14 cm and that of all inner walls is 15 cm. The concrete elements vary in dimensions. An overview of the main product range for both sample buildings with three entrances is provided in Table 7.4 below.

For example, the P2 type features 49 differently designed inner walls and 14 differently manufactured ceiling panels[267].

[267] Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, 1999, p. 25

Tab. 7.4: Geometric parameters of selected ceilings and inner walls from WBS 70/11 and P2/5 and their share in the total number of concrete elements installed in the respective building type (reuse and/or reutilisation potential)[268]

Type of building	Total number of installed ceiling panels	DP Width × length × thickness [mm]	Share of ceiling panels in the total number of ceiling panels [pcs.]	Share of ceiling panels in the total number of ceiling panels [%]
WBS 70/11	471	5,980 × 2,980 × 140	396	84.1
P2/5	348	5,970 × 1,785 × 140	72	20.7
		3,570 × 1,785 × 140	172	49.4
Type of building	**Total number of installed inner walls**	**IW Width × length × thickness [mm]**	**Share of inner walls in the total number of inner walls [pcs.]**	**Share of inner walls in the total number of inner walls [%]**
WBS 70/11	344	5,810 × 2,630 × 150	165 (of which 69 without door)	48
		4,610 × 2,630 × 150	69 (of which 33 without door)	20.1
P2/5	183	3,580 × 2,635 × 150	89 (of which 41 without door)	48.1

The percentage of installed concrete elements allows for conclusions to be drawn with regard to the available potential, but may only serve as a guide. Object-specific recording is unavoidable.

- **Technical features of concrete**

The parameters that are relevant for the use of RC concrete elements in dyke construction, depending on the place of use and the resulting environmental conditions (exposure classes) are:

- Concrete compressive strength,
- Concrete cover and carbonation,
- Permeability, total porosity, water penetration depth,
- Frost resistance with and without deicing agents,
- Acid resistance.

[268] summarised from: Internes Arbeitspapier „Pro Altbeton zum Hochwasserschutz, Mettke, Angelika; Czyganowsky, Jan, as of 11.11.2005, BTU Cottbus, LS Altlasten, FG Bauliches Recycling

The test results are documented in Chapter 6. The conclusion to be drawn from these results is that the analysed range of ceiling panels (DP) and inner walls (IW) from the WBS 70 and P2 building types, which are particularly suitable for further use, can be installed in the dyke body for surface and interior sealing. Tab. 6.7 differentiates the utilisation of the range according to the exposure class. The high impermeability of RC concrete elements with permeability values of kf ~ 10^{-10} m/s and the low water penetration depth of < 3 cm provided evidence of sufficient resistance to chemical attack. Since the concrete elements installed in the dyke or on the dyke (overflow/flooding sections) or at the dyke (dyke paths) may be exposed to water containing substances that are harmful to concrete, further testing of **acid resistance** was carried out. Tests were carried out to determine the impact of various acidic solutions and well water from the field trial on the concrete structure. The results are intended to provide information on the practical use of concrete elements in and by water of varying aggressiveness. In order to compare the results, test specimens have been stored in drinking water.

The pH value[269] of rainwater today is often between 4 and 5. In comparison: the pH value of drinking water should be between 6.5 and 7.5.[270]

Acidic water with pH values between 4 and 6 was produced in consultation with the Chemical-Physical Analysis Department of the Research and Materials Testing Institute at the Brandenburg Technical University in Cottbus.

Drill cores with a diameter of 100 mm were obtained for the investigation programme from the disassembled ceiling panels of the P2 type buidings. The drill cores were halved (cut) transversely. A total of 44 test specimens was produced.

The following were used as "test fluids":

- Drinking water/tap water with a pH value of 7.6 (zero measurement; reference measurement)
- Well water pH value approx. 5.5 to approx. 6.5 (water discharged into the test dyke)
- Sulphuric acid solution (H2SO4) pH value 6.0
- Sulphuric acid solution (H2SO4) pH value 5.0
- Sulphuric acid solution (H2SO4) pH value 4.0
- Nitric acid solution (HNO3) pH value 4.0

The selected storage conditions of the test specimens in water or in diluted acids cover the ranges for non-concrete-aggressive water, acidic water ranging from weakly to very strongly corrosive, and well water with strong corrosive behaviour due to various ingredients as defined in DIN 4030-11[271] .

The specimens were tested after short-term (1 month) and long-term (1 year) exposure on 3 specimens each with regard to

- their volume,
- the dry matter,
- the surface structure

(visual). The test specimens were predominantly stored indoors (laboratory) but also outdoors.

[269] The pH value indicates if the water is acidic, neutral or alkaline.
[270] www.wasserundmehr.de/pH-wert.htm; accessed on 01.03.2009
[271] DIN 4030-1: 2008-06 Beurteilung betonangreifender Wässer, Böden und Gase – Teil 1: Grundlagen und Grenzwerte

The test results are presented in Fig. 7.4 below for the short-term tests and in Fig. 7.5 for the long-term tests.

- **Short-term test result for dry matter**

Whereas the test specimens stored in well water and drinking water exhibit an increase in mass, all test specimens stored in sulphuric acid and nitric acid solutions demonstrate a continuously increasing loss of mass depending on the storage period.

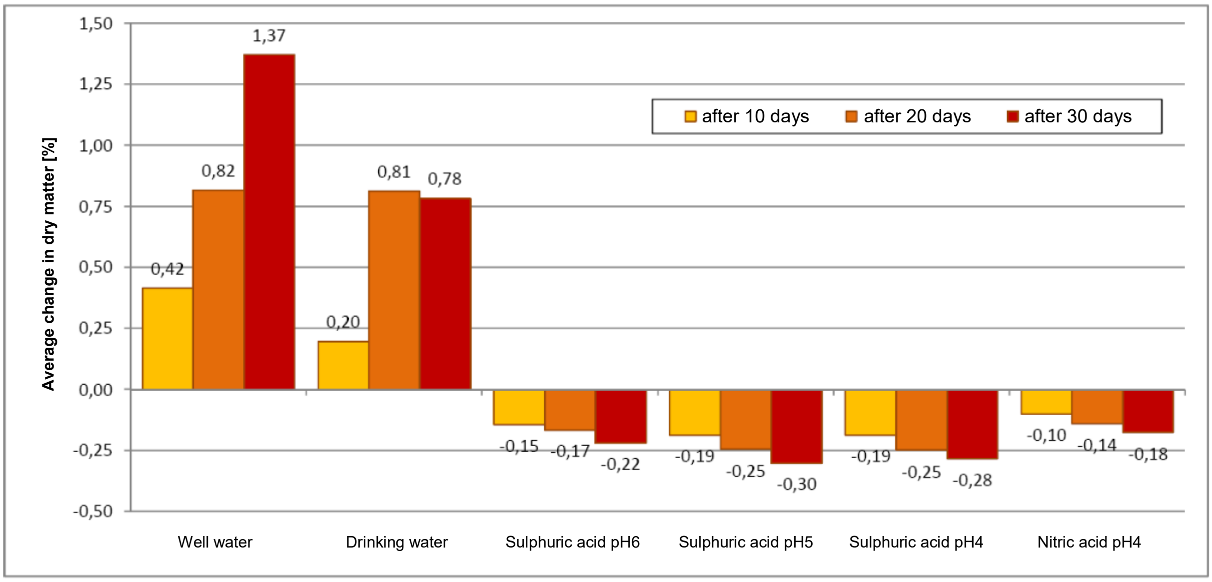

Fig. 7.4: Determined average change in dry mass of the test specimens for acid resistance (short-term test)[272]

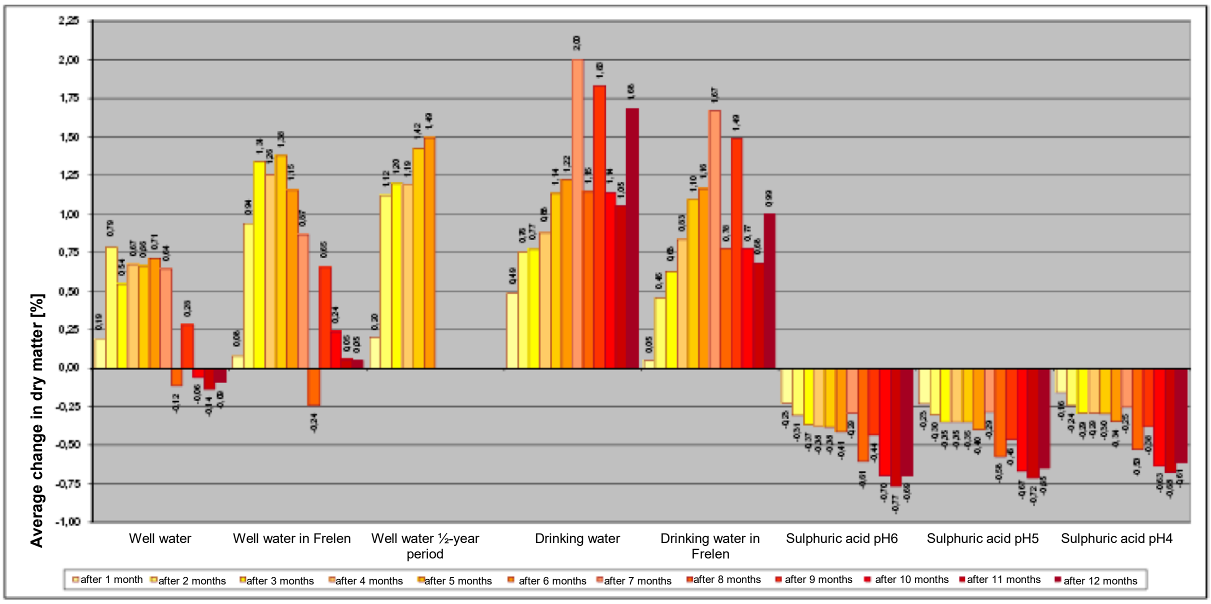

Fig. 7.5: Determined average change in dry mass of the test specimens for acid resistance (long-term test)[273]

[272] Mettke, Angelika; Heyn, Sören: Deichbau – Nutzung ausgebauter großformatiger Betonelemente aus dem Wohnungsbau für den Hochwasserschutz, final report, currently in progress, completion April 2009
[273]ibidem

- **Long-term test result for dry matter**

An increase in dry mass was observed during the storage of the test specimens in well water for up to 6 months. Subsequently, over the next 6 months, mass losses occurred. The test specimens stored outdoors in well water exhibit a significant increase in dry mass up to a period of 6 months. Afterwards, a decline can be recognised.

Storage of the test specimens in drinking water indoors and outdoors results in an increase in dry mass after 12 months, although not always continuously.

All test specimens stored in sulphuric acid solution exhibit an almost continuous loss of dry matter from the first month up to 1 year.

- **Volume changes**

The test specimens stored in well water and drinking water demonstrate minor increases in volume:

- when stored in well water outdoors/winter half-year 0.04 % per month,
- when stored in drinking water in a room after 12 months 0.23 % per month,
- when stored in drinking water outdoors after 12 months 0.13 % per month

The volume changes of the test specimens stored in acid solutions display a relatively wide range of fluctuation: from a decrease in volume to an increase in volume.

- **Visual examination of the surface structure**

No surface changes to the cement paste matrix were detected on any of the test specimens stored in drinking water and in the aggressive media. Even the contact zones between the aggregate and the cement paste remained undamaged. Neither erosion nor loosening of the structure was visible.

Additionally, the total porosity of the concrete was determined to be 12.05 %vol.

The chemical analysis of the well water revealed a decrease in aggressiveness within one year. From formerly strongly attacking (1.080 mg/l SO4), the aggressiveness is now only slightly attacking (764 mg/l SO4). The sulphate content is assigned to the lowest range of the 'severe attack' degree.

Summing it up, it was observed that the loss of dry mass of the concrete at 0.5 to max. 0.9%, predominantly around 0.6%, does not cause any change in the adhesion between the aggregate and the cement paste.

The impact of sulphates on concrete was tested by immersing the test specimens in well water. The well water also contained lime-dissolving carbonic acid with a low pH value. No damage to concrete surfaces was visually detected here either (neither cracks nor chipping). The high resistance of concrete to sulphate attack is due to the strength and impermeability of concrete. As a consequence of the changes in dry mass and volume, it is possible that the concrete substance may be reduced or enriched by ion exchange (e.g. by converting poorly soluble compounds into easily soluble ones) or reduced by leaching processes subsequent to corrosion processes.[274]

Overall, it is concluded that further or secondary use of RC concrete elements in dyke construction can be derived from key parameters such as concrete compressive strength and impermeability.

The test results on frost resistance with and without the impact of deicing agents (see section 6.2.1.2) suggest that RC concrete elements can be used on the dyke surface (overflow and flooding sections) or as top layer in road construction only in reconditioned state. It is recommended to coat the surface of RC concrete elements in accordance with the DAfStb-Guideline for the protection and maintenance of concrete components, October 2001 edition, in order to improve weather resistance and diffusion resistance to carbon dioxide in particular.

The deployment of untreated RC concrete elements from residential construction inside the dyke is possible without restriction due to their high suitability for use. The high impermeability of concrete elements, which is comparable to the impermeability of clay, led to the realisation that the joints between the installed concrete elements will be the weak point of the sealing in dyke construction. The structural design of the dyke variants is discussed below.

7.6.3 Innovation project experimental dyke

- **General description**

The experimental dyke, an area dyked on four sides, was constructed on impermeable ground with dimensions of 39 m × 39 m (see Fig. 7.6). The underflow of the dyke body is prevented by sealing of the subsoil. For this purpose, a 50 cm thick layer of clay was laid over an area of 40 m × 40 m.

The experimental dyke body is surrounded by a homogeneous earth body, where the waterside of the dyke is recreated on the inner slopes. The dyke body was constructed on the landsides and watersides with slope inclinations of 1:2 and is therefore steeper than recommended in DIN 19712: 1997-11 River dykes, 7.2.2 Dyke embankments. The steeper slope was chosen since space is often limited in practical conditions and less dirt would need to be removed. In case of experimental dyke this resulted in saving of 3,060 m³ of dirt to be transported what translates to ~250 lorry runs. Another purpose is to simulate the extreme incident (high damage potential).

The height of the dyke is 3 metres from the top of the base and the dyke crest is 3 metres wide. The selected slope inclination of 1:2 results in a total width of the dyke cross-section of 15 m (instead of 21 m at 1:3). The estimated flood level was set at 2.30 metres. The recommended minimum freeboard of 0.5 m is thus taken into account (see Fig. 7.10).

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[274] Panzer, Julianna; Wollgam, Helrun: Untersuchungsbericht zum Säurewiderstand der eingesetzten Bauteile im Deichbau, FMPA BTU Cottbus, on behalf of FG Bauliches Recycling, April 2008

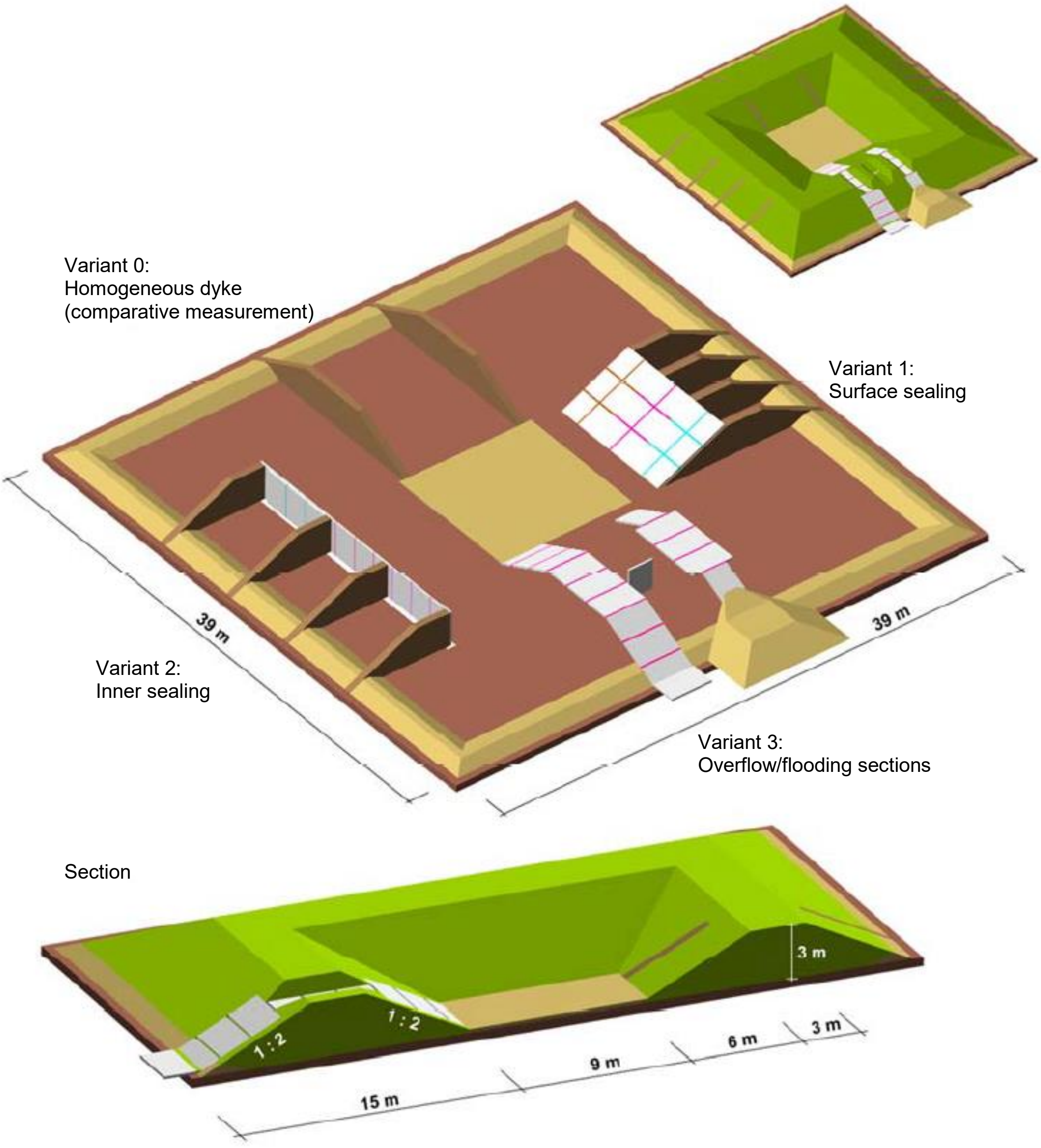

Fig. 7.6: Experimental setup model: Area closed by dyke for water retention

The flooding areas were developed with a dyke height of 2.30 m, a crest width of 5.80 m and a slope inclination of 1:2. One of the areas is designed as a combination of surface sealing and overflow section. In the second area, the inner sealing is to be examined for its behaviour in the event of flooding. The dyke body is made of homogeneous soil material. Approx. 2,600 m³ of soil (silty sand $k_{f, ist} = 7.7 -^{10-8}$ m/s) was used, which was extracted on site.

The permeability coefficient of prefabricated concrete elements $k_f \sim 10^{-10}$ m/s is thus, as required[275], at least two decimal powers smaller than that of the supporting body. However, it was planned to use mixed-grain soil material from the group of narrow-grained sands or sand silt with a silt content of max. 10%, $k_f \sim 10^{-6}$ to 10^{-5} m/s. However, this soil material was no longer available on site.

[275] Heyer, Dirk; Schmutterer, Christian: Einführung in das DWA-Thema „Dichtungssysteme in Deichen“, in: conference proceedings DWA-Seminar „Flussdeiche“, Fulda, May 2007, p. 3

After analysis of the soil sample, the sulphate content is 1,862 mg/kg. This is below the limit value of 2,000 mg/kg and the soil is classified as non-aggressive according to DIN 4030-1, Table 5.[276]

20 year old ceiling panels of the WBS 70 type were installed. The donor building was located in Dresden. The experimental dyke was constructed and tested at the Welzow South opencast mine in consultation with Vattenfall Europe Mining & Generation.

The delivered ceiling panels of the size 5.98 m × 1.785 m × 0.14 m were halved lengthwise in order to increase the number of joints in the surface sealing variant and thus test the weak point, the tightness of the joints. Due to the height of the dyke, it was necessary to halve the panels for vertical shoring anyway.

Different test areas in the experimental dyke body were subdivided by the installation of vertical clay layers. They separate the areas where different joint sealing materials were used.

A circumferential filter prism with drainage has been installed on the landside foot of the dyke. In order to divert drainage water, a gutter was established along the dyke river with a slight gradient to the collector to collect seepage water. The gutter was covered to protect it from rainwater.

- **Proof of stability**

The stability was verified by deliberately setting the slope inclination at 1:2, which deviates from DIN 19712.

According to DIN V 4084-100[277], the stability of the dykes has to be guaranteed for all possible load scenarios. This is demonstrated by the fact that a collapse can be ruled out for every possible sliding surface through the dyke body or the dyke body and the subsoil. This means that both the condition of the dyke body and that of the subsoil are essential for stability.

The proofs were carried out for two load scenarios (LF) in advance of the experimental setup:[278]

- LF 2 with the loads of the dead load, live load on the crest and berm and the BHW[279] water level; required safety factor $\eta = 1.3$,
- LF 3 with the loads of the dead load, live load on the crest and berm, water level up to the dyke crest (full damming) or sinking high water BHW/3, failure of the drainage; required safety factor $\eta = 1.2$.

Border conditions were defined for the modelling of the experimental dyke. In comparison to the calculation approach for the constructed experimental dyke, there is a change due to the higher permeability coefficient of $k_f = 7.7 - 10^{-8}$ m/s instead of $k_f \approx 2.0 - 10^{-6}$ m/s. The applied permeability coefficient was based on analyses of soil samples from another experimental site, which was no longer available for the construction of the experimental dyke due to over-excavation.

[276] Panzer, Julianne; Wollgam, Helrun: Brunnenwasser- und Bodenuntersuchungen, in: Untersuchungsbericht zum Säurewiderstand der eingesetzten Bauteile im Deichbau, FMPA BTU Cottbus, on behalf of FG Bauliches Recycling, April 2008
[277] DIN V 4084-100 Beiblatt 1: 1994-04 Baugrund-, Böschungs- und Gebäudebruchberechnungen – Teil 100 Calculation according to the concept with partial safety coefficients, calculation examples
[278] Czyganowsky, Jan; Reinfeld, Corinna: Nachweisführung zur Standsicherheit unter Einsatz von gebrauchten Betonelementen, BTU Cottbus, FG Bauliches Recycling, 2006
[279] Design flood

Proof was provided in accordance with DIN V 4084-100 by using two hydraulic engineering programmes, GGh-SS Flow and GGW stability, with the result that stability was achieved in all variants of the experimental dyke (see Fig. 7.7 Seepage line curve).

The obtained calculation results have also been evaluated in terms of hydraulic engineering by a local engineering office and checked for plausibility. The verification confirmed that the seepage line curve calculated in the dyke body with and without sealing elements is plausible and comprehensible. The arrangement of a filter prism at the airside foot of the embankment prevents the seepage line from extending above the foot of the dyke and thereby reducing stability.

The arrangement of a berm has a favourable effect on the stability of the dyke.

It has been pointed out that local problems may arise on existing embankments from a slope inclination of 1:2.5 on the waterside in the lower third of the embankment. It is possible to counteract this by installing a suitable geogrid with stabilising effect. The experimental dyke was completed without the use of a geogrid for the cost-effectiveness reasons.

After verification of the calculation results, the experimental setup was approved by the author (project manager) with regard to its structural safety relevance. The results of the stability tests are documented in detail in the research report "Pro Altbeton im HWS"[280] .

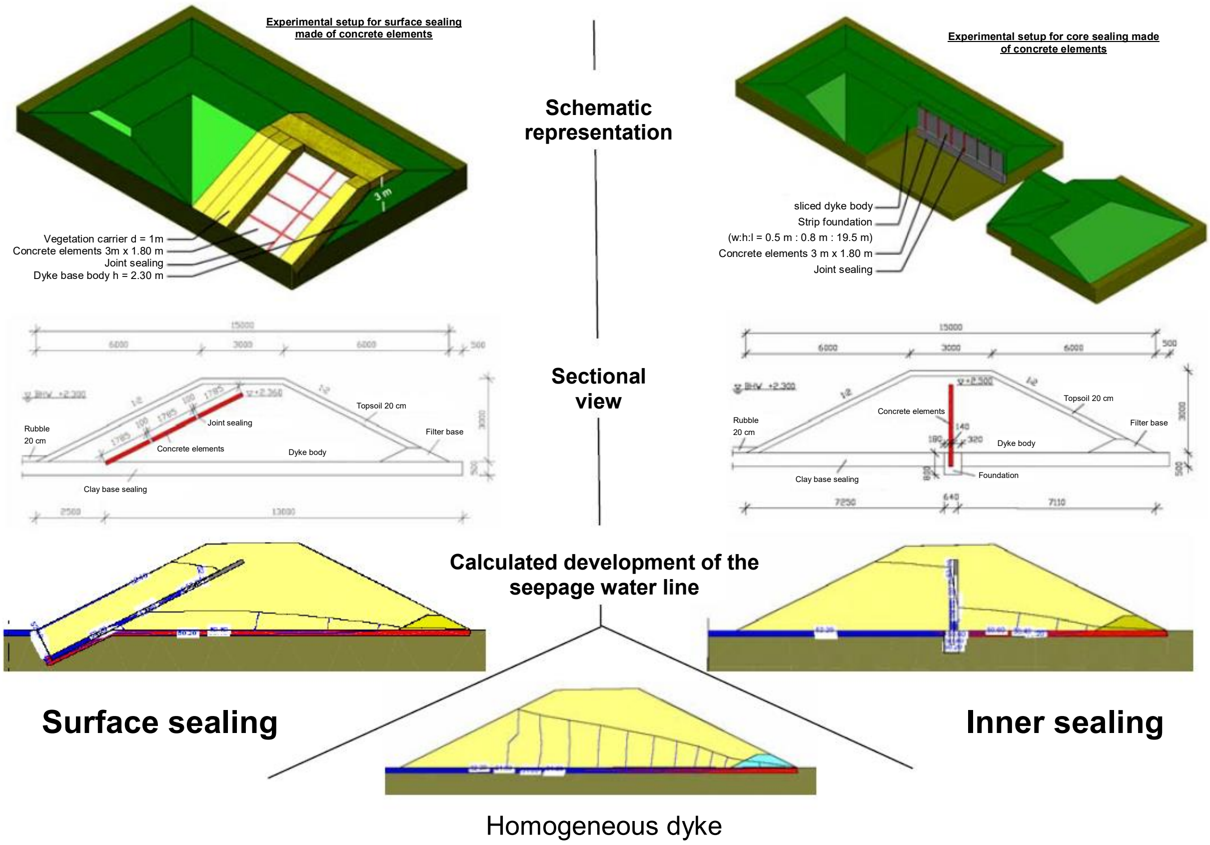

Fig. 7.7: Overview of the developed main application variants

280 Mettke, Angelika; Heyn, Sören: Deichbau – Nutzung ausgebauter großformatiger Betonelemente aus dem Wohnungsbau für den Hochwasserschutz, final report, currently in progress, completion April 2009

- **Water retention in the experimental setup**

By retaining water (well water) in the dyked area, the real loads during flooding can be simulated. Approx. 550 m³ of water were required for one damming.

The experimental dyke has been filled five times. The flooding tests were performed at the end. The damming of the water up to a height of 2.50 m (1st attempt) and 2.70 m (2nd attempt) was performed in the area of the flooding sections by means of sandbags.

- **Structural characteristics**

The compressive strength class of 3 of the 29 supplied ceiling panels was determined by means of a rebound hammer. The measurements resulted in strength class C 20/25 (B 25) for 2 ceiling panels and C 40/50 (B 45) for the third. No carbonation could be detected in the drill cores extracted for the environmental impact assessment. The other characteristic values have already been documented beforehand. The environmental impact assessment resulted in the classification into installation class Z0 according to LAGA (see Chap. 9, Fig. 9.12).

7.6.3.1 Variant 1 – Surface sealing

The concrete elements were installed as surface sealing on the waterside embankment, integrated into the clay-based sealing and covered with 1 m of soil material (silty sand) (see Fig. 7.7, 7.8). The joints between the panels are 10 cm. XYPEX concrete, tamped clay and sealing foam were used as joint sealants.

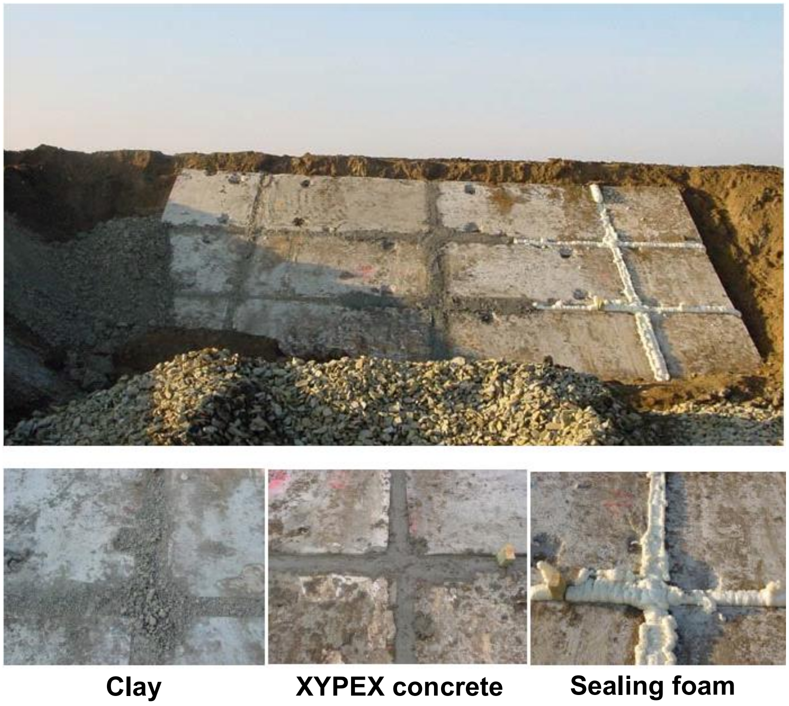

Fig. 7.8: Surface sealing during the construction phase

7.6.3.2 Variant 2 – Inner sealing

The inner sealing consists of concrete panels placed vertically in a row along the dyke axis. The 3 m high concrete panels were fixed 50 cm deep into a strip foundation[281] and ended 50 cm beneath the dyke crest (see Fig. 7.10). Due to structural reasons, the ceiling panels for the sealing wall were installed facing the waterside with the former ceiling underside.

Three additional concrete panels were offset behind three of the vertical joints. Orbit-Flex.B sealing profiles, XYPEX concrete and sealing foam were used as joint sealants (see Fig. 7.9).

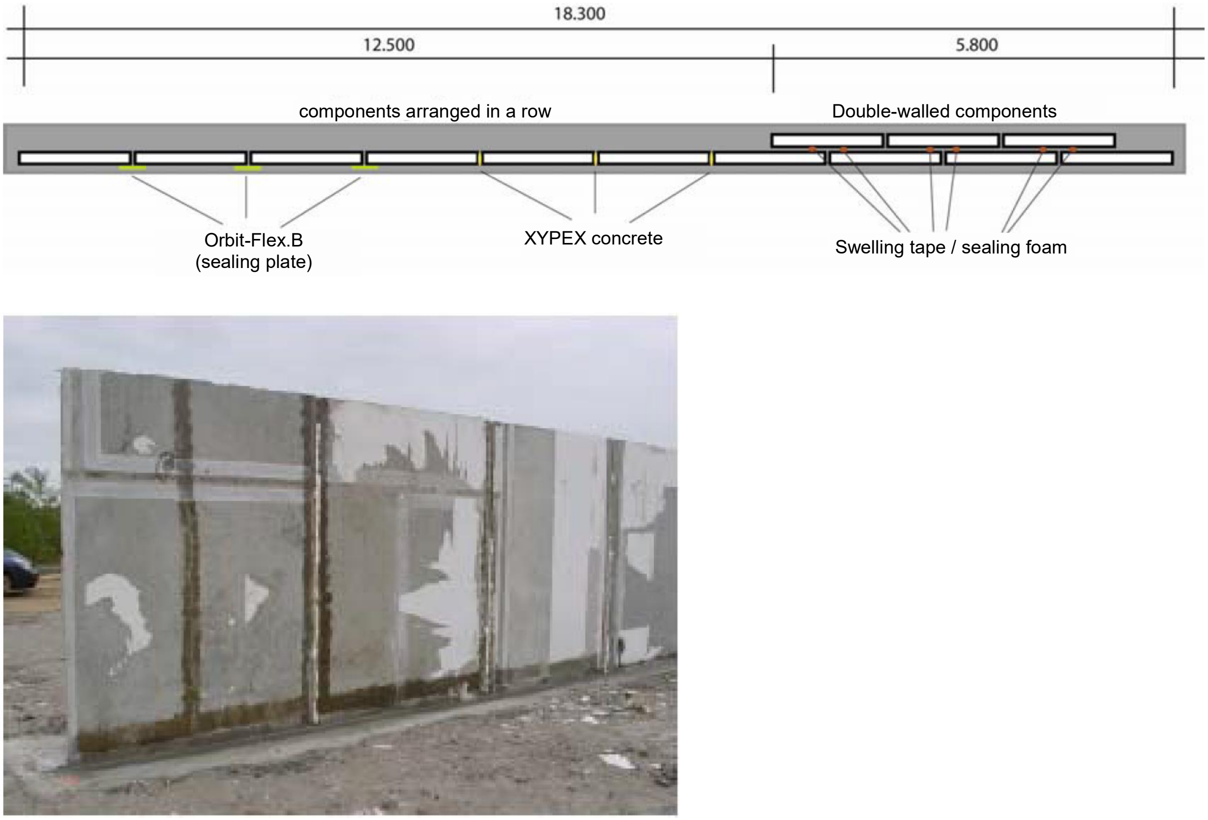

Fig. 7.9: Inner sealing; top view and in the construction phase

7.6.3.3 Variant 3 - Overflow/flooding sections

The use of concrete panels on the dyke surface is intended to protect the dyke from erosion in the event of flooding. The placement of the panels on the dyke crest and on the landside, corresponding to the slope inclination, generate a load that serves to increase the stability of the dyke body. Another additional load was created on the landside by means of a berm made of recycled gravel (see Fig. 7.10). In variant 3.1, the panels have been incorporated into the clay layer on both the waterside and the landside. In variant 3.2, the plates were arranged only in the crest area. The joints between the concrete panels were sealed with XYPEX concrete. Variant 3.3 embodies the inner sealing by installing a plate, offset in the foundation.

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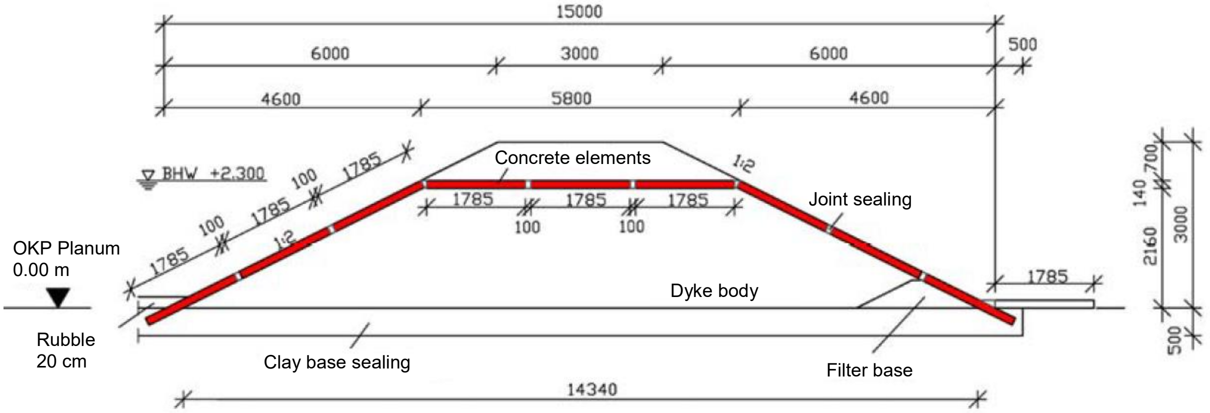
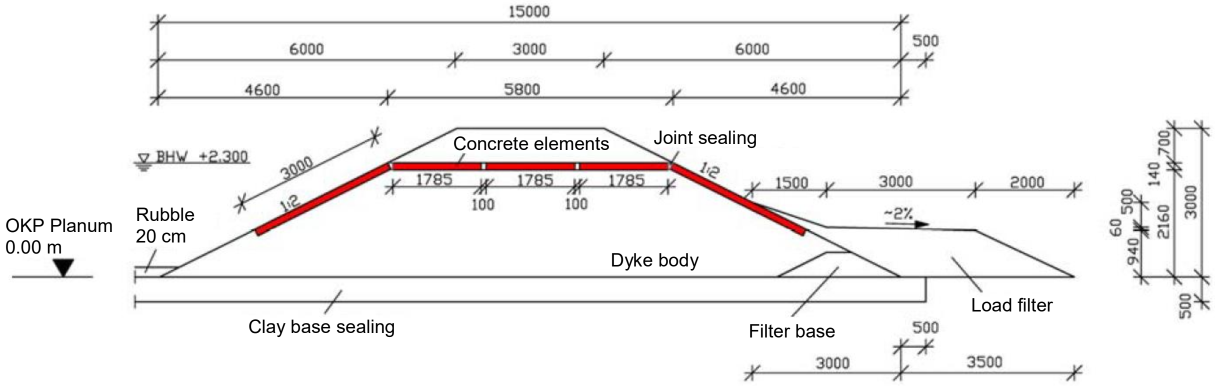
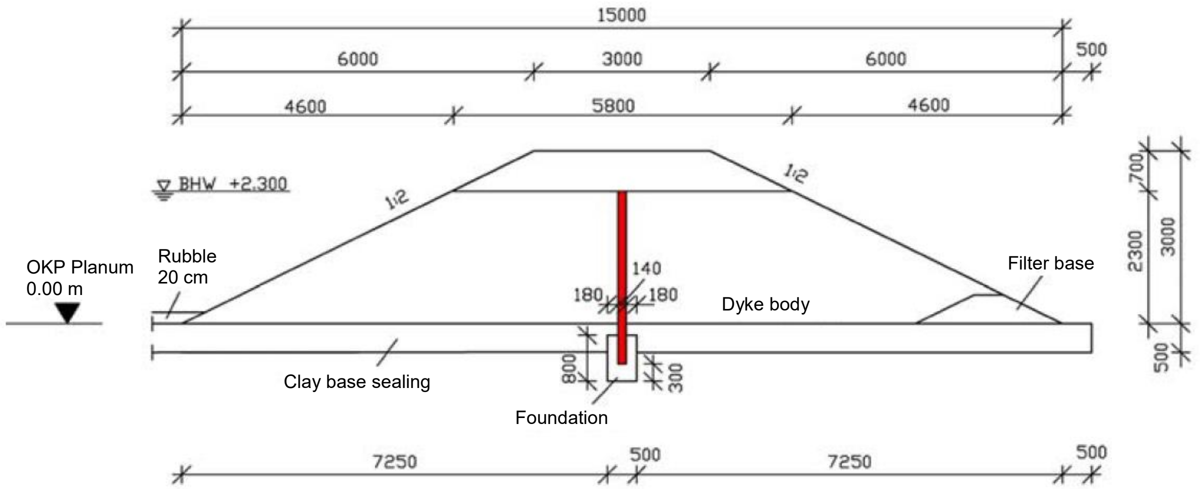
[281] Schmiedehausen, Rudolf: Statische Berechnung Streifenfundament für Innendichtung, on behalf of FG Bauliches Recyc-ling, BTU Cottbus, as part of the research project„Pro Altbeton im Hochwasserschutz“, as of 05.09.2006



Variant 3.1 – Overflow section



Variant 3.2 – Overflow section



Variant 3 – Flooding section

Fig. 7.10: Formation of the overflow sections

7.6.3.4 Trial execution and the results

- **Trial execution**

The trials with a total of 7 measurement campaigns lasted around 1.5 years in order to simulate the influences of flood events at different times of the year and under different weather conditions. The reservoir was filled with well water up to a maximum level of 2.30 metres five times and then emptied again. After the filling had been retained until the seepage water line was set, the water was drained to simulate the conditions of receding floodwater.

The repeated filling - under the influence of different retention times - enables analysis of the function and durability of the installed sealing layers made of RC concrete elements.

Upon completion of this series of trials, investigations into the overflow or flooding were conducted. For this purpose, the water level in the reservoir was raised to 2.50 m in the first trial and to 2.70 m in the second trial. The designated areas were flooded individually by removing the installed sandbags.

- **Measurement technology**

In order to obtain reliable data on the behaviour of the respective developed variant, extensive measurement technology has been installed in the dyke body:

- Fibre-optic temperature measurement technology:
  - to localise the seepage water paths (joints monitoring for leakage) via temperature measurement in the area of the joints of the inner and surface sealing (see Fig. 7.11)
  - to analyse the setting of the seepage line in the homogeneous dyke as comparative measurement (parallel measurement over 5 gauges, see Fig. 7.12)
- Water level tubes with continuous measurement data acquisition (pressure cell) and data logger:
  - to determine the water levels of the seepage water in the dyke body and the water level in the reservoir (selective)
- Rod extensometer:
  - to determine the setting behaviour of the dyke body
- Fixed gutter with measuring collector:
  - to determine the amounts of seepage water flowing through
- Geodetic measuring device including accessories:
  - to determine the dyke deformation by means of fixed points on the dyke body (airside and waterside and a fixed point in open terrain)

Fig. 7.11: Installation of the temperature cable

Fig. 7.12: Installation level

- **Trial results**

The evaluation of the measurement data and the documentation of the visual observations is still pending. However, the findings obtained up to now indicate that neither failure nor instabilities have been recorded during the trial campaigns or afterwards. The utilised concrete parts from building construction are suitable for unprocessed use in earthworks.

Despite irrigation in the dry summer months, no sward was able to develop due to the soil material embedded in the dyke body and the extreme weather conditions in the open-cast mine. Since the stability calculations do not consider sward, the test was carried out without or only with sparse vegetation. This means that the tests were performed under less favourable boundary conditions than in practice.

Regardless of the fact that investigations of the trial campaigns have not yet been completed, it can be deduced that RC concrete elements are suitable for the stabilisation of dykes. The observed reduction in seepage and the low deformation of the dyke sections with sealings (concrete elements) as compared to the homogeneous dyke section are noteworthy.

Currently, no conclusive statement can be made with regard to the tightness of the joint formation. There is a tendency towards the use of bentonite packings.

7.6.4 Assessment of economic feasibility

In the context of investigations into economic feasibility[282] of the various dyke construction options developed, the construction costs were calculated according to sirAdos[283] and compared with two different water management engineering firms.

The objective of the study is to determine the economic competitiveness of the developed dyke construction variants against conventional constructions.

[282] Kania, Gregor: Weiterverwendung gebrauchter großformatiger Betonfertigteile im Deichbau und bei der Deichsanierung, Diplomarbeit, BTU Cottbus, LS Altlasten, FG Bauliches Recycling, July 2008, p. 65 ff.
[283] sirAdos – Baudaten für Kostenplanung und Ausschreibung

The calculation was based on a 100 m long dyke with a 3 m wide crest and a height of the dyke crest of 3 m (the dyke cross-section corresponds to the experimental dyke). The slope inclination of 1:2 applies to the variants:

- Dyke with surface sealing made of RC concrete elements (RC-BE),
- Dyke with inner sealing made of RC concrete elements (RC-CE).

The overflow section with RC concrete elements is arranged at a height of 2.30 metres. The crest width at this point is 5.80 metres.

These variants are compared with the following dyke constructions:

- Homogeneous dyke with a slope inclination of 1:3
- Overflow sections
    1. with a landside and waterside slope inclination of 1:10 and
    2. with a waterside slope inclination of 1:3 and a landside slope inclination of 1:10.

The different joint sealants used in the experimental dyke and the different transport distances were included in the calculation.

The result can be summarised as follows:[284]

[284] summarised from the appendix of the diploma thesis by Kania, Gregor: Weiterverwendung gebrauchter großformatiger Betonfertigteile im Deichbau und bei der Deichsanierung, Diploma thesis, BTU Cottbus, LS Altlasten, FG Bauliches Recycling, July 2008, p. 65 ff.

Tab. 7.5: Comparison of the construction costs of different dyke construction variants

Construction variant	Price €/running metre Metres (values rounded)			Percentage comparison [%] (medium)
	from	medium	to	
Homogeneous dyke 1:3	930	1,173	1,497	100
Dyke with surface sealing RC-CE (clay)[1], 1 : 2				
Trapo RC-CE 25 km	753	940	1,190	80.1
Trapo RC-CE 100 km	757	950	1,205	81.0
Trapo RC-CE 250 km	772	976	1,242	83.2
Dyke with surface sealing RC-CE (XYPEX-concrete)[1], 1 : 2				
Trapo RC-CE 25 km	754	942	1,191	80.3
Trapo RC-CE 100 km	759	952	1,207	81.2
Trapo RC-CE 250 km	771	975	1,242	83.1
Dyke with inner sealing RC-CE (Orbit-Flex.B)[1], 1 : 2				
Trapo RC-CE 25 km	858	1,057	1,318	90.1
Trapo RC-CE 100 km	863	1,065	1,330	90.8
Trapo RC-CE 250 km	871	1,078	1,349	91.9
Dyke with inner sealing RC-CE (XYPEX-concrete)[1], 1 : 2				
Trapo RC-CE 25 km	853	1,052	1,313	90.0
Trapo RC-CE 100 km	858	1,061	1,326	90.5
Trapo RC-CE 250 km	866	1,075	1,346	91.6

[1] ( ) Joint sealant

The results of the cost calculation demonstrate clearly that the dyke construction variants developed by using utilised concrete elements are competitive with conventional construction variants.

Assuming an average price level, the construction variants with surface sealing save around 20% and with internal sealing (new construction) around 10% in costs when compared to the construction of a homogeneous dyke (see Fig. 7.13) even if the concrete elements have to be transported over a distance of 250 km). The different joint materials applied do not play a significant role (the joint sealants used in the experimental dyke were included in the calculation).

The calculated costs correlate with the data from implemented projects such as the construction of the 2.3 km long upgraded dyke in Lunow-Stolpe-Polder. Approximately 2.3 million Euros were invested on behalf of the State Environment Agency to increase the height of the existing dyke. The measures included the installation of a filter prism, flattening of the dyke slope and construction of a new dyke defence path on the dyke crest.[285]

Tab. 7.6: Comparison of costs incurred for the formation of overflow sections for different construction variants

Construction variant	Price €/running metre Metres (values rounded)			Percentage comparison [%] (medium)
	from	medium	to	
Homogeneous dyke				
Overflow section 1 : 10	2,159	2,727	3,486	100
Overflow section RC-CE, 1 : 2				
Trapo RC-CE 25 km	1,009	1,257	1,618	46.1
Trapo RC-CE 100 km	1,035	1,302	1,681	47.8
Trapo RC-CE 250 km	1,075	1,371	1,783	50.3
Homogeneous dyke Overflow section 1 : 10 landside, 1 : 3 waterside	1,539	1,943	2,483	71.3

Even more significant cost savings can be achieved with the overflow sections. In comparison to the traditional construction method with slope inclinations of 1:10, the costs for the delivery of the used concrete elements are only half, even with a transport distance of 250 km. Compared to the overflow section with different slope inclinations (1:3 on the waterside, 1:10 on the landside), the cost savings still amount to almost 30%. It is important to note that it was assumed that the concrete elements would be provided free of charge.

[285] Press release of the Ministry of Rural Development, Environment and Consumer Protection as of 25.03.2008

Fig. 7.13: Comparison of construction costs of different dyke variants with details of cost-saving potential

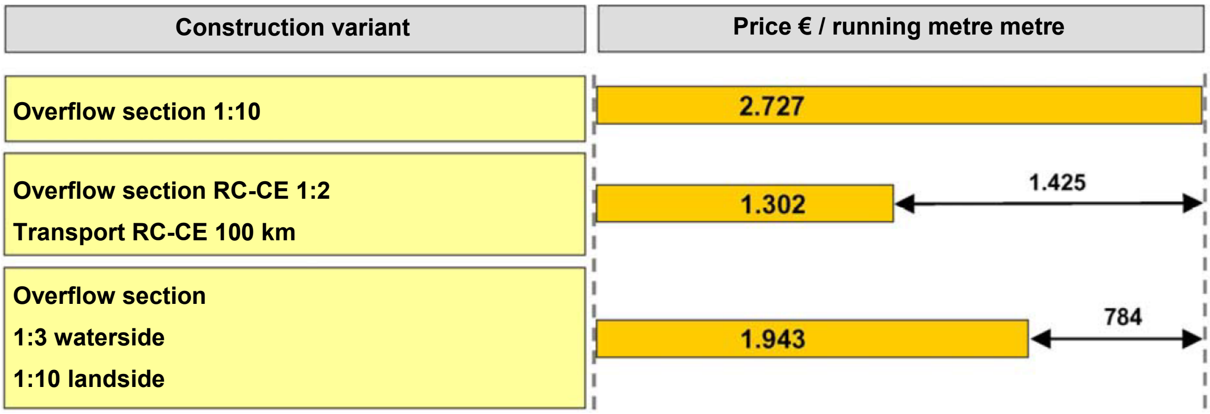


Fig. 7.14: Comparison of construction costs for overflow sections in different construction variants with details of cost-saving potential

7.6.5 Ecological relevance of the utilisation of used concrete components in dyke construction

The following is an ecological evaluation of the developed variants based on the construction of the experimental dyke in comparison with a traditional dyke constructed in accordance with DIN 19712. The objective is to identify potential for environmental relief or pollution resulting from the new developments.

- **Land and soil consumption**

Due to the smaller earth body of the developed dyke construction design, less space and less soil material is required. Consequently, land utilisation and the extraction of natural resources are reduced (see Fig. 7.15, Tab. 7.7).

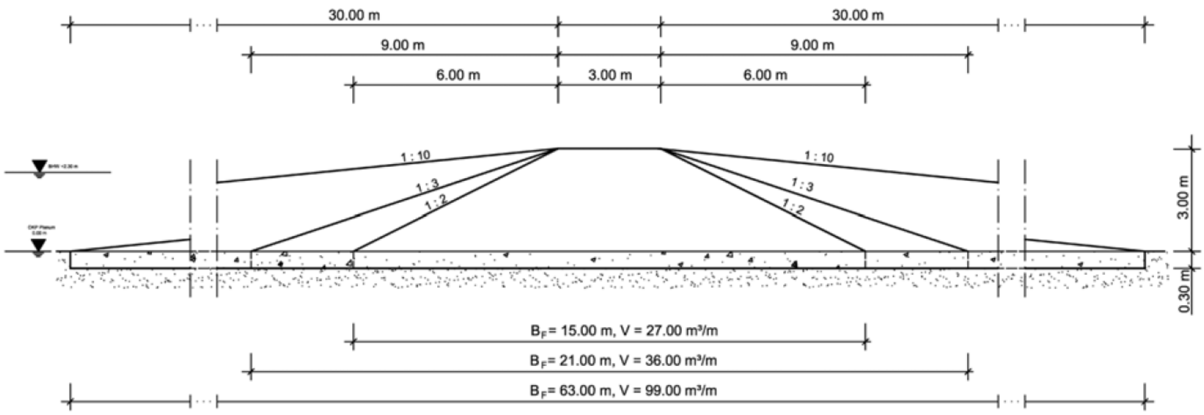


Fig. 7.15: Geometries of the dyke construction variants

Tab. 7.7: Land and soil consumption in different dyke construction variants

Parameters	**Dyke formation**			**Overflow section**		
	homogeneous	With surface sealing	With inner sealing			
	1:3	1:2	1:2	1:10	1:2	1:10 + 1:3
	Height of the dyke crest 3.00 m			Height of the dyke crest 2.30 m		
	Var. 0	Var. 1	Var. 2	Var. 3.0	Var. 3.1	Var. 3.4
Surface consumption [m^2/m]	21	15		63	15	42
Difference Var. 0 : Var. n or Var. 3.0 : Var. 3.n [m^2/m]		-6			-48	- 21
[%]	100	71.4		100	23.8	66.7
	V1	V2	V3	V4	V5	V6
Soil consumption Volume [m^3/m]	36	26	26.5	85	22	58
Difference V1 : Vn or V4 : Vn [m^3/m]		-10	-9.5		-63	-27
[%]	100	72.2	73.6	100	25.9	68.2

It is evident that, in comparison to traditional dyke construction, the amount of land required can be reduced by almost 30%. The savings in soil in relation to the volume amount to ~26-28%. In the case of the developed overflow sections, even greater savings can be achieved due to the steeper slope inclination. Land usage can be reduced by more than ¾ when considering a slope inclination of 1:2 as opposed to 1:10. The amount of soil material is reduced by almost 75 %.

In view of dyke construction and upgrading measures that are still pending in practice as well as the political objective of the German sustainability strategy to reduce land utilisation from current ~ 118 ha/d to 30 ha/d by 2020[286], such alternative variants represent an interesting approach.

- **Energetic assesment**

The energy assessment is based on a simplified approach for the production of 100 metres.

▪ Required number of RC-CE units for the construction variants under consideration

Assumption utilised assortment:

Ceiling panel 1.785 m × 5.98 m × 0.14 m ; ~3.5 t

- Variant 1: Surface sealing (see Fig. 7.7; 7.8): 48 DP
- Variant 2: Inner sealing (see Fig. 7.7; 7.9): 26 DP
- Variant 3.1: Overflow section (see Fig. 7.10): 147 DP

▪ Transport

The number of runs depends on the load weight of the truck. Assuming that a semi-trailer truck with a load weight of 25 tonnes is used, ceiling panels can be transported in a single run. This results in

- Variant 1: 7 runs
- Variant 2: 4 runs
- Variant 3.1: 21 runs

Various distances of 25 km, 100 km and 250 km were taken into account for the transport of the ceiling panels from the place of origin (dismantling site) or, if necessary, from the interim storage site to the installation site. According to PROBAS, the primary energy consumption is 1.36 MJ/t·km.[287]

It is assumed that a solo truck will be used to transport the earth mass for the construction of the dyke body. The primary energy consumption here amounts to 1.97 MJ/t-km. A distance of 30 km is assumed for the transport of the soil material.

This results in the following energy consumption:

[286] cf. UBA (ed.): Nachhaltiges Bauen und Wohnen, November 2008, p. 23
[287] under LKW-DE-2000-Zug-30t, in: www.probas.umweltbundesamt.de/php

Tab. 7.8: Energy required for the transport in relation to the construction of 100 m of the dyke

Transport service	Energy requirement [MJ/t▪km]	Mass [t]	Energy requirement [MJ]			
			25 km	100 km	250 km	30 km
RC-CE transport						
Var. 1 Surface sealing 1:2	1.36	168	5,712	22,848	57,120	
Var. 2 Inner sealing 1:2		91	3,094	12,376	30,940	
Var. 3.1 Overflow section 1:2		515	17,510	70,040	175,100	
Soil material*						
Var. 0 Homogenous Dyke 1:3	1.97	7,020				414,882
Var. 1 Surface sealing 1:2		5,070				299,637
Var. 2 Inner sealing 1:2		5,168				305,429
Var. 3.0 Overflow section 1:10		16,575				979,583
Var. 3.1 Overflow section 1:2		4,290				253,539
Var. 3.4 Overflow section 1:10 + 1:3		11,310				668,421

*Density ρ determined 1.889 g/cm³ to 2.163 g/cm³[288]; calculated with 1.95 g/cm³

- Crane deployment

A mobile crane is required for the installation of the concrete elements. Assuming the construction of the test dyke, ~10 min/CE are required for the construction of the surface sealingand ~ 15 min/CE for the innersealing. This results in the following crane operating times

- Variant 1: ~8 h
- Variant 2: ~13 h (for the installation of 52 DP; panels are halved)
- Variant 3.1: ~25 h

It is assumed that diesel consumption is 42 litres per hour. The primary energy input of 1 litre diesel is 35.3 MJ.[289]

The following costs are incurred for crane deployment, depending on the construction variant:

[288] Test report „Auswertung der Untersuchungen an den verwendeten Deichbaumaterialien", LS für Bodenmechanik und Grundbau, on behalf of Fachgruppe Bauliches Recycling, BTU Cottbus

[289] Mettke, Angelika; Heyn, Sören: Deichbau – Nutzung ausgebauter großformatiger Betonelemente aus dem Wohnungsbau für den Hochwasserschutz, final report, currently in progress, completion April 2009

Tab. 7.9: Energy required for crane deployment for the construction of the dyke variants developed for 100 m section of the dyke

Construction variant	Crane deployment [h]*	Diesel consumption [l]	Primary energy [MJ]
Var. 1 Surface sealing	8	336	11,861
Var. 2 Inner sealing	13	546	19,274
Var. 3.1 Overflow section	25	1,050	37,065

* determined during the construction of the experimental dyke

The following table 7.10 summarises the energy expenditure for transport of the elements and the soil material as well as for the deployment of a crane to install the elements.

Tab. 7.10: Energy expenditure for transport and installation of the RC-CE

Construction variants	Energy consumption [MJ]							
	Transport RC-CE			Transport soil material 30 km	Crane deploy ment	Total		
	25 km	100 km	250 km			25 km	100 km	250 km
Var. 0 Homogeneous dyke 1:3				414,882				
Var. 1 Surface sealing 1:2	5,712	22,848	57,120	299,637	11,861	317,210	334,346	368,618
Var. 2 Inner sealing 1:2	3,094	12,376	30,940	305,429	19,274	327,797	337,079	355,643
Var. 3.0 Overflow section 1:10				979,583				
Var. 3.1 Overflow section 1:2	17,510	70,040	175,100	253,539	37,065	308,114	360,644	465,704
Var. 3.4 Overflow section 1:10 + 1:3				668,421				

- Concrete use

Concrete is used for the construction of the strip foundation (new dyke construction) and for closing the joints in the inner and surface sealing.

The strip foundation for the inner sealing with the dimensions 0.80 m × 0.50 m[290] (height × width) and the clamping height of the concrete elements in the foundation of 0.50 m requires 33 m³ of concrete per 100 m. The use of C 20/25 with a bulk density of 2.3 t/m³ results in 230 t of concrete.

[290] Schmiedehausen, Rudolf: Statische Berechnung Streifenfundament für Innendichtung, on behalf of FG Bauliches Recyc-ling, BTU Cottbus, as part of the research project„Pro Altbeton im Hochwasserschutz“, as of 05.09.2006

The joint sealing for the 52 ceiling panels lined up to ~1.80 m in width and 3.0 m in height, requires ~0.45 m³ of joint concrete or ~1 t (3.0 m × 0.14 m × 0.02 m × 0.0084 m³ per joint × 53 joints ≈ 0.45 m³) per 100 m of dyke length and 2 cm joint width.

The installation of 48 ceiling panels results in a joint length of ~284 m for the surface sealing (in the longitudinal direction: 2 joints × 100 m = 200 m, in the transverse direction: 15 joints × 5.55 m ≈ 83.40 m). The joint volume is ~3.98 m³ and the joint mass is ~9.2 t.

In the case of the overflow section (Var. 3.1), the installation of 147 ceiling panels results in a joint length of ~1,048 m (in the longitudinal direction 8 joints × 100 m = 800 m; in the transverse direction 15 joints × 16.50 m ≈ 248 m). For 1,048 m of joint length with a width of 10 cm and a thickness of 14 cm, ~14.7 m³ or ~34 t of joint concrete are required.

According to Fig. 9.19, 1.272 MJ/m³ (KEA[291]) was determined for gravel concrete. However, according to Probas, 0.994 MJ[292] energy or 994 MJ/t is indicated for the production of 1 kg of concrete. This value comes close to the specifications for standard concrete (non-reinforced) delivered to site according to GaBiE[293] at 657 MJprim/t (KEA). The subsequent calculation is based on 994 MJ/t for the production of non-reinforced concrete. Assuming a transport distance of 25 km from the transport provider to the installation site, an additional ~50 MJ/t (25 km × 1.97 MJ/t - km; see Table 7.9) is required.

The energy consumption for the individual variants is as follows:

Tab. 7.11: Energy consumption for the use of concrete in the individual construction variants in relation to the construction of 100 m of the dyke.

Construction variants	Concrete quantity [t]	Energy consumption [MJ]	Energy consumption Transport [MJ] (transport distance 25 km)	Σ Energy requirement [MJ]
Var. 1: Surface sealing (Joint concrete)	9.2	9,145	460	9,605
Var. 2: Inner sealing (strip foundation and joint concrete)	230 + 1	229,614	11,550	241,164
Var. 3.1: Overflow section (Joint concrete)	34	33,796	1,700	35,496

- Installation of the soil material

The final research report[294] was based on the following characteristics of the implemented machine technology

[291] CED = cumulative energy expenditure or grey energy; calculated as the sum of all primary energy inputs/energy quantities used to manufacture a product (incl. transport of raw materials, material production, etc.).
[292] www.probas.umweltbundesamt.de/php
[293] GaBiE Holistic balancing of processes and products, construction material tables,
Forschungsstelle für Energiewirtschaft: Ganzheitliche Bilanzierung von Grundstoffen Halbzeugen, Teil 2, Baustoffe, 1999; www.ffe.de/taetigkeitsfelder/ganzheitliche-energie-emissions-und-kostenanalysen/200-gabie-ganzheitliche-bilanzierung-von-prozessen-und-produkten, accessed on 08.03.2009
[294] Mettke, Angelika; Heyn, Sören: Deichbau – Nutzung ausgebauter großformatiger Betonelemente aus dem Wohnungsbau für den Hochwasserschutz, final report, currently in progress, completion April 2009

1 wheel loader of 86 kW,

1 bulldozer of 150 kW,

1 roller of 150 kW

for the calculation of energy consumption:

24 l/h diesel consumption for the wheel loader

42 l/h diesel consumption for the caterpillar or roller.

This results in a total energy requirement of 108 l/h. In order to make further calculations, it is necessary to know how much machinery is required for the construction of the dyke (supporting) body depending on the slope gradient. The data must be collected in further analyses and applied as basis. Due to the lack of our own time recordings, we therefore only refer to them here. Although this aspect is missing in the final analysis, the fact that less soil material has to be installed in the developed variants as compared to conventional variants means that the energy required for installation will also be reduced accordingly.

- Overview of the calculated energy expenditure

Table 7.12 below compares the calculated energy consumption for the individual construction variants.

Tab. 7.12: Energy consumption for the individual construction variants

	Energy consumption [MJ]											
Construction variants	Transport of soil material 30 km	Transport RC-CE + crane deployment + transport of soil material			Concrete use	Σ Energy requirement for transport distance for RC-CE			Comparison of energy expenditure [%] Var. 0 with alternative variants			
		25 km	100 km	250 km		25 km	100 km	250 km		25 km	100 km	250 km
Var. 0 Homogeneous dyke 1:3	414,882								100			
Var. 1: Surface sealing 1 : 2	299,637	317,210	334,346	368,618	9,605	326,815	343,951	378,223		79	83	92
Var. 2: Inner sealing 1:2 (new construction)	305,429	327,797	337,079	355,643	241,164	568,961	578,243	596,807		137	140	144
Var. 3.0: Overflow section 1:10	979,583								100			
Var. 3.1: Overflow section 1:2	253,539	308,114	360,644	465,704	35,496	343,610	396,140	501,200		35	41	51
Var. 3.4: Overflow section 1:3, 1:10	668,421								68			

The comparison of the conventional dyke construction with the developed dyke construction variants in terms of energy consumption is presented graphically as follows:

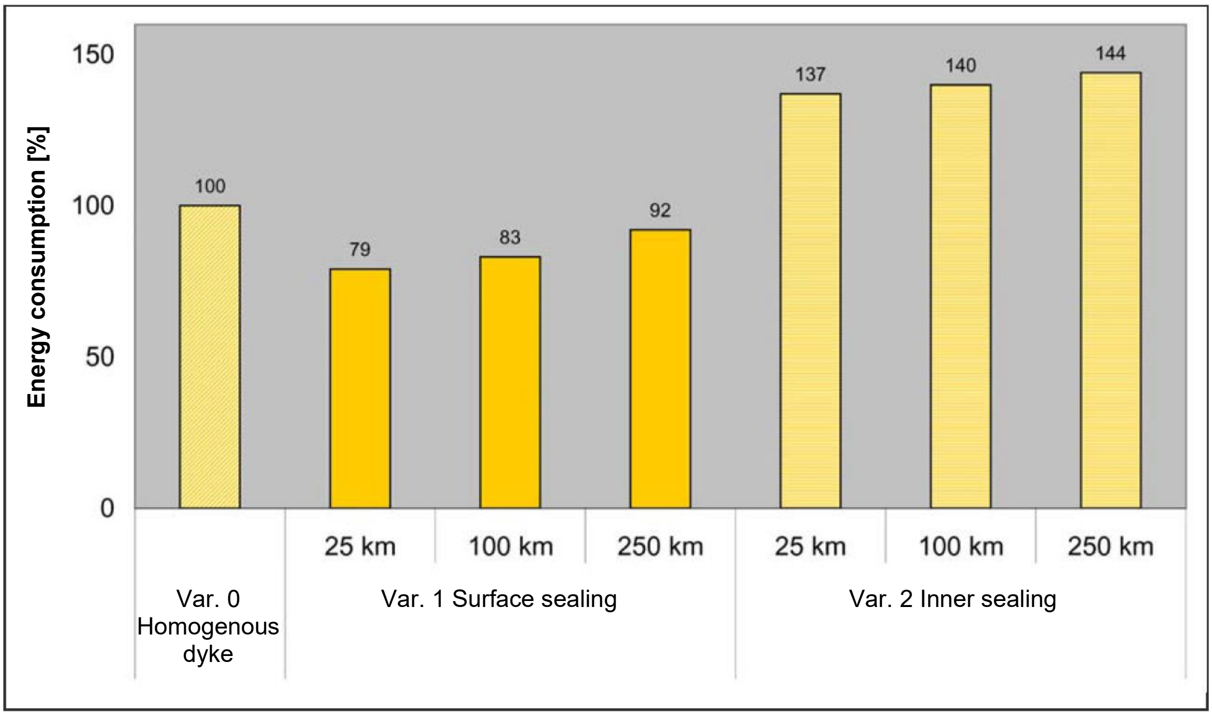
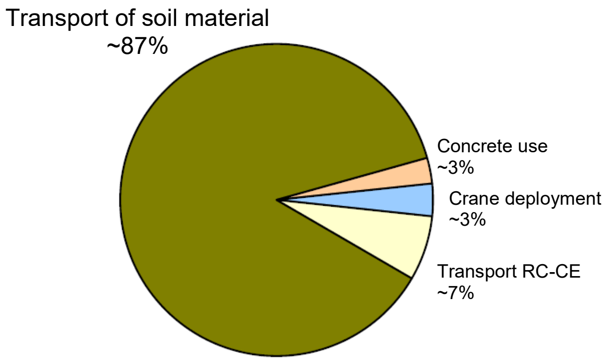


Fig. 7.16: Comparison of energy consumption for selected sub-processes of the developed dyke construction variants with conventional construction

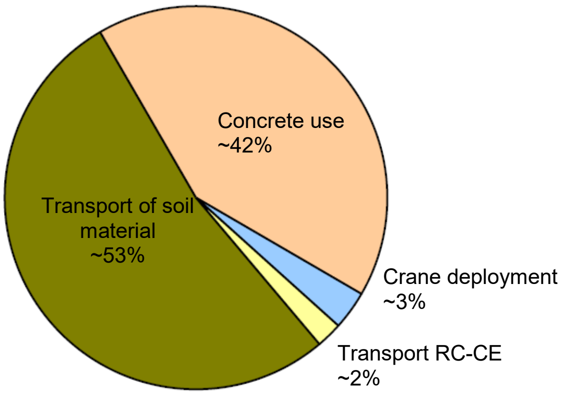
Taking an example of 100 km transport of the elements for the construction of the surface sealing system, the energy consumption for the transport of the used concrete elements is ~6.6% and for the installation (crane use) amounts to ~3.4% (see Fig. 7.17).



Trapo soil	299.637 MJ	87,2 %
Trapo RC-CE	22.848 MJ	6,6 %
Crane deployment	11.861 MJ	3,4 %
Concrete use	9.605 MJ	2,8 %
Σ	343.951 MJ	100 %

Fig. 7.17: Distribution of key sub-processes for the energy required to manufacture the surface seal

This is illustrated below in relation to the construction of the inner wall seal of newly constructed dykes. The transport distance for the RC-CE is also 100 km.



Trapo soil	305.429 MJ	52,8 %
Trapo RC-CE	12.376 MJ	2,2 %
Crane deployment	19.274 MJ	3,3 %
Concrete use	241.164 MJ	41,7 %
Σ	578.243 MJ	100 %

Fig. 7.18: Distribution of key sub-processes for the energy required to manufacture the inner sealing

Overall, the calculation of the main sub-processes reveals a clear advantage in terms of energy for the surface sealing as compared to conventional dyke construction. In terms of energy consumption, savings between 8% (for a distance of 250 km) and 21% (for a distance of 25 km) can be achieved, depending on the distance required to transport the ceiling panels. The main savings potential lies in the reduction of the soil material to be transported for the construction of the dyke (supporting) body.

The energy requirement for the production of the inner sealing is 37% to 43% higher (see also Table 7.18) than a conventional dyke construction variant due to the construction of the strip foundation.

It can therefore be concluded that, in terms of ecology, the production of internal sealings with RC-CE is not recommended for the construction of new dykes. (However, in this case it would be more realistic to compare it with conventional structural solutions such as driving a sheet pile wall). The use of RC-CE as inner sealing seems to be more suitable for upgrading measures. Proof of this would still have to be provided. This is envisaged in further research work.

The comparison of the overflow sections in conventional construction with the developed variants is clearly in favour of the alternative solution. Depending on the transport distance, the energy savings amount to 49% to 65% as compared to the conventional construction variant with a slope inclination of 1:10.

However, it should be noted that only concrete was assessed here as joint material. The tested joint materials, sealing elements, sealing foam and clay must be evaluated in further ecological studies, provided they are technically proven.

7.6.6 Summary and prospects for subsequent utilisation of used concrete elements in dyke construction

According to the current state of knowledge, there are many arguments in favour of using RC concrete elements for the stabilisation of dykes. Surface sealing is particularly promising. The technical, economic and ecological advantages are convincing in comparison to conventional dyke construction methods. The ceiling panels from the industrially manufactured housing construction (prefabricated buildings) have proven their worth. Stability is guaranteed. The RC-CE surface sealing variant is suitable both for the construction of new dykes as well as for upgrading measures.

The RC-CE inner sealing has proven to be suitable from a technical and economic point of view. However, in the context of ecological parameters, new construction is not recommended. It appears to be more practical to reinforce dykes by means of RC-CE, as there is no need for the construction of foundations. It is therefore recommended that the inner sealing variant with RC-CE is analysed in terms of upgrading.

In a comparison of the developed overflow sections with conventional construction variants, all expectations have been met, just as in the case of the surface sealing. From a holistic point of view, the installed RC-CEs proved to be suitable in the overflow tests. Due to the lack of frost resistance of RC-CE, the application of a surface protection system is recommended.

The tightness of the joints or the tightness of the selected joint material has not been clearly resolved yet. Suitable solutions will have to be discussed and tested in further detail. Bentonite packs are generally considered to be useful.

It is worth noting that the use of concrete elements in dyke construction in all three of the developed application variants will lead to a significantly higher durability of the structures. This is the mathematical result of preventing seepage through the dyke by means of the sealing layers of concrete elements, which are watertight.

Furthermore, burrowing animals such as moles, brown rats, rabbits, muskrats and beavers have no chance of directly damaging the dyke body. The construction of corridors ends at the concrete wall at the latest. In this respect, the concrete sealing wall serves as a structural safeguard against burrowing animal infestation.

Moreover, the use of concrete elements is expected to improve erosion protection of the dyke surfaces when the dyke is overflowed. A further advantage results from the significantly lower land consumption of up to almost 30 %. This is particularly relevant from the perspective of property ownership. In most cases, dykes border on the waterside and airside of third-party property. Due to the reduced volume of the earth structure resulting from the use of concrete elements, around 28% of soil material is also saved during dyke construction.

The developed overflow sections result in even greater savings: the land consumption is reduced by more than 76% as compared to the 1:10 slope inclination, and the amount of soil material is reduced by almost 75%. This results in both a cost advantage and an ecological advantage due to the lower transport volume, fewer truck journeys, reduced consumption of natural raw materials, etc.

Accordingly, the developed dyke construction variants offer a promising new technical and technological solution.

Apart from dyke construction, used concrete elements can also be used:

- for recultivation measures in opencast mining areas,
- for the necessary relocation, reorganisation and restoration of natural watercourses and canals, as well as
- in the above-ground drainage of mine water,

- as cost-effective construction of water reservoirs, e.g., for extinguishing water or as sedimentation basins for mine water purification and treatment,
- in protective walls and dams, e.g. for road and path construction,
- in noise protection dams,
- for the protection and sealing, and thus slip-proof construction of embankment systems by preventing moisture penetration in steep embankments,
- for the construction of bank reinforcements for ditches, canals and streams as well as the construction of hydraulic structures for the drainage of large residential and commercial areas, etc.

7.7 Subsequent use of utilised concrete elements in Eastern Europe

The reason for the investigations into cross-border marketing of used concrete elements is to link the challenges of the housing overhang in eastern Germany with the urgent demand for housing in eastern European countries. Within the framework of the research project "Subsequent use of prefabricated building elements in Eastern Europe"[295] funded by the German Federal Environmental Foundation (DBU), it was possible to investigate the possibility of constructing residential buildings with used concrete elements as a sustainable and promising solution on a European level. Particular attention is paid to the holistic assessment in line with the economic, environmental and socially acceptable premises. The task was to determine as to whether and under what conditions this marketing channel could be implemented.

In the context of a successful market launch, three fundamental questions need to be clarified:

1. Ensuring the quality of used concrete elements in the same way as for new concrete parts (see Chap. 6),
2. The price advantage for the property developer/owner and
3. The environmental impact/compatibility of the measure.

The preparatory measures for house construction in the suburbs of St. Petersburg are the most advanced. Selected research results on economic efficiency and ecological relevance are discussed below.

7.7.1 Economic assessment of the construction of residential buildings in Saint Petersburg

The financial expenditure for the provision of used concrete elements in preparation for their reuse K_{bereit}results from:[296]

$$K_{WV\ bereit} = K_{bereit} + K_{Prüf} + K_{Auf} + K_{TUL} + K_{Zoll} \qquad (7.1)$$

$K_{WV\ bereit}$ Costs of the provision of used concrete elements (CE) on the reassembly site

[295] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Ivanov, Evgeny: Wiederverwendung von Plattenbauteilen in Osteuropa, Final report processing phase I of the research project „Wissenschaftliche Vorbereitung und Planung des Rückbaus von Plattenbauten und der Wiederverwendung geeigneter Plattenbauteile in Tschechien“, FG Bauliches Recycling, BTU Cottbus, as of 30.05.2008

[296] cf. Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 143 ff.

K_{bereit} Costs of the provision of reusable CE on the disassembly site

$K_{Prüf}$ Costs of the analysis of the building condition (conformity test/certification)

K_{Auf} Costs of the construction component reconditioning

K_{TUL} Costs of transport, transshipment and interim storage

K_{Zoll} Custom fees

In terms of money, reuse is currently accepted and will continue to be accepted in the near future if

$$K_{WV\ bereit} << K_{Neu} \qquad (7.2)$$

with K_{Neu} component parts price

The requirement of lower costs for (re)construction as compared to conventional new buildings must be met in order to ensure a successful placement of the 'new' product 'old panel/used panel/RC concrete element' on the already highly competitive construction market. It is important to consider the costs at which the reusable RC construction element can be provided, whether it is competitive in comparison with new precast concrete elements and to what extent RC concrete elements are available.

Providers (the dismantling company or the owner of the donor building) in Germany are not only interested in purchasing dismantled concrete elements in order to minimise the costs of disposal, but also in selling them in order to be rewarded for the additional work involved in careful disassembly of the raw concrete elements. This essentially applies to the removal of the screed layer on the ceiling panels, insofar as this was not installed as 'floating screed.'

- **Costs for the provision of reusable RC concrete elements**

The current price per square metre of element surface is between 3 and 4 Euros for dismantled concrete elements. For instance, a 6 m × 1.80 m ceiling panel would cost between € 32.40 and € 43.20 (to compare: a new ceiling panel of the same size costs around € 890 in Germany).

- **Costs for the analysis of the building condition**

It is difficult to quantify the inspection costs as the inspection criteria to be examined and the scope of the inspection are currently dependent on the specifications of the inspection engineer and the respective building permit. A survey carried out by the Specialist Group for Structural Recycling in 2005 with regard to the inspection costs (assessment of compressive strength and concrete cover) reveals a significant price range of € 48.50 to € 300 per component inspection.[297]

- **Costs for component reconditioning**

[297] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Ivanov, Evgeny: Wiederverwendung von Plattenbauteilen in Osteuropa, Final report processing phase I of the research project „Wissenschaftliche Vorbereitung und Planung des Rückbaus von Plattenbauten und der Wiederverwendung geeigneter Plattenbauteile in Tschechien“, FG Bauliches Recycling, BTU Cottbus, as of 30.05.2008, p. 215 f.

Reconditioning measures will mainly – if at all – be limited to the removal of punctually adhering mortar residues on ceiling and wall panel edges. If reprofiling is required (see Chap. 4.9.1), this will be carried out in practice after reassembly in the course of joint grouting.

Costs of € 2.20/m² are assumed for the removal of solid contaminants from ceiling panels, for example.[298] If all edges of a 6 m × 1.80 m × 0.14 m ceiling panel (system dimensions) had to be cleaned, the cost would result in € 4.80 per ceiling panel.

Depending on the type and scope of the reconditioning or repair work, there is a wide range of different materials and processes in different price segments. A cost determination is therefore only possible in the specific case.

The quality of the disassembly or the opening/separation of the joints and fasteners as well as the selected attachment variant are decisive in determining whether reconditioning is necessary or not.

The accompanying scientific investigations, which were carried out in connection with the decision-making process for reuse as part of the main evaluation prove that the range of ceiling panels and inner walls in particular can be provided in ready-to-use condition without the need for reconditioning.

Due to the low labour costs in Eastern European countries as compared to Germany, it can be assumed that, should the reconditioning be necessary, these costs will not be significant.

- **Transport costs**

Investigations into the transport of components to St Petersburg were carried out on the basis of several variants (the respective core transport vehicle is highlighted in bold):

a) Combination truck – **rail** – truck (only land transport),

b) Combination truck – rail – **Roll on/roll-off ferry**[299] – truck (land – sea – land transport),

c) Combination truck – rail – **Roll on/roll-off ferry – rail** – truck (land – sea – land transport),

d) **Trucks** (only land transport),

e) Combination truck – **container ship** – truck (land – sea – land transport),

f) Combination truck – **inland waterway vessel – container ship** - truck (land – sea – land transport).

In the first step, the calculation was based on the following approach:

- The construction of a housing estate with single-family houses and apartment blocks requires the transport of 1,270 concrete elements (470 ceiling panels, 800 inner walls) with a total mass of around 3,950 t.
- The donor building is located in Cottbus.

[298] ibidem, p. 218

[299] The RoRo (roll on/roll off) process involves transport of goods that have already been loaded onto vehicles, e.g. semi-trailers, freight wagons. RoRo ferries are equipped with appropriate devices such as railway tracks.

Fig. 7.19 provides an overview of the number of required handling processes (ongoing No. 1 to 5) depending on the transport variant.

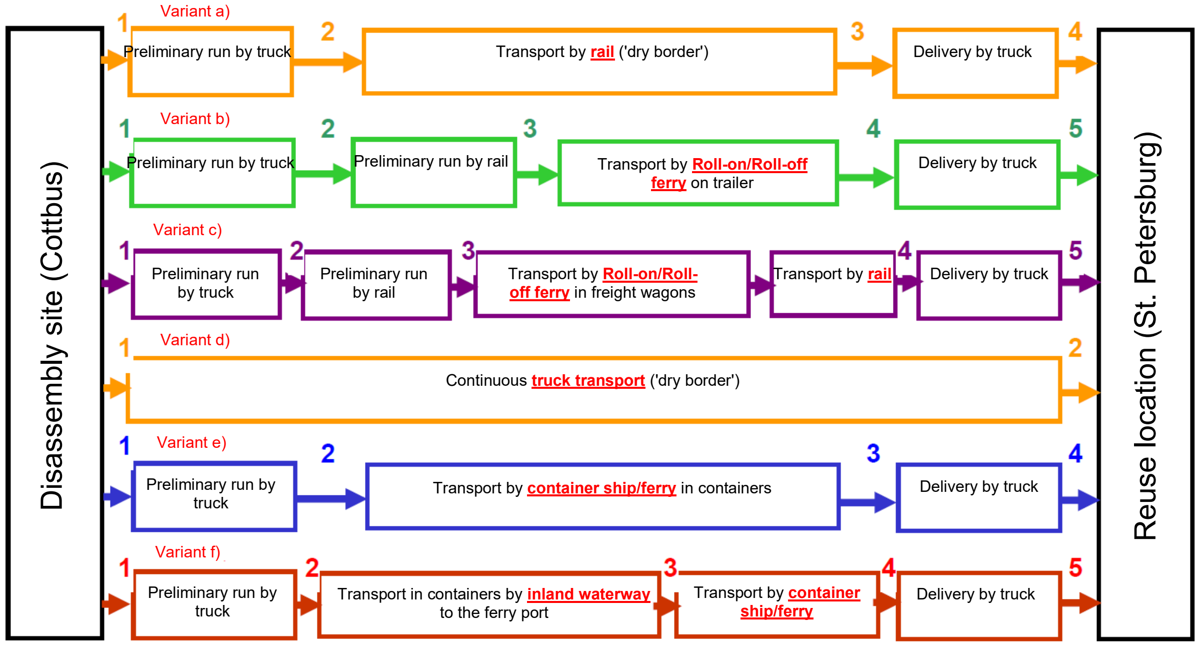


Fig. 7.19: Demonstration of possible transport variants for the transport of construction elements to St. Petersburg[300]

The calculated transport costs per tonne of construction element per kilometre are presented in the following Fig. 7.20.

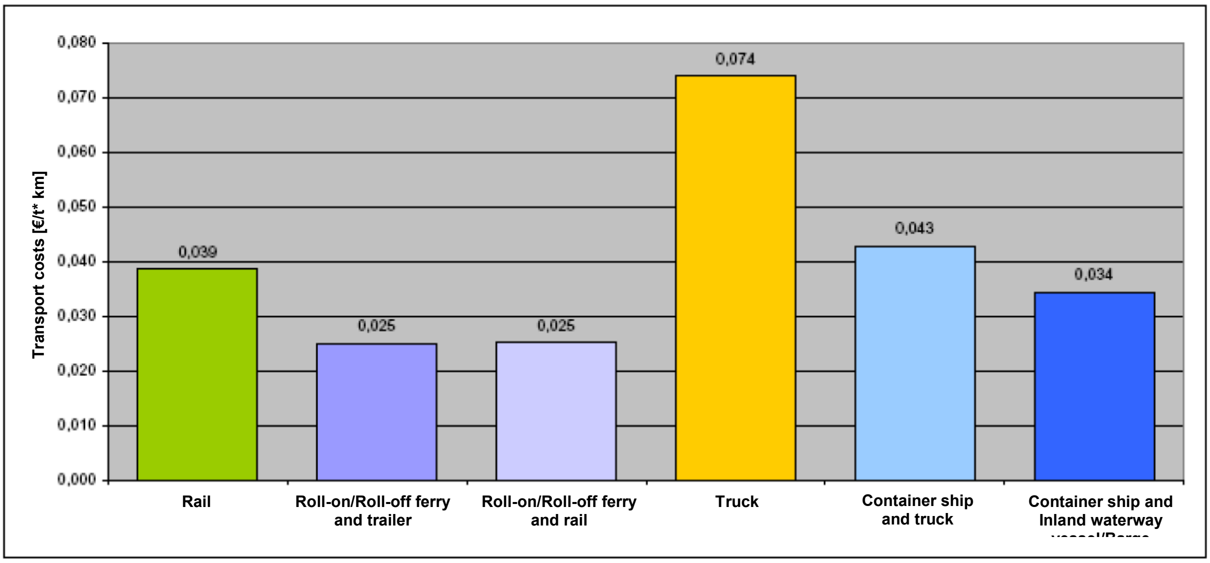


Fig. 7.20: Comparison of the costs of the various transport combinations[301]

[300] Ivanov, Evgeny: Vermarktung gebrauchter Stahlbetonelemente im Raum St. Petersburg, Student research project, FG Bauliches Recycling, BTU Cottbus, 2007, p. 8

[301] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Ivanov, Evgeny: Wiederverwendung von Plattenbauteilen in Osteuropa, Final report processing phase I of the research project „Wissenschaftliche Vorbereitung und Planung des Rückbaus von Plattenbauten und der Wiederverwendung geeigneter Plattenbauteile in Tschechien", FG Bauliches Recycling, BTU Cottbus, as of 30.05.2008, p. 215 f.

A comparison of the investigated transport options combined with different means of transport demonstrates a clear advantage in favour of RoRo ferries as the main means of transport.

However, it should be noted that these are only indicative values, as average values and extrapolations were used as the initial basis.

- **Cost comparison: reutilisation of used concrete elements with precast concrete parts newly produced in Russia**

The costs for the shell construction were estimated on the example of a developed single-family house with 116 m² of living space. According to the project design, the ratio of ceiling panels to inner wall panels is 3:5 (10 ceiling panels, 16 inner wall panels, 10 of which with a door opening).

Base prices and conversion coefficients determined by the Federal Agency for Construction and Public Utilities (1st quarter 2007, for Leningrad region: 3.66) were used as reference for new part prices in Russia.

The new price (incl. 18% VAT) for comparable precast concrete parts produced in concrete plants in the St. Petersburg area is the equivalent of approx.

€ 264 for a ceiling panel 5.97 × 1.785 × 0.14 m, 3.5 t

€ 462 for an inner wall 3.58 × 2.635 × 0.15 m, 3.15 t

€ 330 for an inner wall with door 3.58 × 2.635 × 0.15 m, 2.63 t.[302]

with the assumption that

$K_{WV\ bereit}$ = € 35 / element

$K_{Prüf}$ = € 20 / element (with 3 random samples per assortment: 9 tests at € 60 = € 540 : 26 elements)

K_{TUL} = € 171/ ceiling panel (Var. b); € 198/ ceiling panel (Var. c)

K_{TUL} = € 169 / inner wall (Var. b); € 196 / inner wall (Var. c)

K_{TUL} = € 142 / inner wall with door (Var. b); € 163 / inner wall with door (Var. c)

there are significant cost advantages according to Var. b) for the installation of used concrete elements as compared to newly manufactured elements in Russia (see Fig. 7.21). This does not include reassembly costs, as the comparison only relates to the provision of materials for the erection of the (re)construction, not an actual re(construction). However, customs duties have to be included in further calculations.

[302] ibidem, p. 245

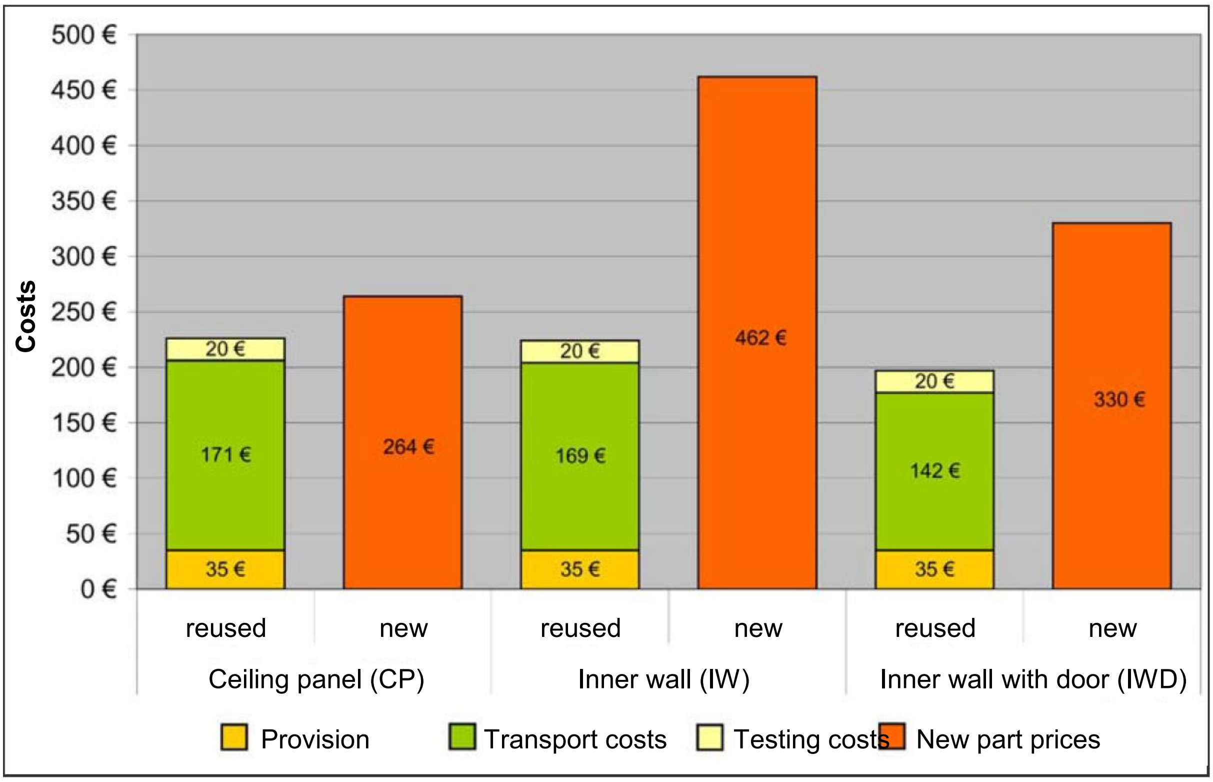


Fig. 7.21: Comparison of the new part prices for concrete elements manufactured in St. Petersburg and the costs of used concrete elements from Germany according to Var. b) + Var. c) (transport, provision and testing costs)

The utilisation of used CE results in the following element-related cost advantages if transport variant b) applies:

for a ceiling panel: € -38

for an inner wall: € -238

for an inner wall with door: € -133

The material costs for the above-mentioned single-family house are as follows, comparing used and new precast concrete elements:

Tab. 7.13: Cost estimate for the construction of a single-family house with new precast concrete elements and RC concrete elements in Russia

Element assortment	Dimensions	Required quantity	Costs		Total cost		Cost advantage RC-CE
			CE new	RC-CE	CE new	RC-CE	
	[m]	pcs.	[€ / element]		[€]		[%]
Ceiling panel	5.97 × 1.785 × 0.14	10	264	226	2,640	2,260	14.4
Inner wall	3.58 × 2.635 × 0.15	16	462	224	7,395	3,584	51.5
Inner wall with door	3.58 × 2.635 × 0.15	10	330	197	3,300	1,970	40.3
Total costs for the provision of CE					13,332	7,814	41.4

The cost advantage for the provision of used wall and ceiling elements from a donor building in Cottbus as compared to newly manufactured identical elements for the construction of a single-family house in St. Petersburg amounts to 41%. Although customs duties still have to be included, the cost advantage is so significant that (re)constructions are financially attractive and it is estimated that over 30% of costs can be saved in practice.

However, the actual cost advantage can only be determined in a pilot project by means of practical implementation.

The subsequent use of concrete elements becomes more cost-effective if the transport distances between the donor building and the harbour are short. The model calculation presented here assumes an unfavourable case, i.e., a longer transport route. However, an interim storage area at the harbour will be required due to logistical reasons.

Since transport costs make up the largest share of the costs for the provision of RC concrete elements (see Fig. 7.21), certain requirements must be placed on the transport, such as utilisation of the load capacity of the transport vehicles and transshipment in 'panel packs' (containers).

The research project "Economic and ecological balancing of the transport of concrete panels from dismantling residential buildings in Germany to Eastern European countries and their reuse in the construction of new residential buildings", which is currently being funded by the DBU, is aimed at effective analysis and resolution of these issues.

7.7.2 Energy assessment

- **Consideration of transport costs from the perspective of energy consumption**

The energy requirement for the transport effort results from the deployed means of transport, the transport distance, transport speed and transport capacity utilisation.

The following approach is used as basis for the assessment of energy expenditure:

- the combination: land – sea – land transport is evaluated,

  Variant b) Rail – Roll on/Roll-off ferry – Truck and

  Variant c) Truck – Rail – Roll on/Roll-off ferry – Rail – Truck

as cost-effective variants.

- The distance between the disassembly and reassembly construction site is ~2,082 km in the case of variant B) and ~2,400 km in the case of variant c) (see Fig. 7.22).

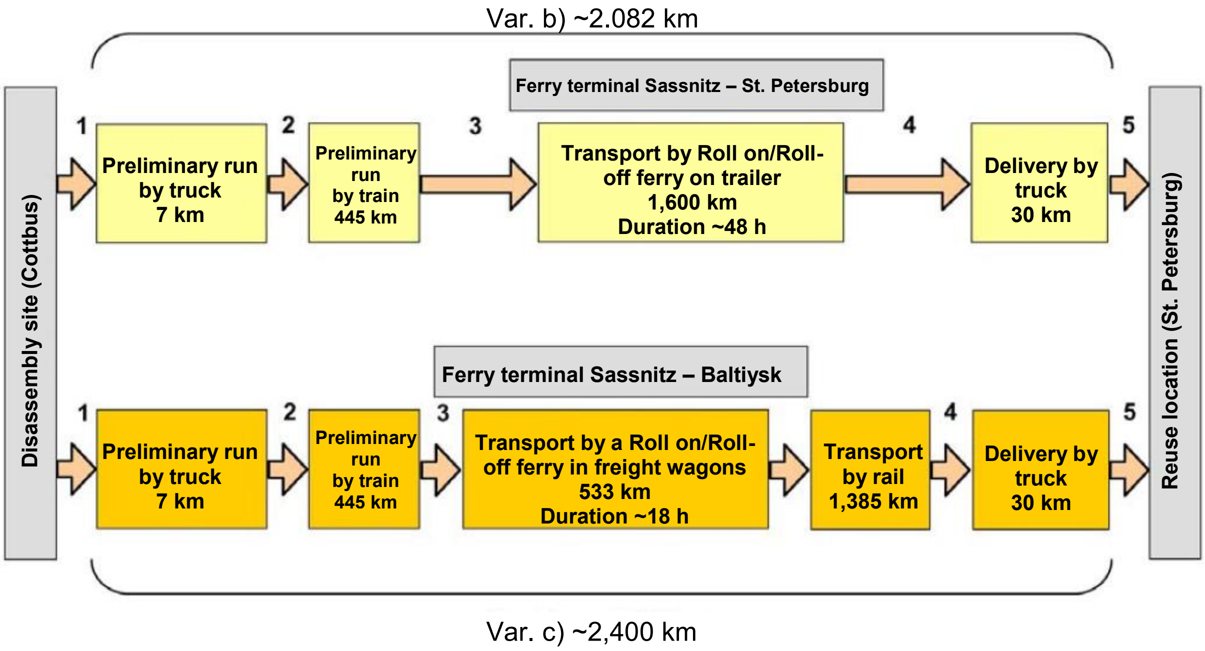


Fig. 7.22: Transport distances for the respective means of transport for the transport of construction parts from Cottbus to St. Petersburg

The ProBas database[303]serves as basis for the energy and emissions data for transport. The energy consumption for the various means of transport is presented in Tab. 7.14

Tab. 7.14: Energy expenditure of the various means of transport

Means of transport	Energy sources	Energy expenditure [MJ/t*km]
Overseas freighter	Heavy fuel oil	0.100
Rail	Diesel	0.327
Inland freight vessel	Diesel	0.350
Rail	Electricity	0.360
Truck	Diesel	1.33

The energy required to transport RC concrete elements from Cottbus to St. Petersburg for reuse in the construction of a single-family house is ~29.7 GJ in the case of Var. b) and ~57.3 GJ in the case of Var. c) (see Tab. 7.15).

[303] ProBas: Process-oriented basic data for environmental management instruments; www.probas.umweltbundesamt.de/php/index.php

Tab. 7.15: Comparison of the energy requirement of the two most cost-effective transport variants for the construction of a single-family house (116 m²) with 36 RC CE units.

Sub-processes	Means of transport	Transport for reuse /new parts			
		M [t]	s [km]	KEA [MJ/t · km]	Energy expenditure [MJ]
Variant b)					
Preliminary run	Truck (Diesel)	80.2	7	1.33	747
Rail transport	Rail (Electricity)		445	0.36	12,848
Sea transport	Freighter (heavy fuel oil)		1,600	0.10	12,832
Nachlauf	Truck (Diesel)		30	1.33	3,200
	Total				**29,627**
Variant c)					
Preliminary run	Truck (Diesel)	80.2	7	1.33	747
Rail transport	Rail (Electricity)		445	0.36	12,848
Sea transport	Freighter (heavy fuel oil)		533	0.10	4,275
Rail transport	Rail (Diesel)		1,385	0.327	36,322
Nachlauf	Truck (Diesel)		30	1.33	3,200
	Total				**57,392**

It is therefore apparent that transport variant b) consumes almost half as much energy.

- **Primary energy content of RC precast concrete elements**

The following section compares the energy required to transport the RC concrete elements to their inherent energy consumption in order to determine if an energy advantage can be achieved over a long transport route.

The energy content of precast concrete elements is assumed as KEAH of 3,080 MJ/t[304] (see Chap. 8.2.3). In order to reduce the complexity, a strength class C 20/25 (B 25) was assumed for all precast concrete elements based on Portland cement, steam curing.

This results in 247,016 MJ for the exemplary single-family house with 80.2 tonnes of precast concrete elements.

The element transport according to Var. b) consumes ~29,627 MJ. This is just 12% of the energy required for new production. This results in savings of 217,389 MJ (≙ 60,386 kWh). This balance is clearly in favour of reuse, even with a transport distance of over 2,000 km.

[304] GaBiE, Forschungsstelle für Energiewirtschaft: Ganzheitliche Bilanzierung von Grundstoffen und Halbzeugen, Teil 2 Baustoffe, 1999, p. 60

7.8 Conclusion, prospects

The presented and mostly initiated possibilities for subsequent use of disassembled concrete elements in the area of residential, sports, leisure and environmental buildings are intended to encourage more efficient use of the available assets and resources than it has been the case up to now. The technical feasibility, the price and the ecological benefit in terms of reuse and subsequent utilisation are absolutely convincing. The most cost-effective way of reuse and subsequent utilisation is, obviously, when the donor and recipient buildings are close to each other in terms of time and space.

There is much more potential for customisation than expected, especially in house construction. The extensive scope for reuse and subsequent utilisation is demonstrable and impressive thanks to the measures that have been implemented. And the projects that are still in the planning phase will deliver other components once they have been completed.

An increase in the implementation of partial deconstruction measures can also be expected in the coming years. More measures are being implemented in occupied conditions. There are several benefits to this, the major one being that the precast concrete parts are not affected by the separating process, but are produced without damage and are therefore ready for use. For safety reasons, partial demolition without a buffer storey is carried out with utmost care and precision, which has an absolutely favourable effect on the structural condition of the concrete elements. It is estimated that the availability of RC concrete elements from dismantling projects is guaranteed for the next 10 years, as there is still a considerable housing surplus in eastern Germany.

Nevertheless, with regard to further acceleration of reuse and subsequent utilisation measures, it will be necessary to improve the legal aspects in terms of authorisation. Currently, there are no standardised federal regulations for reuse and subsequent utilisation of concrete elements that have already been used once, which will and will have to minimise the previous approval effort required in individual cases.

The objective is to generate further impetus for innovative, sustainable solutions, including cross-border solutions, by providing effective publicity and engineering support for product recycling measures. House construction measures are currently being planned in the suburbs of St. Petersburg and Kaliningrad as well as in towns close to the border in Poland. A cross-border deployment of used concrete elements has not taken place yet.

The construction of multi-purpose buildings and holiday houses and, above all, the construction of community centres involving the utilisation of used concrete elements are on the agenda in Germany. Furthermore, there are plans for the development and testing of protective structures designed for disaster situations.

Additionally, further research is to be conducted into the subsequent use of panels in dyke construction. These include load tests in the crest area, utilisation of low permeability soils for the construction of the dyke body with innovative sealing systems in order to prove the stability of the dykes and to test the RC-CE inner sealing for upgrading measures.

8 Economic and ecological evaluation of the recycling of concrete components and products

This is where a holistic economic and ecological assessment of the reuse of concrete elements in comparison to the utilisation of recycled concrete elements processed in RC plants is to be made. The data is based on the author's own subsequent calculations, published in the research reports cited below, as well as on additional information from literature. Since the database is still very limited, the determined parameters can only be used as reference values.

The assessment is based on the following model/measure to be implemented:

A 5-storey prefabricated building with 3 entrances (standard building, P2 type with 30 residential units) is to be dismantled by 2 storeys or 12 residential units. The components resulting from the dismantling process can either be reused as a component or – in line with the state of the art – channelled to a RC plant. The economic and ecological assessment is based on 3 scenarios.

- Scenario 1 "The sustainability scenario"[305](cf. Fig. 8.1) includes the following sub-processes

▪ Disassembly of 12 residential units (top storey and 2 standard storeys)

  - ~60 tonnes of concrete are installed per residential unit
  - a total of 345 CE are installed; this includes 39 loggia elements[306]
  - it is assumed that all installed ceiling panels (DP) and load-bearing inner walls (IW) are suitable for reuse (cf. Chap. 6.2); the following Tab. 8.1 provides an overview in this respect:

Tab. 8.1: Ceilings and inner walls installed on the 4th and 5th storey of a P2 building

Assortment	Quantity	Total number per assortment	Dimensions of the CE	Mass	Mass i. M.	Total mass:	Total mass per assortment
		[pcs.]	[m]	[t/CE]	[t/CE]	[t]	[t]
Ceiling panels (DP)	48	72 9.60 m² / DP)	5.97 × 1.785 × 0.14	3,536	3.2	169.8	226
	24		4.17 × 1.785 × 0.14	2.34		56.2	
Inner walls (IW)	12	48 10.3 m² / IW)	4.095 × 2.785 × 0.15	2.77	2.8	33.3	134.2
	18		3.58 × 2.785 × 0.15	2.99		53.8	
	6		3.41 × 2.785 × 0.15	3.15		18.9	
	12		3.58 × 2.785 × 0.15	2.35		28.2	
∑		120				360.2	

▪ If we assume that 10 DP and 16 IW are required for the construction of a single-family house (cf. Chap. 7.6.1), the number of installed elements equates to reusable material for the construction of

[305] Future-oriented solution proposal under review
[306] from Mettke, Angelika (ed.): Plattenbauten, Wieder- und Weiterverwendungen, Anwendungskatalog II, BTU Cottbus, 2003, p. 12 ff.

another 3 single-family houses. Additionally, there are still 42 ceiling panels available that can be used for other purposes, such as in farm buildings or garages.

- Transport of 30 ceiling panels and 48 inner walls to the reassembly site; assumed transport distance from donor to recipient building: 30 km
- Reassembly of the RC-CE
- Transport of 42 ceiling panels to an interim storage facility located 30 km from the site (Var. a) or pre-crushing of the 42 ceiling panels (~120 t) along with other dismantled construction elements (~360 t) at the disassembly site with subsequent delivery of the construction waste to an RC plant located at a distance of 30 km.

In other words, Scenario 1 involves partial deconstruction with reuse of ceiling panels and inner walls for 3 single-family houses and a) reuse and / or subsequent utilisation of the remaining ceiling panels that are suitable for reuse, and delivery of the remaining concrete masses to the RC plant, or b) all other deconstructed construction elements are transported to the RC plant for material processing.

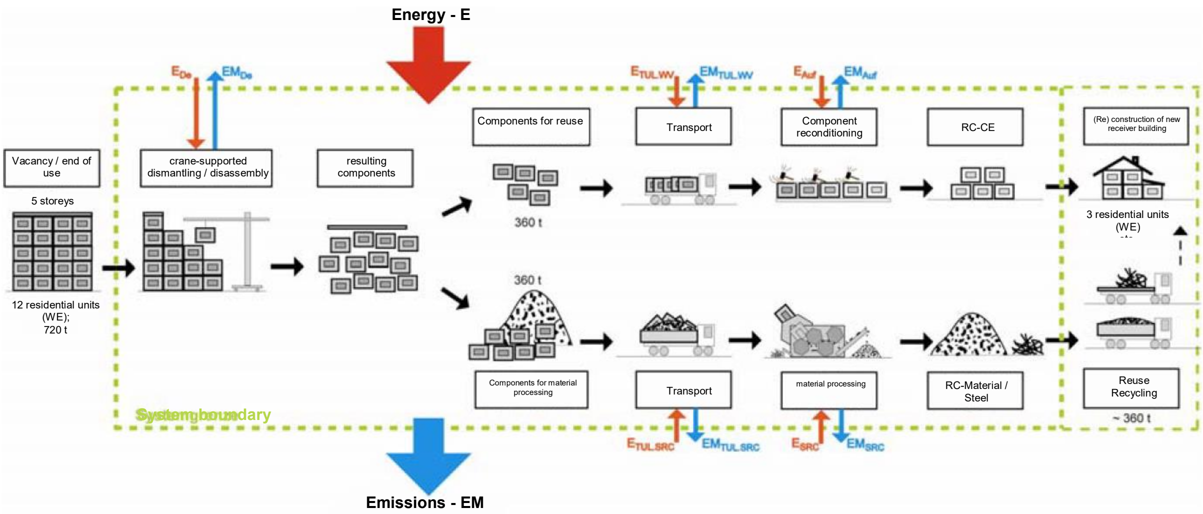


Fig. 8.1: Procedure for determining the costs and system boundaries for the eco-screening Scenario 1 "The sustainability scenario"

- Scenario 2 "The reference scenario 1"[307] (cf. Fig. 8.2) comprises the following sub-processes:

- Disassembly of the top storey, the 5. and 4. storey (12 residential units, 345 concrete elements); adequate to Scenario 1
- Pre-crushing of all dismantled CEs at the disassembly site; then transport of ~720 tonnes to the RC plant located 30 km away
- New construction of 3 single-family houses with newly manufactured 30 ceiling panels and 48 inner walls
- Assembly of the newly manufactured CE

[307] traditional process

- Scenario 3 "The reference scenario 2"[308] (cf. Fig. 8.2) includes the following sub-processes:

Since demolition of 2 storeys is not technically feasible without damaging the remaining 3 storeys, the demolition of 1 entrance over 6 storeys (= 12 residential units) is used as a basis for comparison and simplification. This requires disassembly of the adjacent CEs of the remaining stock.

- Disassembly of the adjacent CE ~195 t
- Demolition of 12 residential units incl. the top storey ~525 tonnes of concrete rubble
- Delivery of ~720 tonnes of concrete rubble to an RC plant located 30 km away
- New construction of 3 single-family houses with newly manufactured 30 ceiling panels and 48 inner walls (same as Scenario 2)
- Assembly of the newly manufactured CE

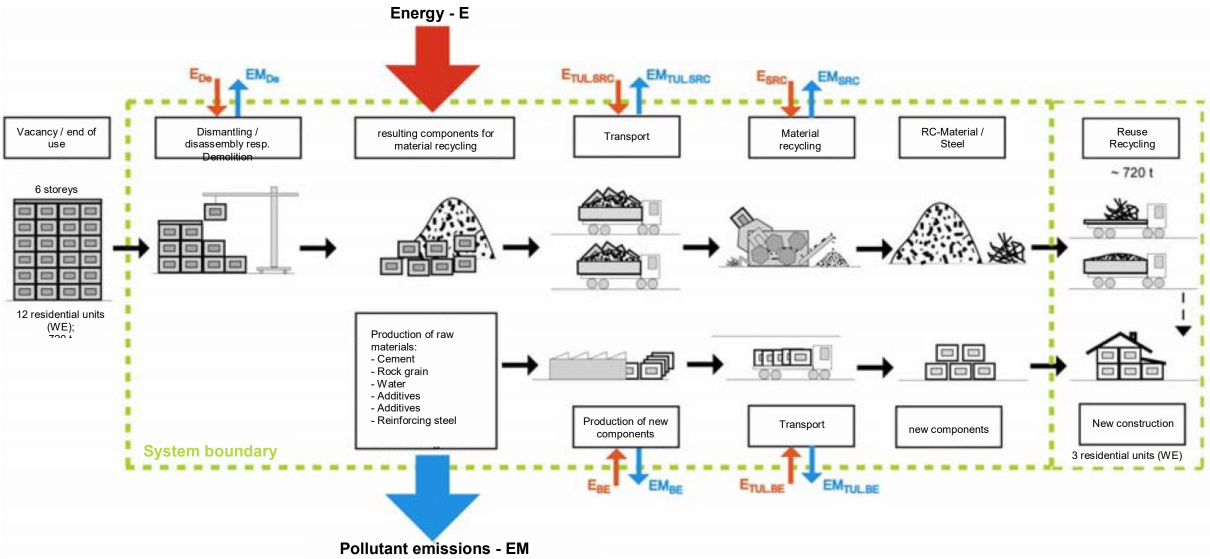


Fig. 8.2: Procedure for determination of costs and system boundaries for the eco-screening Reference Scenarios 2 and 3

The financial expenditure comprises:[309]

- in the case of Scenario 1 "The sustainability scenario"

$$K_{ges.SZ1} = K_{WV} + K_{SRC} \quad (8.1)$$

$$K_{WV} = K_{De} + K_{Bereit} + K_{Prüf} + K_{Auf} + K_{TUL} + K_{Re} \quad (8.2)$$

$$K_{SRC} = K_{Vorz} + K_{TRAPO} + K_{Anna} \quad (8.3)$$

incl.

K_{ges} Total financial expenditure

[308] traditional process
[309] cf. Mettke, Angelika: Wiederverwendung von Bauelementen des Fertigteilbaus, 1995, p. 143 ff.

K_{WV} Costs for the reuse of used concrete elements (CE)

K_{De} Disassembly costs

K_{Bereit} Costs of the the provision of used / reusable CEs at the disassembly site

$K_{Prüf}$ Costs of the analysis of the building condition (conformity test / certification)

K_{Auf} Costs of component preparation

K_{TUL} Costs of transport, transshipment and interim storage

K_{Re} Costs of reassembly

K_{Voz} Costs of pre-shredding

K_{Trapo} Costs of transport of building rubble

K_{Anna} Acceptance fees of the RC plant

and the objective

$$K_{WV} < K_{Konv}, \quad (8.4)$$

whereby, due to resource conservation reasons,

$$K_{WV} = K_{Konv} \quad (8.5)$$

the reuse variant should already be considered.

- in the case of Scenario 2 "The reference scenario 1"

$$K_{ges.SZ2} = K_{De} + K_{SRC} + K_{Konv} \quad (8.6)$$

incl. K_{Konv} Costs for conventional construction methods (new precast concrete elements, masonry, in-situ concrete, etc.)

- in the case of Scenario 3 "The reference scenario 2"

$$K_{ges.SZ3} = K_{Abb} + K_{SRC} + K_{Konv} \quad (8.7)$$

incl. K_{Abb} costs for demolition (simplified approach without consideration of the disassembly costs for the protection of the adjacent stock)

The total financial costs K_{ges} of the respective scenarios are compared.

8.1 Economic evaluation of the selected scenarios

The costs for the sub-processes are summarised according to the selected scenarios. As it has already been mentioned, the research results developed by the FG Bauliches Recycling are primarily used here without going into detail as to how the costs were derived. This has been documented in detail in Part 2 of the final research report "Deconstruction of industrial buildings - large-format concrete elements in the ecological cycle"[310]. Further information on the subject is provided in Chapter 4.8.5 and 7.6.3 of this thesis.

In addition to the costs identified so far in this thesis, the transport costs depending on the transport distance, new part prices for precast concrete parts and other common construction materials, assembly and reassembly costs as well as demolition costs are presented below.

- **Transport costs**

In 2006 and 2007, 22 offers were obtained for transport prices of DP IW and AW. Different transport distances of 30 to 300 kilometres were specified for the transport companies. Overall, it can be observed that the transport costs in relation to the quantities decrease with the increasing distance (Fig. 7.3). This is due to the effort required for the loading and unloading, which is undeniably the same. On average, € 0.20 was calculated for 1 tonne of precast concrete to be transported by truck / low-loader. When extrapolated to the component surface area, this amounts to 7 cents per km (0.07 €/m² - km).

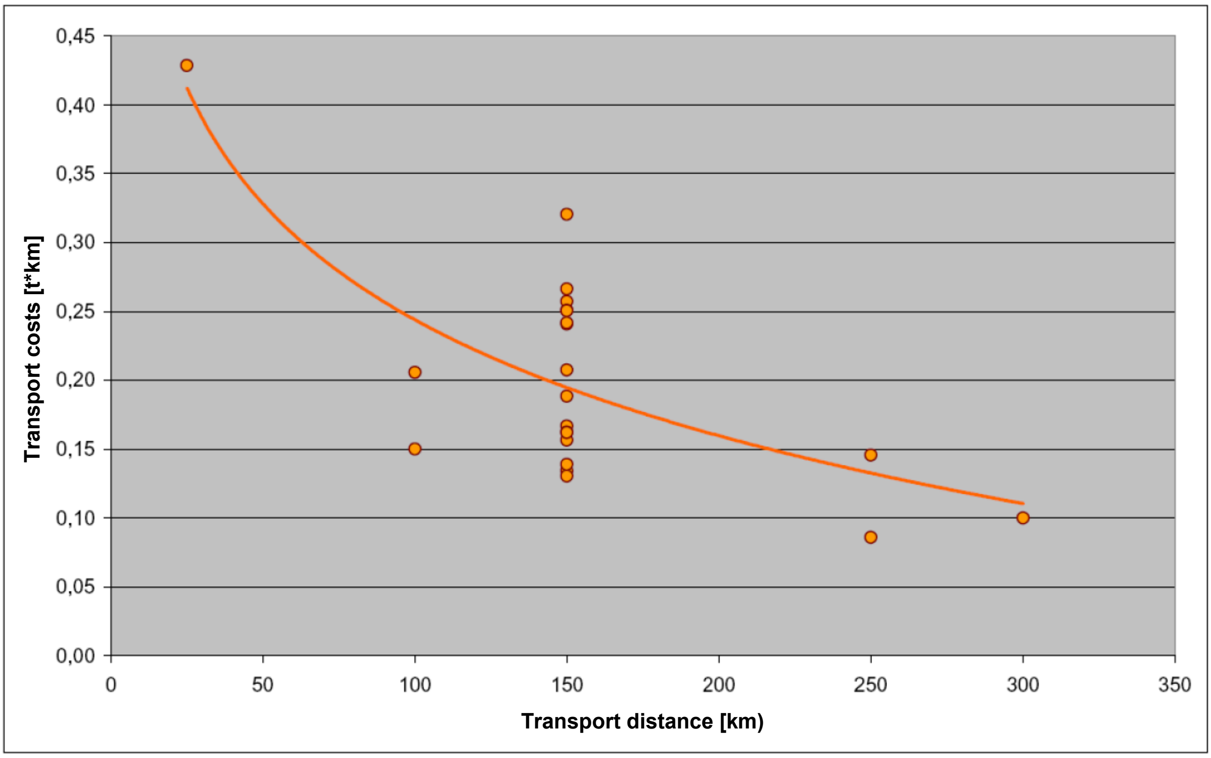


Fig. 8.3: Dependence of transport costs on transport distance by truck/low loader (2006/2007)[311]

[310] Mettke, Angelika; Heyn, Sören; Thomas, Cynthia: Final report on the research project „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf", Teil 2 Wiederverwendung und Weiterverwendung großformatiger Betonbauteile, BTU Cottbus, FG Bauliches Recycling, 2008, p. 173 ff.
[311] ibidem, p. 185

- **New part prices for precast concrete parts**

In 2007, offers were obtained from manufacturers for precast concrete elements with adequate dimensions of the concrete elements mainly used in prefabricated buildings. The offers of 6 providers are as follows[312]:

- Ceiling panels with system dimensions 6 × 3 × 0.14 m : € 686.70 to € 1,080; on average € 889.34 or ~49.40 €/m² ceiling element,
- Inne walls with system dimensions 6 × 2.80 × 0.15 m: € 576.25 to € 1,092; on average € 846.05 or ~50.36 €/m² wall,
- Inne walls with door with system dimensions 6 × 2.80 × 0.15 m : € 600 to € 1,240; on average € 894.58 or ~ 53.25 €/m² wall.

In terms of the dimensions of the concrete elements considered in the model, a new interior wall with a component surface area of 10.3 m² would cost approx. € 534 and a ceiling panel of 9.6 m² would cost approx. € 475.

- **Construction costs for the production of new ceilings and walls**

Data from BKI[313] was used as basis for K_{Konv}:

Tab. 8.2: Construction costs for ceilings and walls according to BKI

Construction method	Costs of		extrapolation of costs for inner walls (IW) and ceiling panels (DP) (selected product range)	
	Inner wall	Ceiling	IW [€ / CE]	DP [€ / CE]
Installation of new concrete elements	110 €/m²	77 €/m²	1,133	821
Solid concrete component in cast-in-situ concrete with reinforcement	83 €/m²	91 €/m²	855	970
Prestressed concrete TT ceilings with reinforcement and concrete overlay	-	160 €/m²		1,705
Sand-lime brickwork	53 €/m²	-	546	
Brickwork	69 €/m²	-	711	
Perforated brickwork	53 €/m²	-	546	
Poroton brickwork / aerated concrete blocks	62 €/m²	-	639	

[312] Mettke, Angelika; Heyn, Sören; Thomas, Cynthia: Final report on the research project „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 2 Wiederverwendung und Weiterverwendung großformatiger Betonbauteile, BTU Cottbus, FG Bauliches Recycling, 2008, p. 188
[313] BKI – Construction Cost Catalogue 2006, Part 2, Stuttgart 2006

In the case of brickwork, the application of plaster must also be taken into account, as precast concrete elements are surface-finished areas. Approximately € 14 to € 19/m² must be included in the calculation for plastering of interior wall surfaces, depending on the design.

- **Reassembly costs**

According to the subsequent calculation for the construction of three urban villas with the installation of used components assembled by means of a 25 t FZK, UNRUH / NAGORA[314] recommends a cost of € 200 / element for reassembly. In terms of the construction elements used for reuse in the model in Table 8.1, this would amount to ~ € 19 for the 6 m long ceiling panels and ~ € 18 to € 20 for the 3.58 m and 4,095 m long inner walls, for example, when applied to 1 m² of element surface.

On the basis of a pilot project, ASAM[315] calculated ~17 €/m² for wall reassembly and ~ 22.50 €/m² for ceiling reassembly. In relation to one tonne, this results in reassembly costs of approx. € 57 for the ceiling panel and approx. € 72 for the inner wall.

- **Demolition costs**

Demolition costs on average range from € 20 to € 50 per m² of living space; in some cases they are even less than 20 €/m² of living space.

The demolition costs in relation to the element surface area amount to ~€ 4 in a case study of our own.[316] Disposal costs are included here – just like in the case of disassembly costs. In terms of mass, the demolition costs for ceilings are approx. 13.50 €/t and for walls approx. 15.50 €/t, i.e., on average 14.50 €/t - 15.00 €/t.

The individual costs of the sub-processes are summarised in Table 8.3 below (all cost figures are rounded):

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[314] Unruh, Hans-Peter; Nagora, Anja: Rückbau von Plattenbauten, 2002, p. 213
[315] Asam, Claus: Untersuchung der Wiederverwendungsmöglichkeiten von demontierten Fertigteilelementen aus Wohnungsbautypen der ehemaligen DDR für den Einsatz im Wohnungsbau, EMB, Nr. 1 – 15 / 2004, p. A – 1 ff.
[316] Mettke, Angelika,; Heyn, Sören; Thomas, Cynthia: Final report on the research project „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, Teil 2 Wiederverwendung und Weiterverwendung großformatiger Betonbauteile, BTU Cottbus, FG Bauliches Recycling, 2008, p. 177

Tab. 8.3: Overview of the calculated costs for the individual items[317]

Single item		**Costs per m² of component surface [€/m²]**	**Cost per tonne of finished component [€/t]**
Disassembly of components that are suitable for reuse (incl. recycling of residual mass)	K_{De}	DP: 17.80 IW: 16.60	DP: 54 IW: 61
Demolition (incl. material preparation)	K_{Abb}	4	15
Acceptance fees for construction rubble (cf. Fig. 4.21)	K_{SRC}	DP: 1.70 - 2.70 IW: 1.36 - 2.18	5 - 8
Transport (30 km)	K_{TUL}	0.11 €/m² · km	0.35 €/t · km ≈ 11 €/t
Component reconditioning (removal of solid impurities; no building physics upgrading)	K_{Auf}	2.20	6
Building condition analysis (see Chap. 7.6.1)	$K_{Prüf}$	2	5
Reassembly wall element	$K_{Re.Wa}$	19.50	72
Reassembly ceiling panel	$K_{Re.DP}$	21	63
Provision of reusable CE	K_{Bereit}	3 - 4	DP: 9 - 12 IW: 11 - 15

Costs for the provision of used concrete elements for reuse at the disassembly construction site K_{Abgabe} without consideration of disassembly costs include the following:

$$K_{Abgabe} = K_{Bereit} + K_{prüf} \quad (8.8)$$

Costs for the used inner wall, weighing 2.8 t on average, result in KAbgabe costs of ~ € 50.40 [(€ 13 + € 5) x 2.8 t].

The cost of K_{Abgabe}, DP for the RC ceiling panel weighing 3.536 t is ~ € 57 [(€ 11 + € 5) x 3.536 t].

The difference to the new part prices for precast concrete elements amounts to ~ € 483 [€ 534 - € 51] for inner walls and ~ € 418 [€ 475 - € 57] for ceiling panels.

Furthermore, the customer has to bear the costs for the TUL processes (loading, transport, unloading) and any interim storage costs, if applicable.

If costs for disassembly of the components, including transport to the construction site located 30 km away, are considered, the following picture emerges (Fig. 8.4):

[317] ibid., revised and expanded

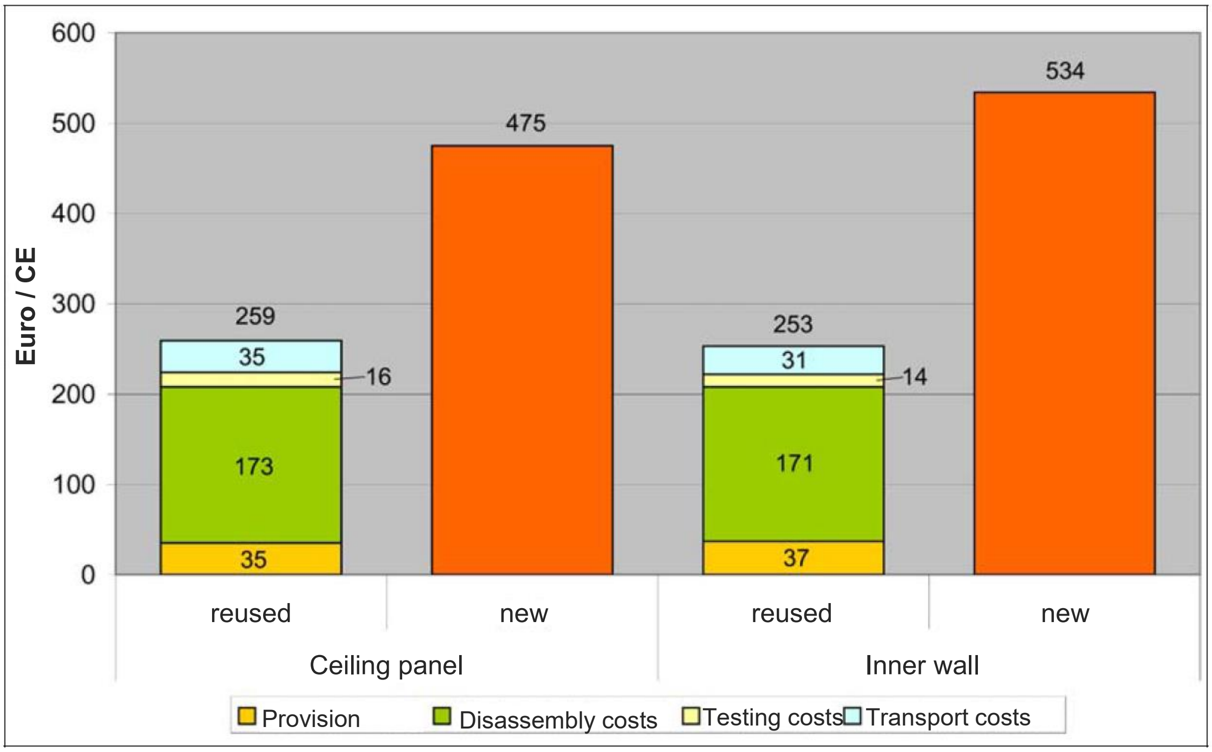

Fig. 8.4: Comparison of new part prices for concrete elements with provided, used concrete elements

This cost analysis is particularly important for building owners investing in dismantling and new construction. Cost savings of € 216 (~45%) can be achieved with ceiling reuse, and more than half of this amount can be saved per element with inner wall reuse at € 281 (~ 53 %).

This results in the following individual costs for the reuse measures KWV of 3 single-family houses to be constructed 30 km away from the disassembly construction site (Tab. 8.4):

Tab. 8.4: Costs for Scenario 1

Single item KWV (8.2) $K_{ges.SZ1}$ (8.1)	**Quantity [t]**	**Costs [€/t]**	**Total cost [€]**	**spec. Total cost [€]**
K_{De} (inkl. K_{SRC})				
DP	226	54	12,204	
IW	134	61	8,174	41,258
Remaining	360	58	20,880	
(cf. Chap. 4.8.5)				
K_{Bereit}				
DP	226	9 - 12	2,712	
IW	134	11 - 15	2,010	
$K_{Prüf}$	360	5	1,800	
K_{Auf}	360	6	2,160	28,404
K_{TUL} (only transport CE 30 km)	360	11	3,960	
K_{Re}				
48 IW	135	72	9,720	
30 DP	106	57	6,042	
		$K_{ges.SZ1}$		69,662

It should be noted that K_{De} includes the costs for K_{SRC}, i.e., the disposal costs (pre-shredding of the CE, transport of the construction waste to the RC plant, acceptance fees for construction waste). The highest amount was assumed for the provision of the components. According to (8.1), $K_{ges.SZ1\ it}$ amounts to €69,662.

The costs for Scenario 2 are composed of the following:

Tab. 8.4: Costs for Scenario 2

Single item $K_{ges.SZ2}$ **(8.6)**	**Quantity [t]**	**Costs [€/t]**	**Total cost [€]**	**spec. Total cost [€]**
K_{De}				
DP	226	54	12,204	
IW	134	61	8,174	41,258
Remaining	360	58	20,880	
(cf. Chap. 4.8.5)				
K_{Konv}				
Assembly 30 DP	106	233	24,698	
Assembly 48 IW				79,325
(see Tab. 8.2, Installation of new concrete elements	135	405	54,627	
		$K_{ges.SZ2}$		120,583

According to (8.6), this results in a total of € 235,185 for Kges.SZ2. The costs for Scenario 3 result from:

Tab. 8.4: Costs for Scenario 3

Single item $K_{ges.SZ3}$ **(8.7)**	**Quantity [t]**	**Costs [€/t]**	**Total cost [€]**	**spec. Total cost [€]**
K_{Abb} (incl. K_{SRC})	720	15	10,800	
K_{Konv}				
Assembly 30 DP	106	233	24,698	79,325
Assembly 48 IW	135	405	54,627	
	$K_{ges.SZ3}$		**90,125**	

According to (8.7), $K_{ges.SZ3}$ amounts to €190,125 excluding dismantling and cutting work.

The costs of the 3 different scenarios are summarised as follows:

Scenario 1 K_{WV}	**Scenario 2** K_{De} + K_{Konv}	**Scenario 3** K_{Abb} + K_{Konv}	K_{konv}
69,662 €	120,583 €	90,125 €	79,325 €

Thus, according to (8.4)

$K_{WV} < K_{Konv}$ $K_{WV} < K_{Abb} + K_{Konv}$

69,662 € < 79,325 € 69,662 < 90,125 €

(88 %) (100 %) (77.3 %) (100 %)

The resulting cost savings for the construction of 3 single-family houses by utilising used concrete elements in comparison to construction with new precast concrete elements amount to ~12%.

Comparison of Scenario 1 ($K_{WV} = K_{ges.SZ1}$) with Scenario 3 results in a saving of at least 23%.

If the costs for disassembly K_{De} are deducted from K_{WV}, this results in a total of € 28,404 for the provision and reassembly of the DP and IW (see Tab. 8.4). Compared to K_{Konv} at € 79,325, the cost savings for the shell construction of the single-family house with used concrete elements amount to ~64%.

If bricks were used for the walls instead of the new precast concrete elements, the calculation would deliver the following result:

Tab. 8.7: Cost comparison of wall construction in brickwork with used inner wall elements

Wall surface to be constructed for 3 single-family houses	**Costs***			**Costs [€]****	
	Brickwork	**Plaster**	**Total**	**$K_{De, IW} + K_{WV, IW}$*** **	**$K_{De} + K_{WV, IW}$*** **
495 m²	69 €/m²	16 €/m²	42,075 €	8,174 + 14,678 ∑ 22,852	41,258 + 14,678 ∑ 55,936
Percentage comparison [%]			100	54.3	133

* cf. Tab. 8.2

** cf. Tab. 8.4

*** $K_{WV, IW} = K_{Bereit, IW} + K_{Prüf, IW} + K_{Auf, IW} + K_{TUL, IW} + K_{Re, IW}$

The comparison demonstrates that, depending on the chosen approach, either savings are achieved or the costs are not offset. In this case, it would not be sufficient if only the inner walls were reused. Since the customer, as purchaser of the used CE, does not bear the disassembly costs in practice, but bears the costs directly associated with reuse (in the case of $K_{WV, IW}$ = € 14,678) the production costs are only ~35 % as compared to brickwork.

The scenarios used here as examples demonstrate that cost reductions of at least 12% can be achieved for shell construction by means of reuse.

If the costs directly associated with reuse ($K_{Bereit} + K_{Prüf} + K_{Auf} + K_{TUL} + K_{Re}$) are considered exclusively, the costs are only around ⅓ of those for new precast concrete elements that are installed.

Fig. 8.5 below summarises the costs per square metre for various construction materials to provide a quick overview and cost estimates for the shell construction of residential buildings.

This approach included the following factors:

Assortment	Weight per CE [t]	Component surface per CE [m²]	Costs* [€/t]							Costs K_{WV} [€/m²]
			K_{De}	K_{Bereit}	$K_{Prüf}$	K_{Auf}	K_{TUL}	K_{Re}	ΣK_{WV}	
Wall panel	⌀ 2.8	⌀ 10.3	61	15	5	6	11	72	170	46.20
Ceiling panel	3,536	9.6	54	12	5	6	11	57	145	53.40

* cf. Tab. 8.4

If the components are reused, a transport distance of 30 km between the donor building and the recipient building is included.

The ceiling surface covers ~320 m² for 3 single-family houses with 116 m² living space each and wall surface ~495 m².

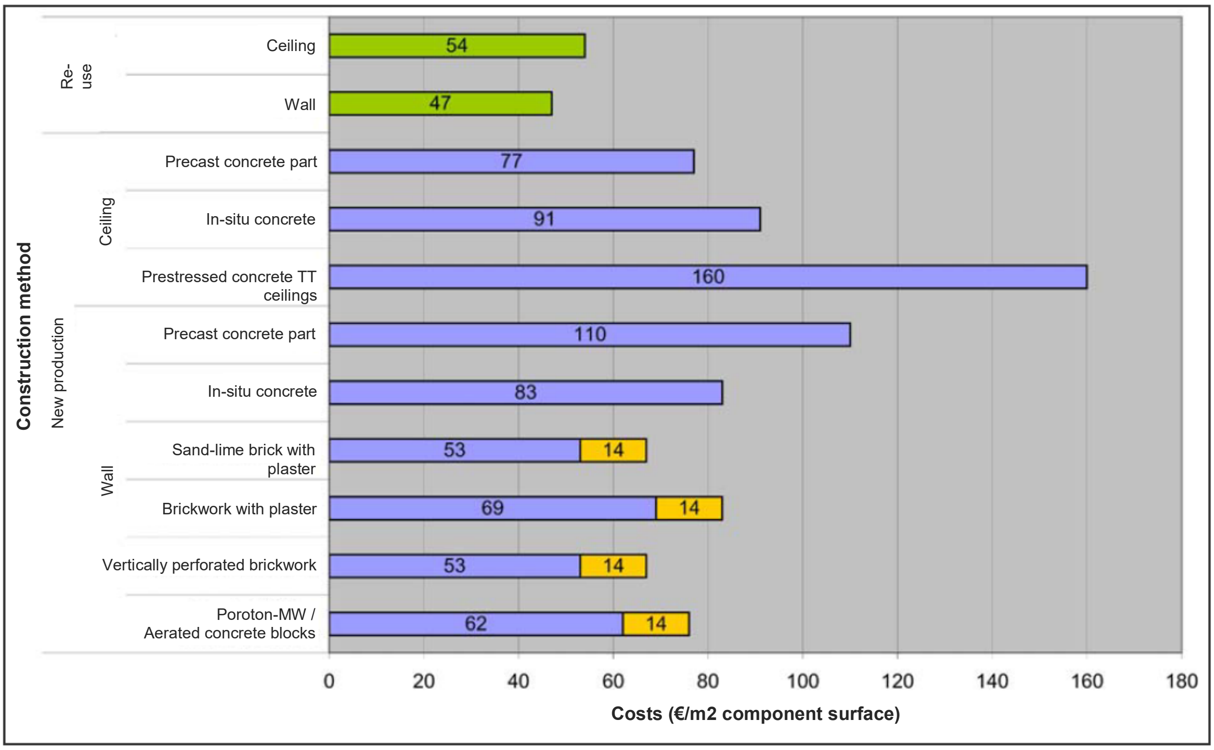

Fig. 8.5: Cost comparison of reuse with new building materials for the production of 1 m² of component surface

The construction of one square metre wall from used inner walls is € 20 less (30%) than the cheapest traditional, plastered wall construction made of sand-lime brickwork or vertically perforated brickwork.

The reuse of one square metre of ceiling (RC-DP) can save at least €23 (30%) as opposed to a comparable ceiling made with new precast concrete elements or by means of a different construction method.

The pilot project for the construction of a community centre in Kolkwitz is currently being tested to determine the extent to which the theoretical calculation corresponds to reality. A total of 40 ceilings and 39 walls (outer and inner) will be reused. The reassembly is scheduled for the 12th week of 2009.

The overall economic advantage results from comparison of the scenarios. Despite the minimal reuse rate (DP and IW) of ~35% in relation to the number of elements installed in the selected model and due to the fact that the reuse potential was not even fully utilised in the construction of the 3 single-family houses (reuse rate 27%), the reuse measure proves to be more cost-effective than conventional construction with new materials.

The next step is to analyse if the reuse also provides for a relevant ecological advantage.

8.2 Ecological assessment of the selected scenarios

8.2.1 General aspects of life cycle assessment, special features, delimitation of the scope of research

The objective of sustainable management is to integrate ecological aspects into the decision-making process alongside economic and social aspects. Following the DIN EN ISO 14040[318] and DIN EN ISO 14044[319] series of standards, the life cycle assessment (LCA) has become a valuable tool for analysing and objectifying ecological issues.

A distinguishing feature of construction materials and products such as 'buildings' as construction commodities is that they have a long service life as compared to other technical products such as TV sets, computers, cars, etc. The service life of a reinforced concrete structures is assumed to be 80–120 years. Nevertheless, there is still need for a comprehensive approach to the life cycle. Environmental life cycle assessments are primarily used as a strategic decision-making tool in the selection of construction materials as well as in the analysis and optimisation of construction products and processes. Apart from research or pilot projects, 'cradle-to-grave' analyses are fairly rare in the construction industry.

The purpose of the life cycle assessment is to record and evaluate the material and energy flows associated with the construction product and their impact on people and the environment. This involves consideration of the entire life cycle (cf. Fig. 2.3).

The environmental impact of the construction product or the 'building' as a construction product can be qualified and quantified by means of a product balance at different balance sheet levels (see Fig. 8.6). In terms of the balance sheet target, it always requires comparison with the natural (usual) influences in order to evaluate the impact. The life cycle inventory data constitutes the basis for impact assessment, e.g., greenhouse effect, resource depletion or land consumption (see Tab. 8.8).

[318] DIN EN ISO 14040: 2006-10 Environmental management - Life cycle assessment - Principles and framework
[319] DIN EN ISO 14044: 2006-10 Environmental management – Life cycle assessment – Requirements and instructions

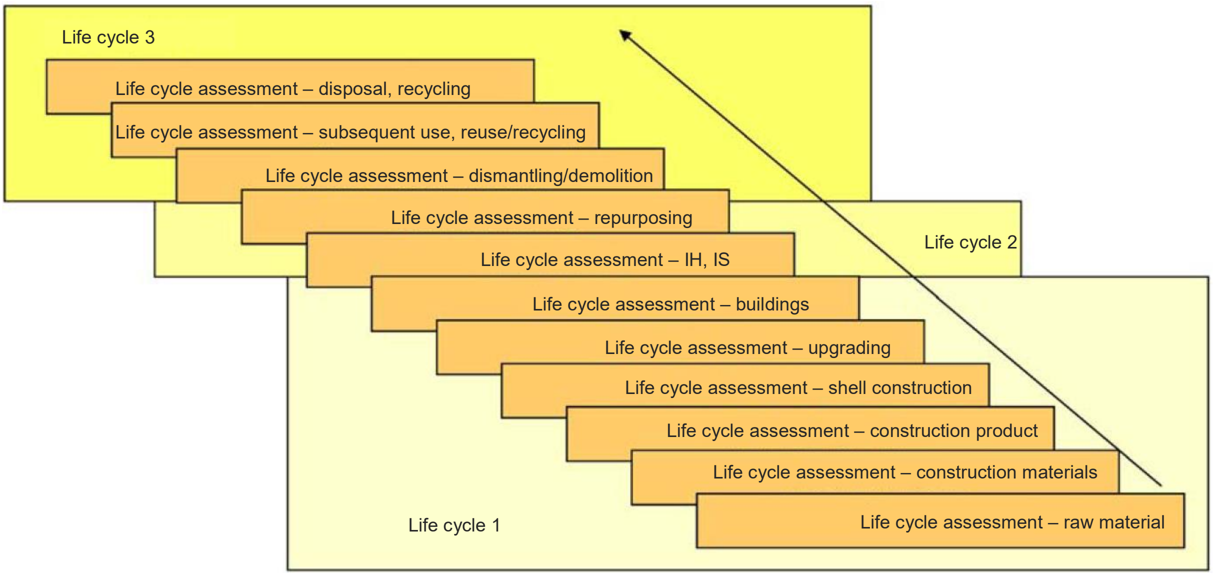

Fig. 8.6: Balance sheet levels of product life cycle assessment of buildings[320]

This modular approach requires assigned balance sheet boundaries to ensure comparability.

Tab. 8.8: Impact categories for the assessment of environmental impacts – examples[321]

Criteria of a life cycle inventory	Impact assessment	Description, examples
Demand for energy sources Demand for raw materials	Resource depletion	Utilisation of nature, land use
Land use	natural habitat	Utilisation of natural space, land use
	Land use	Factory space
Waste quantities, emission release	Global warming potential	Emissions into the air: Carbon dioxide (CO2): Influencing the thermal balance of atmosphere
	Acidification potential	Nitrogen oxides (NO_x) Sulphur dioxide (SO_2)
	Photochemical oxidant formation (summer smog)	Nitrogen oxides (NO_x)
	Toxicity	Dusts, fibre emissions

Fig. 8.1 and 8.2 below define the system boundaries for ecological screening carried out in life cycle 3. The following is an analysis and evaluation of the deconstruction or demolition phase of a section of a prefabricated building, the reuse of the reclaimed concrete elements and the disposal of the resulting rubble. The life cycle ends when the precast concrete parts are reused, recycled or disposed of.

[320] extended after Mettke, Angelika; Thomas, Cynthia: Wiederverwendung von Gebäuden und Gebäudeteilen, 1999, p. 92
[321] ibid.; cf. Graubner, Carl-Alexander; Huske, Katja: Nachhaltigkeit im Bauwesen, Grundlagen – Instrumente – Beispiele, 2003, p. 115

The investigations are limited to the installed concrete elements and/or parts of the shell structures.

The environmental impact of dismantling/demolition is significantly influenced by the depth of gutting and also depends on the technology selected by the company responsible for the work. The energy input and operating materials for the deployed machinery and equipment in the dismantling and demolition process were taken into account (Chap. 8.2.3) Additionally, the impacts/impairments from dust and noise emissions as well as vibrations (Section 8.2.5) have been recorded.

Subsequent use involves the reuse of concrete elements and utilisation of recycled aggregates, e.g., for the production of concrete.

Analysis and evaluation of the impact on the environment and people in the system is fundamental for characterisation of the ecological profile in the dismantling/demolition, reuse/recycling life cycle phase. This means that the results obtained so far in Chapters 4.10 and 9.6 have to be linked or integrated into the system. Furthermore, the feedback of the results in the system is expected to identify the main areas of influence in order for targeted countermeasures to be taken.

Material, energy and emission balances are key indicators for the assessment of life cycle 3

The following individual analyses are conducted to investigate the resource requirements and the emission load, especially the atmospherically relevant pollutants resulting from the energy generation process (CO_2, SO_2, NO_x):

- Material balancing,
- Determination of energy and energy source consumption in the individual engine-related processes,
- Determination of the atmospheric load derived from energy consumption.

Only the major energy-related processes are analysed, excluding expenditure on the manufacture of work equipment and tools.

8.2.2 Material balance

This analysis is based on scenarios 1 to 3, visualised in Fig. 8.1 and 8.2.

The assumption for the scenarios is that ~720 t of concrete mass will be produced during the dismantling of 12 residential units. The mass of the inner walls and ceiling panels, which are intended for reuse, amounts to approx. 360 t. Therefore, a minimum reuse rate is assumed, as exterior walls, loggia elements, roof cassette panels, stair elements and bathroom cells are also suitable for reuse or subsequent utilisation.

The prestressed concrete ceiling panels measuring 5.97 × 1.785 × 0.14 m were fabricated in B 300 (B 25; C 20/25) and the slack reinforced 4.17 × 1.785 × 0.14 m in B 225 (B 15; C 16/20) according to the project planning catalogue. The inner walls were constructed in B 160 (B 10; C 12/15) strength class concrete. The concrete formulation is not known. Therefore, the following standard formulations are assumed (see Tab. 8.9).

Tab. 8.9: Case study of material savings achieved by reusing concrete elements

C 12/15	kg/m³	t per m³ concrete	per t of concrete	installed in inner walls of 12 residential units [t]	for reuse, case study 16 inner walls/single-family house; 48 inner walls$_{total}$ [t] for 3 single-family houses	leftover for reuse
Cement	210	0.21	0.09		12.08	-
Aggregates	2.032	2.30	0.85	134.2 Concrete	144.07	-
Mixing water	158	0.16	0.07		9.39	-
Reinforcing steel		0.02 t	0.008		1.07	-
C 16/20				**installed in ceilings of 12 residential units, slack reinforced [t]**	**for reuse or subsequent utilisation; interim storage, if required**	
Cement	260	0.26	0.11			6.18
Aggregates	1,976	1.97	0.82	56.2 Concrete		46.08
Mixing water	164	0.17	0.07			3.93
Reinforcing steel		0.02 t	0.008			0.45
C 20/25				**Installed prestressed concrete ceilings [t]**	**for reuse Case study 10 ceiling panels/single-family house; 30 ceiling panels total**	
Cement	330	0.33	0.14		14.85	8.92
Aggregates	1,820	1.82	0.76	169.8 Concrete	80.62	48.43
Mixing water	190	0.19	0.08	(30 ceiling panels: 106.08)	8.49	5.10
Reinforcing steel		0.02 t	0.008		0.85	0.51

30 prestressed concrete ceilings and 48 inner walls are required for the 3 single-family houses considered in the model. This results in savings of ~27 t of cement, ~195 t of aggregates, ~18 t of mixing water and ~2 t of reinforcing steel. There are also 18 prestressed concrete ceilings and 24 slack reinforced ceilings available for subsequent use. This results in further savings of ~15 t of cement, ~95 t of aggregates, ~9 t of mixing water and ~1 t of reinforcing steel.

In total, the material savings from the reuse and / or subsequent use of ceiling panels and inner walls in the dismantling of a P2 type with 12 residential units over 2 storeys are as follows:

- ~ 42 t cement
- ~ 290 t aggregates
- ~ 27 t mixing water
- ~ 3 t reinforcing steel

- **Material intensity**

In view of the imbalances between the input (quantitative input of the input materials) and the output for a product (quantitative yield/end product), the MIPS indicator (material input per service unit)[322] was used to determine that the ecological backpack is 6 times higher for 1 t of precast concrete element.[323] This means that 6 t of resources have to be provided for 1 t of concrete product.

The material intensity of C 20/25 for a prestressed concrete ceiling is demonstrated as an example.

Tab. 8.10: Material intensity for a prestressed concrete ceiling of the P2 type

	Material intensity [t/t]				MIT - value table, Wuppertal Institute		
Constructio n materials	Abiotic material	Water	Air	∑ from columns 1 - 3	Material content [M-%]	Material quantity related to 1 DP [t]	Total resource consumpti on 1 DP [t]
	1	2	3	4	5	6	7
Concrete B 25	1.33	3.4	0.044	4,774	99.18	3,507	16.74
Steel	8.14	63.7	0.444	72,284	0.82	0.029	2.10
			∑			**3,536**	**18.84**

Extrapolated to the case study, the reusable ceiling panels and inner walls amount to 360.2 tonnes, or approximately 2,160 t of natural resources that could be conserved by reuse.

The more natural resources can be saved, the less land is used and the lower the energy consumption and the associated material flows and emissions.

8.2.3 Energy aspects

- **Primary energy of RC concrete elements**

The primary energy content (PEI) describes the energy consumption required to manufacture a product in megajoules (MJ)[324]. In other words, it specifies the grey energy or cumulative energy consumption of a building material (from the extraction of the raw material to the provision of the product). The cumulative energy consumption (CEC) is defined in VDI Guideline 4600[325].

According to the test results of FfE[326], the CED for the production of precast concrete elements is estimated at 3,080 MJ/t for all elements. Precast concrete elements in C 20/25 with Portland cement are used as reference.

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[322] Schmidt-Bleek, Friedrich: The MIPS concept "MIPS is a measure of how much benefit is derived from a certain amount of resource." The "ecological backpack" of lignite, for example, is ten times heavier than coal itself.
[323] Mettke, Angelika: Qualitätsmerkmale gebrauchter Betonelemente – Potenziale und Facetten der Nachnutzung, in: Tagungsband Alte Platte – Neues Design, Teil 2, ed. Angelika Mettke, BTU Cottbus, 2008, p. 199
[324] 100 MJ correspond to a calorific value of about 2.8 litres of heating oil. www4.architektur.tu-darmstadt.de/powerhouse ...accessed on 18.03.2009
[325] VDI 4600: 1997-06 Cumulative energy expenditure – Terms, definitions, calculation methods
[326] GaBiE, Forschungsstelle für Energiewirtschaft: Ganzheitliche Bilanzierung von Grundstoffen und Halbzeugen, Teil 2 Baustof-fe, 1999, p. 60

This results in 739,816 MJ of energy for the 48 used inner walls with an element mass of 134.2 tonnes and the 30 ceiling panels of 106 tonnes that were installed in the 3 single-family houses (cf. Tab. 8.11).

Tab. 8.11: Energetic content of RC concrete elements

Assortment	installed in 12 residential units [t]	reused in 3 single-family houses [t]	leftover for reuse [t]	KEA_H [MJ/t]	$KEA_{ges.}$ [MJ]
IW	134.2	134.2	-	3,080	413,336
DP	226	106	120		696,080
Total	360.2	240.2	120		1,109,416

Overall, the inner walls and ceilings contain approx. 1,109 GJ or approx. 1.11 TJ of energy. If the precast concrete parts had to be newly manufactured, then this amount of energy would have to be provided for production.

In order to generate 1,109 GJ of thermal energy, with heating values of 8.40 GJ/t for lignite, ~132 tonnes of lignite or approx. 30,805 litres of heating oil would have to be used.

If we only consider the concrete elements for the 3 single-family houses, then ~93 t of lignite or, for example, approx. 20,550 litres of heating oil would be required.

- **Disassembly/demolition of the installed concrete elements**

The energy required for disassembly and demolition work is analysed in Chap. 4.10.2 ff. The results are applied. This results in the following energy requirements for the analysed scenarios:

Tab. 8.12: Energy costs for the dismantling and demolition of 12 residential units

Dismantling / Demolition	Energy consumption [MJ]	
	per tonne*	for 12 residential units (720 t)
Disassembly by means of FZK; $E_{DE,FZK}$	157	113,040
Disassembly by means of TDK; $E_{DE,TDK}$	73	52,560
Demolition; E_{Abb}	106	76,320

* cf. Fig. 4.22

- **Material processing – material recycling**

The energy required for processing varies depending on the deployment of technical machinery. The average values provided in Table 8.13 have been considered as a general approach for the determination of energy requirements.

Tab. 8.13: Average energy requirement for sections of a processing plant for mineral construction waste[327]

Plant section	Energy sources	Energy requirement [MJ/t]
Crushing (crusher)	Electricity	2.9
Dust removal	Electricity	2.2
Classification (sieves)	Electricity	0.4
Conveyor belts	Electricity	0.2 – 0.4
Loading (wheel loader)	Diesel	4.3 – 10.5
Pollutant selection (excavator)	Diesel	36.8*
Plant average		50

* is equivalent to the deployment of an 30 t, 130 kW excavator for approx. 2 minutes at 100 % capacity.

Note: The energy requirement increases if the material is sifted by air (wind sifting) or water (cf. Tab. 9.6).

The arithmetic approach is as follows:

$$E_{SRC} = m \cdot E_{Auf} \quad (8.9)$$

E_{SRC} Total energy requirement for material recycling [MJ]

m Mass [t]

E_{Auf} Energy requirement for processing [MJ/t].

The RC plant receives 360 t of construction waste in Scenario 1 and 720 t of pre-shredded concrete elements in Scenarios 2 and 3.

Consequently, ESRC amounts to 18,000 MJ for scenario 1 and 336,000 MJ for scenarios 2 and 3.

- **Transport costs**

The energy consumption for truck transport (diesel) is estimated at 1.36 MJ/t · km on the basis of the energy and emissions data according to PROBAS (cf. Chapter 7.6).

A transport distance of 30 km results in energy consumption of ~40 MJ/t.

The energy consumption for Scenario 1 to 3 is therefore as follows:

[327] updated according to Thomas Cynthia; Birle, Andreas: Stoff- und Energieflüsse bei der Aufbereitung mineralischer Baureststoffe, Studienarbeit, LS Baustoff- und Neuwerttechnik, BTU Cottbus, 1995

Tab. 8.14: Energy requirement for truck transport: from the disassembly site – donor building or demolition site to the RC plant/construction site/recipient building/interim storage facility

Scenario	Description Truck transport from demolition site/donor building	Transport for material recycling M [t]	s [km]	KEA [MJ/t*km]	Energy consumption E_{Tul}* [MJ]
1	to the RC plant	360	30	1.36	14,688
	to the construction site	240			9,792
	to the interim storage/to the component exchange	120			4,896
2 or 3	to the RC plant	720 t			29,376

* transport only

- **(Re)assembly**

The average time required for the (re)assembly of wall elements during the construction of a community centre, which is currently in progress, was measured at approx. 10–13 minutes per wall element. Apart from the knock-on and knock-off, this includes securing the position of the element by means of assembly struts and adjusting the wall elements. The original lifting eyelets were used as attachment points. About 92% of the (re)assembly work was carried out by a 50 t FZK (mobile crane). Due to the limited space conditions, a 70 t FZK had to be deployed to achieve the required projection of 3 concrete elements.

Since the data records for (re)assembly are still far too limited, the performance of disassembly by means of FZK is applied to a simplified calculation (cf. Chap. 4.10.2). The average disassembly time for walls was estimated at 11 minutes. Thus, the time expenditure roughly corresponds to the measured reassembly times.

An energy expenditure of 157 MJ is assumed for 1 tonne of concrete to be relocated.

- **Summary of energy expenditure and comparison of the scenarios**

Tab. 8.15 is a summary of all energy expenditures determined for the life cycle under consideration, using one tonne of concrete element as a reference.

Tab. 8.15: Overview of the calculated energy expenditure per tonne of component[328]

	Energy expenditure	[MJ/t]
E_{BE}	Production of new parts*	3,080
$E_{De.FZK}$	Disassembly by means of a mobile crane	157
$E_{De.TDK}$	Disassembly by means of a tower crane	73
E_{Abb}	Demolition	106
E_{SRC}	Material processing	50
$E_{T.SRC}$	Transport to the RC plant (30 km)	40
$E_{T.BE}$	Transport of new parts (30 km)	40
E_{Re}	Reassembly by means of a mobile crane	157

*If RC material is used for concrete production, the energy input would increase by ~28 to 402 MJ/t according to Fig. 9.19.

The high energy requirement for the production of new components is evident. In this respect, it is essential to achieve the highest possible reuse rate.

The energy expenditure for Scenario 1 is composed as follows:

Tab. 8.16: Calculation of total energy expenditure for Scenario 1

Sub-processes	Energy expenditure per tonne CE [MJ/t]	Scenario 1 Component mass [t]	Scenario 1 Energy expenditure [GJ]
Disassembly of 12 residential units			
either by means of mobile crane (FZK)	157	720	113.04
or by means of tower crane (TDK)	73	720	52.56
Transport RC-C for 3 wall elements/3 single-family houses	40	240	9.60
Transport of construction debris to the RC system	40	360	14.40
Material processing	50	360	18.00
Transport RC-CE (leftover DP) to interim storage / component exchange	40	120	4.80
Reassembly RC-CE 3 WE / EFH by means of FZK	157	240	37.68
Total by means of FZK	**484**		**197.48**

[328] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Ivanov, Evgeny: Wiederverwendung von Plattenbauteilen in Osteuropa, Final report on the processing phase I of the research project „Wissenschaftliche Vorbereitung und Planung des Rückbaus von Plattenbauten und der Wiederverwendung geeigneter Plattenbauteile in Tschechien“, FG Bauliches Recycling, BTU Cottbus, as of 30.05.2008, p. 271

Total by means of TDK during disassembly	**400**	**137.08**

Scenario 2 deviates from Scenario 1 in the sense that all disassembled concrete elements are materially processed and 3 residential units or 3 single-family houses are constructed from identical new concrete elements (see Tab. 8.17).

Tab. 8.16: Calculation of total energy expenditure for Scenario 2

Sub-processes	**Energy expenditure**	**Scenario 2**	
	per tonne CE [MJ/t]	**Component mass [t]**	**Energy expenditure [GJ]**
Disassembly of 12 residential units			
either by means of mobile crane (FZK)	157	720	113.04
or by means of tower crane (TDK)	73	720	52.56
Transport of construction debris to the RC system	40	720	28.80
Material processing	50	720	36.00
Energy content of the old/RC-CE resp. new construction parts for 3 single-family houses	3,080	240	739.20
Transport of new construction parts 3 EFH	40	240	9.60
Assembly by means of FZK 3 EFH	157	240	37.68
Total by means of FZK	**3,524**		**964.32**
Total by means of TDK during disassembly	**3,440**		**903.84**

Scenario 3 follows the basic structure of Scenario 2, except that demolition is performed instead of disassembly. This variant is eliminated for the variant of dismantling storey-by-storey. This measure is only effective in the case of segmental removal of the building fabric, whereby under practical conditions the adjacent components of the remaining structure have to be dismantled for safety reasons. That would be around 60 t from the wall disassembly and ~ 135 t from the ceiling structure. Preparatory cutting work is required on the ceiling support. In this scenario, 77 running metres or ~ 11 m² of cutting work would have to be performed over 7 storeys across the building depth of approx. 11 m. The effort required for the support of the ceiling panels would have to be considered as well. This effort is not included in the following summary.

Tab. 8.16: Calculation of total energy expenditure for Scenario 3

Sub-processes	Energy expenditure per tonne of component [MJ/t]	Scenario 3 Component mass [t]	Energy expenditure [GJ]
Disassembly of adjacent CE (FZK)	157	195	30.62
Cutting work *) total			1.37
Demolition	106	525	55.65
Transport of construction debris to the RC system	40	720	28.80
Material processing	50	720	36.00
Energy content of the old/RC-CE resp. New construction parts for 3 residential units or 3 single-family houses	3,080	240	739.20
Transport of new construction parts for 3 single-family houses	40	240	9.60
Assembly by means of FZK 3 EFH	157	240	37.68
Total			**938.92**

*) Wall saw output 15 kW; effective output 0.4 to 0.8 m²/h [data from: Lippok, Jürgen; Korth, Dietrich: Abbruch-arbeiten, 2007, p. 272]; this results in an operating time of 21 h and an actual energy requirement of 315 kWh.

Comparison of energy costs for the individual scenarios (Table 8.19) demonstrates clearly that Scenario 1 is by far the most favourable variant in terms of energy consumption. The minimum possible reuse rate was assumed from the very start.

Tab. 8.19: Comparison of the determined energy expenditure of the examined scenarios

Scenario		Energy expenditure [GJ] Disassembly by means of FZK	Energy expenditure [GJ] Disassembly by means of TDK
1	Disassembly / reuse ~33 M.-% (3 EFH) / material processing	198	137
2	Disassembly / material processing / new construction 3 EFH	965	903
3	Demolition (including technological disassembly) / material processing / new construction 3 EFH	939	

Scenarios 2 and 3 show an evident, approximately 5-fold increase in energy consumption as compared to Scenario 1. There is virtually no difference in energy consumption between Scenarios 2 and 3. Scenarios 2 and 3 are indisputable from the energy perspective in comparison to Scenario 1.

8.2.4 Emissions assessment

The data records that are still required for the evaluation of the scenarios are listed below in continuation of the emissions determined for disassembly (Chapter 4.10.4).

The emission data for the provision of electricity and diesel are specified in Tab. 4.14.

- **Manufacture of concrete components**

The following climate-relevant emissions have been determined by the Research Centre for Energy Economics for the production of one tonne of precast concrete elements from standard concrete with Portland cement under steam curing:

Tab. 8.20: Energy-related emissions for new production of 1 tonne of precast concrete[329]

Precast concrete	SO_2	NO_x	CO_2
Emissions [kg/t]	0.806	0.604	394

The reuse of one tonne of concrete element prevents the emission of ~ 800 g sulphur dioxide, ~ 600 g nitrogen oxides and 394 kg carbon dioxide into the atmosphere.

Consequently, according to Scenario 1, the reuse of 240 tonnes of concrete elements for the construction of 3 single-family houses results in emissions savings of approx. 193 kg SO2, 145 kg NOx and 94.6 t CO2.

- **material processing**

According to Tab. 8.13, the energy required for processing in an RC plant is composed of 5.8 MJ/t of electricity and 44.2 MJ/t of diesel. This results in the following emissions:

Tab. 8.21: Energy-related emissions for material processing per tonne of component

Total requirement [TJ]	specific emissions [kg/TJ_{Input}] – fuel [kg/TJ_{End}] – electr. Energy			Emissions [kg/t]		
	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2
Material recycling						
Diesel: 0.000044	77,386	-	74 396	0.0034	-	3.27
Electricity: 0.000006	107,037	175,766	178 885	0.0006	0.0011	1.07
	Total			**0.0040**	**0.0011**	**4.54**

- **Transport**

The energy source for transport by truck is diesel fuel. Energy-related emissions for the transport of one tonne of precast concrete element over a distance of 30 km:

[329] GaBiE, FfE - Forschungsstelle für Energiewirtschaft: Ganzheitliche Bilanzierung von Grundstoffen und Halbzeugen, Teil 2 Baustoffe, 1999, p. 60

Tab. 8.22: Energy-related emissions from transport services

Transport of:	Mass [t]	Distance [km]	Total requirement [TJ]	Emissions [kg]		
				SO_2	NO_x	CO_2
1 t concrete component	1	1	0.0000014	0.0001	-	0.104
Scenario 1	1	30	0.000042	0.0030	-	3.12

- **Summary of energy-related emissions for the sub-processes in the life cycle under consideration**

The calculated energy-related emissions are summarised and presented below in Tab. 8.23 in relation to one tonne of precast concrete element.

Tab. 8.23: Summary of the calculated energy-related emissions for 1 t of construction component

Emissions		[kg/t]		
Abbreviation	Sub-processes	SO_2	NO_x	CO_2
EM_{De}	Disassembly			
$EM_{De.FZK}$	by means of a mobile crane (FZK)	0.012	-	11.7
$EM_{De.TDK}$	by means of a tower crane (TDK)	0.007	0.012	12.8
EM_{Trapo}	Transport 1 km truck	0.001	-	0.104
EM_{Abb}	Demolition	0.008	-	7.9
EM_{SRC}	Material processing	0.004	0.0011	4.54
EM_{BE}	New production of components	0.806	0.604	394
EM_{Re}	Reassembly (FZK)	0.012	-	11.7

For the individual Scenarios 1 to 3, the following emissions are obtained for the case study used as an example:

Tab. 8.23: Summary of the calculated energy-related emissions for Scenario 1

Scenario 1 Sub-processes	Component mass [t]	Emissions [kg] SO_2	 NO_x	 CO_2
Disassembly of 12 residential units				
either by means of a mobile crane (FZK)	720	8.64	-	8,424
or by means of a tower crane (TDK)	720	5.04	8.64	9,216
Transport RC-CE for the construction of 3 EFH (30 km)	240	0.24	-	24.96
Transport of construction debris to the RC plant (30 km)	360	0.36	-	37.44
Material processing	360	1.44	0.396	1,634.40
Transport RC-CE (leftover DP) to interim storage / component exchange	120	0.12	-	12.48
Reassembly RC-CE 3 EFH (FZK)	240	2.88	-	2,808
Total emission with FZK		**13.68**	**0.396**	**12,941.28**
Total emission with FZK		**10.08**	**9,036**	**13,733.28**

In Scenario 2, the emissions from disassembly are considered just like in Scenario 1, whereby the disassembled components are completely materially recycled and the precast concrete components are newly produced for the new construction.

Tab. 8.23: Summary of the calculated energy-related emissions for Scenario 2

Scenario 2 Sub-processes	Component mass [t]	Emissions [kg] SO_2	 NO_x	 CO_2
Disassembly of 12 residential units				
either by means of a mobile crane (FZK)	720	8.64	-	8,424
or by means of a tower crane (TDK)	720	5.04	8.64	9,216
Transport of construction debris to the RC plant (30 km)	720	0.72	-	74.88
Material processing	720	2.88	0,792	3,268.80
New production CE for 3 EFH	240	193.44	144.96	94,560
Transport CE for 3 EFH (30 km)	240	0.24	-	24.96
Assembly CE by means of FZK 3 EFH	240	2.88	-	2,808
total for disassembly with FZK		**208.80**	**145,752**	**109,160.64**
total for disassembly with TDK		**205.20**	**154,392**	**109,952.64**

The energy-related emissions for Scenario 3 are displayed in Tab. 8.26

Tab. 8.23: Summary of the calculated energy-related emissions for Scenario 3

Scenario 3 Sub-processes	Component mass [t]	Emissions [kg] SO_2	 NO_x	 CO_2
Disassembly of CE adjacent to the existing building (FZK)	195	2.34	-	2,281.50
Demolition 12 WE	525	4.20	-	4,147.50
Transport of construction debris to the RC plant (30 km)	720	0.72	-	74.88
Material processing	720	2.88	0,792	3,268.80
New production CE for 3 EFH	240	193.44	144.96	94,560
Transport CE for 3 EFH (30 km)	240	0.24	-	24.96
Assembly CE by means of FZK 3 EFH	240	2.88	-	2,808
Total		**206.70**	**145,752**	**107,165.64**

Table 8.27 summarises and compares the emissions determined for the individual scenarios.

Tab. 8.23: Summary of the calculated energy-related emissions for all scenarios

Scenario			Emissions [kg] SO_2	 NO_x	 CO_2
1	Disassembly / reuse ~33 M.-% (3 EFH) / material processing				
		$EM_{De.FZK}$	13.70	0.40	12,941
		$EM_{De.TDK}$	10.10	9.04	13,733
2	Disassembly / material processing / new construction 3 EFH				
		$EM_{De.FZK}$	208.80	145.75	109,160
		$EM_{De.TDK}$	205.20	154.39	109,952
3	Demolition (incl. technological dismantling) / material processing / new construction		206.70	145.75	107,165

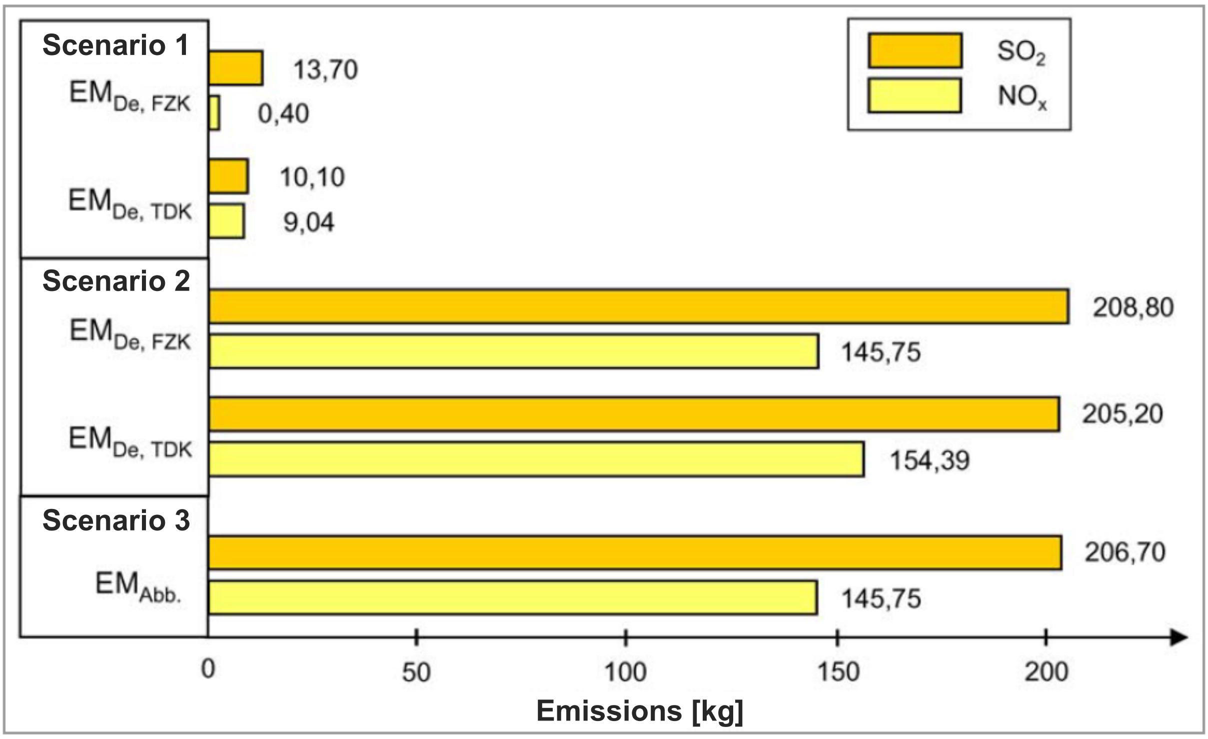

Fig. 8.7: Comparison of the determined energy-related SO2 and NOx emissions for the individual scenarios

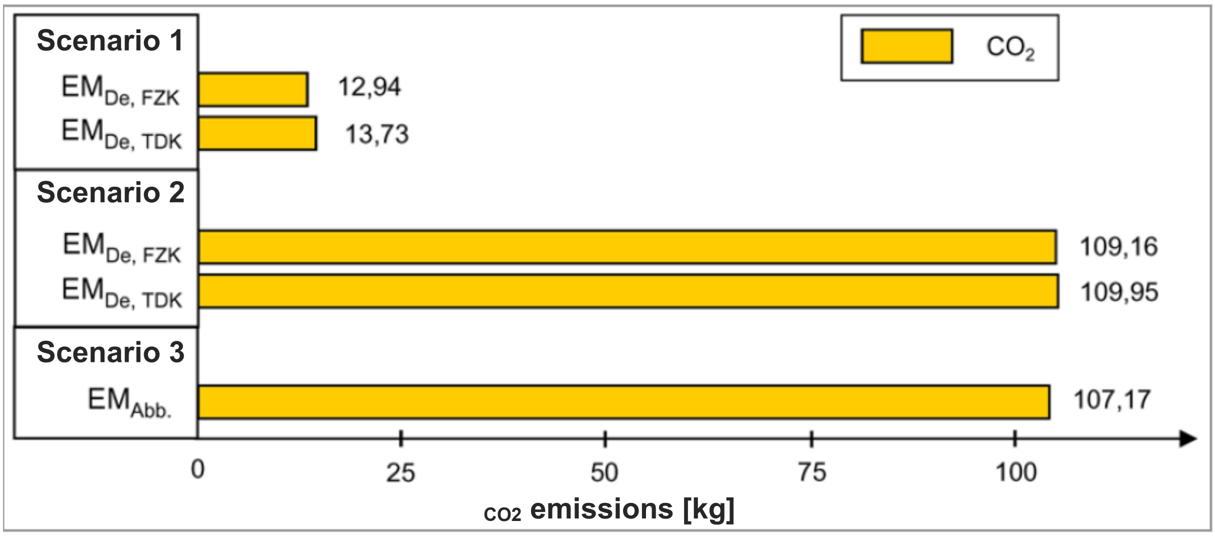

Fig. 8.7: Comparison of the determined energy-related CO2 emissions for the individual scenarios

The reuse of the disassembled inner walls and a part of the disassembled ceilings from the 12 dismantled residential units used e.g., for the construction of 3 single-family houses reduces the emissions to a considerable extent as compared to conventional procedures (Scenarios 2 and 3). Scenarios 2 and 3 include the production of new precast concrete elements for reasons of comparability. The energy requirements for the production of precast concrete elements are very high and the height of these requirements correlates with the emission rate, resulting in high climate-relevant emissions as expected. The CO2 emission rate for scenarios 2 and 3 is determined to ~87% by the new production of precast concrete elements. New production is even responsible for ~93% of the acidification potential.

The rough calculation of new production to construct walls as brickwork results in ~2,220 MJ/t (PEI 1,487 MJ/m³)[330] with a global warming potential of 133 kg/m³ for a wall thickness of 36.5 cm. The mortar has to be included. In this respect, there is no significant reduction in emission rates.

In further life cycle assessments, the various types of MW formations for the construction of walls as well as alternative ceiling constructions (cf. Fig. 8.5) have to be considered.

8.2.5 Investigations into noise, dust pollution and vibrations in demolition and dismantling work

Measurements of noise, dust and vibrations were conducted as part of the research project "Dismantling industrial building fabric - large-format concrete elements in the ecological cycle "[331] in the course of dismantling or removing (demolishing) several prefabricated buildings. The focus was not only on identifying the impact on the labour force, but also on recording the environmental impact and the impact on residents in adjacent buildings as well as public traffic.

The research results are documented in detail in the research report.[332] The results obtained are presented below in compressed form.

- **Noise exposure in the neighbourhood of the disassembly and demolition site**

Noise measurements were carried out in eight locations. Since sound intensity varies depending on the source, the measured noise values were averaged over time. The resulting measurement data was expressed as the equivalent continuous sound level Leq.

The measurements were performed randomly at different times of the day, in different weather conditions and at different wind speeds. The measurement times varied consistently between 1 and 1.5 hours. The respective measuring points had to be determined on site and were located at a distance of approx. 30–35 m and 50 m away from the emission source.

Noise pollution was assessed during crane-guided dismantling, during a combination of demolition and disassembly as well as during demolition.

It was observed that the excavator is the dominant noise source even during crane-guided dismantling. Chiselling work to open the joints between the concrete elements requires the use of a mini excavator in the dismantling object. Apart from that, excavators are used for pre-crushing of the concrete elements on the disassembly site.

The pulsating noises result from dropping or impacting the panels and from loading processes. Furthermore, road traffic noise was also a contributing factor.

The measurement results L_{eq} are presented in summarized form as follows:

[330] Eyerer, Peter; Reinhardt, Hans-Wolf: Ökologische Bilanzierung von Baustoffen und Gebäuden – Wege einer ganzheitlichen Bilanzierung, 2000, p. 80
[331] Mettke, Angelika; et.al.: Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf, gefördert vom BMBF, Projektlaufzeit: 04/2000 – 03/2007, BTU Cottbus, LS Altlasten, FG Bauliches Recycling
[332] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Krangeführter Rückbau, Part 1 of the final report „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, 2008, p. 176 ff.

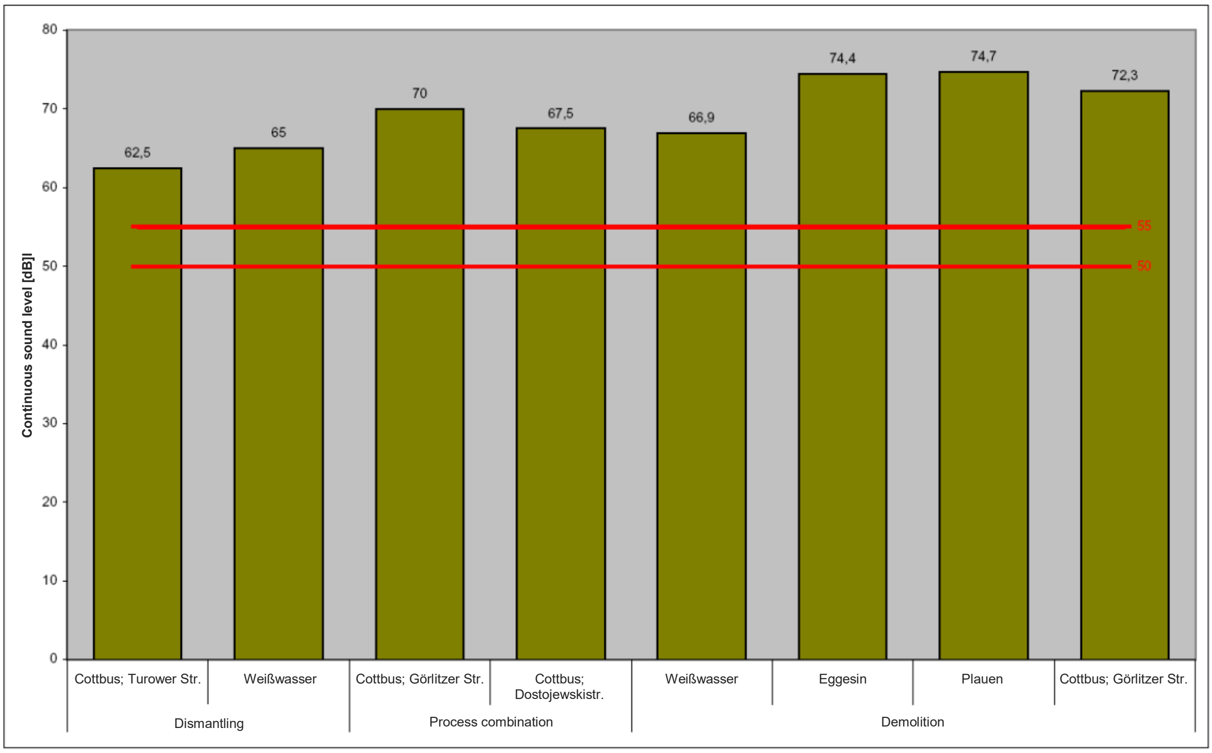

Fig. 8.9: Summary of the results of the noise measurements (Leq mean values)[333]

The question of possible harmful environmental effects (hazards, significant disturbances and impairments) for the residents will be evaluated in accordance with the General Administrative Regulation for Protection against Construction Noise – Noise Emissions (AVV Baulärm)[334].

Fig. 7.2 8.9, the immission reference values are marked in red. In areas that are predominantly residential, 55 dB (A) applies during the day, and 50 dB (A) applies in areas that are exclusively residential.

Comparison of the calculated noise levels of the various technologies deployed against the specified immission reference values demonstrates that the requirements were not met by any of the technologies. Although in the case of dismantling (without pre-crushing) the Leq is approx. 14 to 16 % lower as compared to demolition, the required sound pressure level is still exceeded. Reference is made here to the AVV Construction Noise, which contains examples of mitigation measures if the immission values are exceeded by 5 dB (A). Options for reduction are also listed in the final report on the research project "Deconstruction of industrial buildings – large-format concrete elements in the ecological cycle", Part 1.

Continuous noise exposure can be ruled out, since dismantling and demolition work is always limited in time, naturally influenced by the scope of the project, and work was discontinued daily by 6 p.m. at the latest. Consequently, noise that could be harmful to health is not generated.

[333] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Krangeführter Rückbau, Part 1 of the final report „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf“, 2008, p. 185
[334] General administrative regulation for protection against construction noise – noise immissions as of 19 August 1970

- **Dust contamination**[335]

Dust contamination is unavoidable when carrying out demolition work and loading operations. Water is used as a wetting and atomising agent to reduce the amount of dust during demolition.

The following measurement results reflect the investigations of dust measurements during demolition work on industrially constructed buildings and during sandblasting and construction cleaning work. The results of the investigation are comprehensively documented in the final report "Demolition of industrial buildings – large-format concrete elements in the ecological cycle", Part 1[336].

Dust exposure measurements were carried out during demolition in three different locations. Similar to the noise measurements, random measurements were carried out in a time period of about 1 hour each. The primary collection device was always positioned in the prevailing wind direction.

The analysis of the filter samples in a laboratory with stable climatic conditions

- revealed ~12.71 mg/m³ air for the demolition of a residential building in strip construction and
- for the dismantling / demolition of prefabricated residential buildings approx. 0.54 to 0.87 mg/m³ (crane-guided dismantling) and 4.82 mg/m³ air (demolition).

This means that the dust threshold values according to TRGS 900[337] for the inhalable fraction (E) (old: "total dust" G) of 10 mg/m³ air during the demolition of prefabricated buildings are significantly reduced, resulting in no potential health hazards.

The higher dust exposure during demolition of strip construction results from the plaster layer on the inside and outside of the walls.

The measurement results, obtained during sandblasting work on the façade of a block of flats, are demonstrated, due to the fact that such measures are required by architects for reconditioning work on concrete elements, subject to secondary utilisation requirements.

According to TRGS 906[338], work activities involving the exposure of employees to respirable dusts, including crystalline silicon dioxide (SiO2) in the form of quartz[339], are to be classified as carcinogenic. This means that fine quartz dust must be treated as a hazardous substance in accordance with Section 3 (2) No. 3 GefStoffV.

The hazard from fine quartz dust refers to A dust. Quartz, also in the form of fine dust, is chemically inert.

The occupational exposure limit value for the respirable fraction of silicogenic dusts of 0.15 mg/m³ of air previously stipulated in TRGS 900 has been withdrawn. The current TRGS 900 specifies 3 mg/m³ for A dust instead.

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335 Definition of dust according to BGI 5047 Mineral dust: "Mineral dust is a dispersed distribution of solid substances in the air, created in particular by mechanical processes or by being whirled up. A distinction is made between the respirable (A fraction, A dust; formerly: fine dust) and the inhalable dust fraction (E fraction, E dust; formerly: total dust).

336 Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Krangeführter Rückbau, Part I of the final report „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf", 2008, S. 191 ff.

337 TRGS 900 Occupational exposure limits, edition January 2006, last amended and supplemented in June 2008

338 TRGS 906 List of carcinogenic activities or processes according to § 3 para. 2 No. 3 GefStoffV, July 2005 edition, last amended and supplemented in March 2007

339 Quartz: is a natural, rock-forming mineral and is widespread in our natural environment. Quartz serves as construction material as well as raw material for the ceramic, glass and cement industries. [http://www.euroquarz.de, accessed on 22.03.2009]

If the value of 0.15 mg/m³ is nevertheless used as a benchmark for the risk assessment, then the value was exceeded by 3.5 times during blasting of the loosened concrete components and by 5 times during sweeping of the blasting agent and the concrete components, especially the cement paste.

The analysed material samples exhibited different quartz concentrations. However, no analysis was performed to determine whether the abrasive contained more than 2% by weight (permissible ≤ 2% by weight) of free crystalline silica.

A generalisation of these results is not possible, however, due to the limited analysis results.

Mitigation measures for dust pollution can be found in BGI 5047[340], the practical guide "Quartz fine dust "[341] or the final report "Dismantling industrial building fabric - large-format concrete elements in the ecological cycle "[342].

- **Vibrations**

Measurements of vibrations that occur during demolition work were performed. The primary aim was to determine whether the adjacent buildings could be damaged. Apart from the usual vibration loads that occur during demolition work involving excavators, an extreme case has been deliberately created and tested. The heaviest installed concrete element (outer wall panel) was dropped from the 11th storey.

The measurements and calculations of the vibrations at a distance of 25, 50, 75 and 100 m from the vibration centre do not have a damaging effect on the adjacent residential buildings, even if the most extreme vibration event occurs. The results are proven in detail.[343]

8.3 Summary and discussion of the scenario results

Concrete element recycling was compared with material recycling from an economic and ecological point of view against the background of achieving higher resource productivity and optimised marketing.

Disassembly involving reuse and/or subsequent utilisation ("sustainability scenario") was compared, balanced and evaluated against disassembly or demolition with recycling and new construction ("reference scenarios") on the basis of practical scenarios. The impact of the sub-processes on the environment and humans was considered in the characterisation of the ecological profile.

Life cycle 3 of a building structure was analysed, starting from partial deconstruction or demolition to reuse and/or including processing of the construction waste (cf. Fig. 8.1; 8.2; 8.6). Only the shell construction was analysed on the basis of the 3 different scenarios.

The practical interest of the buyer/customer is the extent to which costs can be reduced by utilisation of used components. It was established that approx. € 51 would be required for the provision of the concrete elements on the disassembly site (excluding disassembly costs), and approx. € 57 for a 1.80 m wide prestressed concrete ceiling panel (system dimension). Compared to new part prices of around € 534 for an inner wall and € 475 for a ceiling panel, the RC-IW costs 1/10 and the RC-DP only 1/8 of that amount. However, costs for the transport to the recipient building for (re)assembly of the used precast concrete parts have to be included. Given a transport distance of 30 km, the inner walls would

[340] BGI 5047 Mineral dust, December 2006 edition, p. 11
[341] NePSi: Good Practice Guide on workers' health protection through good handling and utilisation of crystalline silica and silica-containing products, Good Practice Guide - Crystalline Silica (Good Practice Guide), September 2006
[342] Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Krangeführter Rückbau, Part I of the final report „Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf", 2008, p. 200 ff.
[343] ibid., p. 203 ff.

incur cost of ~11 €/t for transport, 72 €/t for reassembly and 6 €/t for preparation (cf. Tab. 8.4) This is approx. € 249 per inner wall with an average weight of 2.8 t. The total costs for the installation of an inner wall are approx. € 300 (approx. 10.3 m² component surface). The construction of a new precast concrete wall costs € 793 in comparison (cf. Tab 8.5). In this respect, the costs are reduced by more than half when an inner wall is reused.

If the reuse of a prestressed concrete ceiling is considered, the costs for transport (11 €/t), reassembly (57 €/t) and processing (6 €/t) total ~€ 319 (10.7 m² component surface). The difference to the installation of a new ceiling panel at ~€ 824 is therefore ~€ 505. In this case, the costs only amount to around ⅓.

The financial advantage for the building owner is therefore clearly demonstrable.

Implemented projects exhibit 10-41% lower shell construction costs than conventional designs due to the reuse of RC concrete components.

Even if the overall "sustainability scenario" process is considered, from dismantling to reuse, ~56% is saved on an inner wall and ~30% on the installation of a ceiling as compared to traditional designs.

Comparison of the scenarios considered as examples demonstrates that partial deconstruction and reuse results in a cost advantage of 12% in comparison to new construction and nearly 33% in comparison to demolition and new construction.

Maintaining the added value of the ready-to-use concrete elements results in an economic advantage. The amount of this advantage is significantly influenced by the reutilisation rate.

Calculations of the energy costs resulting from the deployment of the main machinery and equipment for the individual scenarios indicate that disassembly (FZK) coupled with the reuse of the dismantled concrete elements (in the case under consideration only ~33% of the mass) and material processing of the remaining construction waste would reduce the energy costs by ~80% as compared to disassembly with material processing of the construction waste and new construction (equivalent to reuse). Compared to demolition with material processing and new construction, there is practically no difference in terms of energy consumption.

If Scenario 1 "Sustainability scenario" is considered, the energy required for the reuse of one tonne of precast concrete element by means of FZK amounts to ~484 MJ. In contrast, the energy input for one tonne of concrete elements, for example, is 3,080 MJ (cf. Tab. 8.16). Comparison of Scenarios 1 (disassembly, reuse, material processing) and 2 (disassembly, material processing, new construction) reveals an energy saving of 3.04 GJ per tonne in the case of reuse. When extrapolated, the saving for a prestressed concrete ceiling panel of 3.536 t is 10.75 GJ.

The following theoretical comparison may be of interest: The energy requirement of a 2-person household (2-P household) is around 2,800 kWh[344] or 10,080 MJ (10.08 GJ) per year. In comparison, the reuse of a single prestressed concrete ceiling panel could supply a 2-person household with enough energy for a whole year.

[344] Average household electricity consumption per year by household size in Germany:
1-P household approx. 1,600 kWh
2-P household approx. 2,800 kWh
3-P household approx. 3,900 kWh
4-P household approx. 4,500 kWh
[Source: VDEW, at http://www.energiesystem.de/Auswahl..., accessed on 24 March 2009]

The following comparison is also environmentally relevant: 3,080 MJ of energy are required for the production of one tonne of precast concrete. Assuming that 1 litre of heating oil produces 42,700 kJ, then ~72 litres of heating oil are required for 1 tonne of precast concrete. The provision of used concrete elements for reuse, on the other hand, requires only 3.7 litres/t of precast concrete element (c.f. Tab. 8.15).

Projected onto an inner wall, 202 litres of heating oil are generally required and 255 litres for a ceiling panel (6 m x 1.80 m system dimensions). In contrast, a used inner wall contains only 10 litres and a ceiling panel 13 litres. This means that only around 5% of the energy is required for reuse in comparison to the new part.

The 3 single-family houses with 30 ceiling panels and 48 inner walls constructed in the sustainability scenario would result in savings of 16,476 litres of heating oil as compared to the delivery of new precast concrete elements. In other words, instead of 17,346 litres of heating oil, 870 litres of heating oil are required.

The level of energy consumption correlates with the release of emissions. The SO2 emissions of Scenario 2 (disassembly, material processing, new construction) and Scenario 3 (demolition, material processing, new construction) are around 15 times higher than Scenario 1 (disassembly, reuse, material processing). The CO2 emissions of Scenarios 2 and 3 are a solid 8 times higher than Scenario 1. New production of precast concrete parts is responsible for the high emission rate in Scenarios 2 and 3. A reduction in pollutants is demonstrably achieved by reuse of concrete elements.

Moreover, reuse enables conservation of natural resources. The reuse of a single prestressed concrete ceiling panel, for example, eliminates the need to use 21 t of natural raw materials. Land consumption is reduced and material flows are minimised simultaneously.

In addition to the above-mentioned air pollutants, the influences of machine-related emissions and immissions, as well as their impact on the environment and human health also include irritating environmental factors such as noise and fine dusts. As humans and the environment are never exposed to just a single pollutant or a single pollution factor, the interaction of these should at least be emphasised. The noise measurement results for crane-guided dismantling of prefabricated buildings are lower than for demolition, although the immission values have been exceeded in general. However, the noise levels during demolition work are around 10 dB (A) higher than during crane-guided dismantling. Dust emissions during demolition are, despite wetting the building with water, 5 to 9 times higher than those measured during crane-guided dismantling. Increased dust exposure was observed during the demolition of residential buildings constructed by means of the strip construction method as a result of internal and external plaster layers. For this reason, it is essential to include appropriate mitigation measures for dust pollution in the preparatory phase of the project.

No vibrations occur during crane-guided dismantling. However, vibrations measured during conventional demolition work did not have a damaging effect on the adjacent residential buildings.

9 *Recycling of building materials*

10 Modern, future-oriented developments for waste prevention in building construction

In the following, reference is made to modern, future-orientated developments in waste prevention in building construction [12], [20], [21], [30].

10.1 Introduction

Strategies are required when dealing with ecological issues that are primarily directed towards preventive environmental protection and only secondarily towards subsequent protection (cf. Fig. 2.4).

Each construction activity and utilisation of a building/property has an impact on the environment (c.f. Chap. 8.2). Therefore, the consideration of ecological aspects has become indispensable. However, limiting the ecological approach merely to selecting the right construction materials and type of construction contradicts the integral approach of ecological building.

This leads to the question: Which buildings are sustainable/future-oriented and contribute to waste prevention in building construction?

The following protection goals can be demonstrated as examples of sustainability in the construction sector:

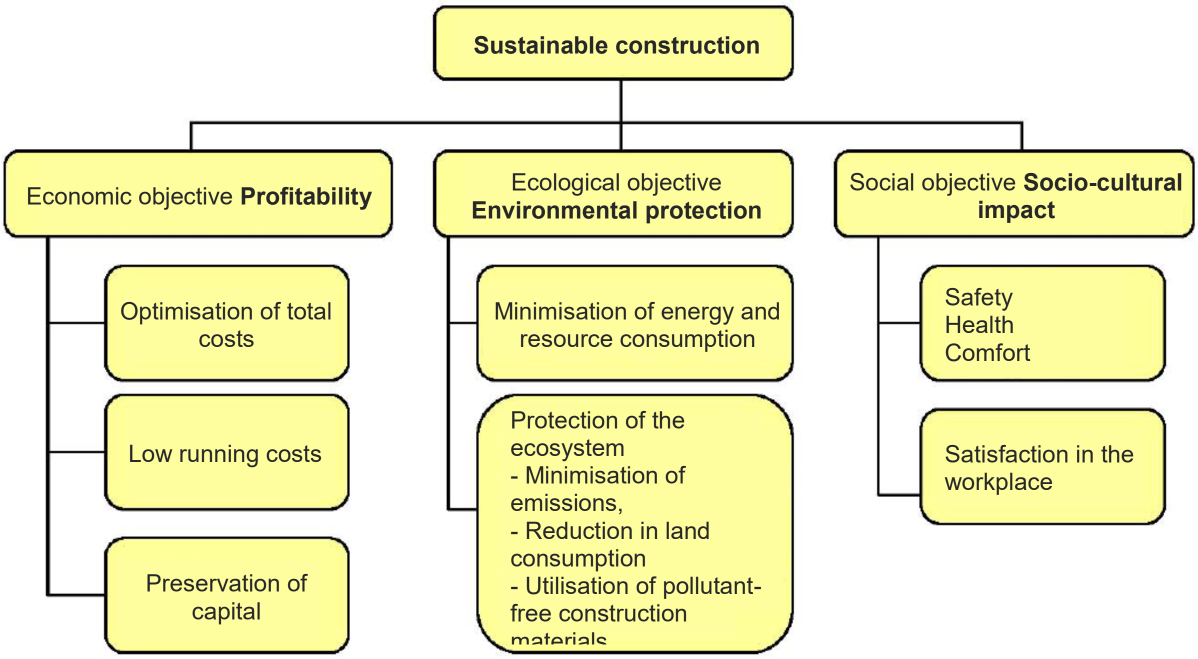

Fig. 10.1: Examples of objectives for sustainable construction[473]

[473] cf. the three-pillar concept of sustainable construction at http://www.bbr.bund.de,
Vogdt, Frank: Bewertung der Nachhaltigkeit von baulichen Maßnahmen, Erstbewertung entsprechend des Leitfadens Nachhaltiges Bauen des Bundesministeriums für Verkehr, Bauen und Wohnungswesen, PP-Presentation; Mettke, Angelika; Heyn, Sören; Asmus, Stefan; Thomas, Cynthia: Rückbau industrieller Bausubstanz – Großformatige Beton-elemente im ökologischen Kreislauf, Teil 0 Zielstellung und Zusammenfassung der wissenschaftlich-technischen Ergebnisse des Forschungsvorhabens, BTU Cottbus, LS Altlasten, FG Bauliches Recycling, 2008, p. 9

The spectrum of the various dimensions of sustainable construction thus demonstrates complexity and interaction. The focus is on minimising the energy and resource consumption for all life cycle phases of the building. Each individual planning/implementation step must be scrutinised with regard to economic efficiency and not just the overall economic efficiency of the project. Furthermore, health protection, comfort and the overall design of a residential property have a significant role to play.[474]

This means that all criteria in each life cycle (cf. Fig. 8.6), such as ensuring quality and durability/safety, functionality, cost-effectiveness and design, have to be aligned with the criteria of health and environmental compatibility. The specific requirements and framework conditions of a particular project should therefore be taken into account in a balanced manner. In the initial planning stage of a construction project, the opportunity to exert influence on all dimensions, including costs, is at its maximum.

The special feature of a property as compared to other industrial products is its lifespan and, in principle, its immobility.

10.2 Challenges and objectives for a sensible, modern and ecologically oriented recycling of construction elements and materials

High volume of construction waste in Germany (cf. Chap. 9.1, Fig. 9.4) and the amount of ready-to-use concrete elements generated during crane-guided dismantling (cf. Chap. 3 and 4) clearly demonstrate the significance of material and product recycling.

Since the Closed Substance Cycle and Waste Management Act came into force, the requirement to prevent waste also applies to the dismantling of buildings. Possible avoidance measures at source with regard to the reduction of waste quantities and their hazardousness are discussed in section 2.2. Furthermore, the following tasks are considered for material and product recycling: High-quality recycled construction materials, which are produced, e.g. during shredding of reinforced concrete elements, and dismantled ready-to-use concrete elements constitute an economic asset that is expected to become even more important in the future. New standards for waste utilisation have been defined by the Federal Soil Protection Act, the Soil Protection and Contaminated Sites Ordinance and the Federal Water Act, all of which take priority over waste legislation when it comes to recycling. Stricter recycling requirements for unbound use of RC aggregates in road and path construction are likely to be limited, and this would lead to an increase in the amount of material going to the landfills. In view of these changes, the recycling path in building construction could be a resource-relevant alternative. Although there are technical regulations and guidelines for the utilisation of RC aggregates in concrete construction, the use of RC concrete in building construction has hardly progressed beyond applications within the scope of research and pilot projects. There is a deficit in high-quality utilisation, as the quality of RC aggregates is not optimally utilised. This is why it is also referred to as 'downcycling.'

This issue is to be addressed, among other things, in the joint project on a construction plan with the use of approx. 500 m³ of RC concrete in order to establish sustainable development in RC concrete construction on a broad scale. The efficiency of suitable dismantling and processing methods and their influence on the quality of the material batches is evaluated in order to minimise the cost factor.

Quality monitoring is a suitable instrument, however it should be standardised in Germany.

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[474] cf. Guideline for Sustainable Construction, ed. Federal Office for Building and Regional Planning on behalf of the Federal Ministry of Transport, Construction and Housing Industry, January 2001

Material recycling of former concrete elements ensures their continued presence in the economic cycle, but only at a low level of added value (including RC aggregates used in concrete), as the original shape of the construction products, the energy and labour input and the latent environmental footprint (land use, energy, emissions, etc.) are lost.

Consequently, the proportion of quantities to be fed into circular loops with a lower requirement level (in particular downcycling) is only acceptable if product recycling is not feasible or the conditions for this are not met a priori.

Product recycling demonstrates a significantly more positive balance in terms of economy and ecology as compared to material recycling (construction material recycling). Moreover, the principle of prevention is fully complied with. Nevertheless, the reuse of construction products in their entirety (product recycling) requires a future-oriented development of new bonding technologies in order to safeguard the next recycling stage (multiple use). Construction with new components and building materials on a large scale can thus be reduced, as 85% of all mineral raw materials used in Germany are converted into construction materials[475].

Another objective is to minimise the proportion of residual materials and mixed residual materials from dismantling and demolition. In this context, recycling-friendly, waste-preventing construction site operations such as separation of recyclable materials from mixed construction waste and separate storage in different containers are also important.

The overriding objective is therefore to move away from follow-up support towards a market-based, ecologically oriented and therefore forward-looking economy.

This means that the aspects of sustainability should be considered in the planning, construction, utilisation and dismantling of concrete structures. These include:

- integration of sustainability aspects (holistic approach) into existing planning and implementation principles,
- definition of planning objectives with regard to optimised material flows for construction products in all life cycles,
- early coordination of the structural analysis with regard to removable structural components,
- further development of disassembly and reassembly technologies,
- further development and standardisation of construction regulations for demountable buildings,
- use and utilisation of durable, ecologically sound construction materials and products,
- development of standards for used concrete construction elements in preparation for their secondary utilisation,
- development of reuse projects with the utilisation of used concrete elements in modular systems in terms of demountability,

[475] Sustainable Construction and Living – Shaping a Needs Field for the Future, ed. Federal Environment Agency, Nov. 2008, p. 10

- development of adaptable construction systems (flooring, pipework, media routing, partition walls) in consideration of current building physics requirements (sound insulation, thermal insulation, fire protection),
- provision of user-friendly spaces, etc.[476]

The overriding objective is to utilise resources in a smarter and more efficient way.

Crane-guided demolition plays a key role in partial deconstruction of prefabricated buildings. This is beneficial in any case when it comes to generating construction waste according to type at the point of origin (quality assurance for RC construction materials) and/or selectively collecting contaminated components.

Reuse or subsequent utilisation of concrete elements from former shell constructions of GDR buildings is still more an exception rather than a rule, except in the case of demonstration projects. On the other hand, dismantling companies are becoming increasingly involved in delivering disassembled concrete elements, mainly ceiling panels, but also outer and inner walls, directly to the customer.

The reuse of historic building components, by contrast, is associated with a centuries-old tradition of utilisation and appreciation. And yet the greatest asset of historical construction materials is their age. One particularly aesthetic aspect is seen in the preservation and appreciation of typical regional construction elements (cf. Chap. 9.4).

Thorough preliminary engineering planning is a prerequisite for reuse. It can be structured into individual evaluation phases and work stages (cf. Fig. 7.1, Tab. 7.1).

The initial stage of every reuse measure is an inventory of the installed structural elements of the building to be dismantled. After assessment of the suitability for reuse, it is recommended that an element parts list is prepared. The developed element catalogues are suitable aids[477].

Successive disassembly and dismantling in decreasing order of accessibility to the disassembly and shell components ensures that

- the building materials are separated by type,
- it is possible to eliminate contaminated materials and components at the source,
- value retention and thus reuse and/or subsequent utilisation is possible.

A significant increase in the reuse of concrete elements in residential construction requires further development of recyclable constructions.

However, sustainable planning and construction should not be understood as a fixed, rigid concept, neither for new buildings to be constructed with used concrete elements nor for the existing building

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[476] Hegger, Josef; Schneider, Hartwig; Brunk, Marten; Zilch, Konrad et.al.: Ressourcen- und energieeffiziente, adaptive Gebäudekonzepte im Geschossbau – Teilprojekt C Nachhaltiges Bauen mit Beton, 2007, p. 318 ff.; Arbeitshilfen Recycling - Vermeidung, Verwertung und Beseitigung von Bauabfällen bei Planung und Ausführung von baulichen Anlagen, ed. Federal Ministry of Regional Planning, Construction and Urban Development, 1998, p. 14 ff.

[477] Mettke, Angelika (ed.) Element catalogue, overview: element assortment of type P2, 2003; Mettke, Angelika (ed.) Element catalogue, overview: element range of the WBS 70 type on the example of building type WBS 70/11, BTU Cottbus, LS Altlasten, FG Bauliches Recycling, 2007

stock. On the contrary, there is demand for innovative and specific concepts with the most urgent objective of saving energy both in the utilisation phase and also during construction.

10.3 Aspects and basic requirements for recyclable constructions

Nowadays, the objective of all construction measures is to plan, construct and manage buildings that are "functionally flexible, resource-efficient, non-polluting and which avoid generating construction waste."[478]

Construction that is recyclable and demountable is implemented in order to be adaptable throughout the service life of the building; adaptable to new utilisation requirements, social changes, other locations; expandable, mobile, changeable, replaceable, downsizable while retaining the added value of the components in ecological control loops.

Such requirements have to be met by industrial and commercial buildings in particular. The triggering factors are manifold. A major factor is the inherent divergence between the long standardised service life of buildings on the one hand and the short service life of the equipment on the other. Cycles with different functional requirements between two utilisation phases are becoming progressively shorter.

However, the demand is also apparent in residential construction when flats need to be adapted to changing family circumstances, e.g. after children have moved out, and the floor plan and flat size require changing. Provided this can be carried out without any problems, the house gains in attractiveness and value (user-friendly and senior-friendly design). Furthermore, adaptation costs can be reduced by planning in advance.

The type of construction and the construction process itself are significant for the long-term functionality of a sustainable environmental cycle. The focus here is on the preservation of value, which is ensured, among other things,

- by assuring the flexibility of repurposing: (easily detachable connection / bonding technology; e.g. screw or plug-in connections, easily accessible),
- structural separation of the differently utilised components according to their service life (separation of the load-bearing structure, space-creating and technical finishing),
- uniform service life for components of the same function.[479]

Environmental and health-friendly productivity is ensured, among other things, by:

- increased and preferential use of non-toxic RC materials and products,
- low-residue structures and construction processes (restriction to the unavoidable minimum).

Accordingly, manufacturers must be required to provide clear information on the ingredients and composition of construction products.

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[478] The guideline was developed under the umbrella of the BayFORREST research network „Nachhaltigkeitsaspekte bei Neu- und Bestandsbauten“, 2006

[479] further statements are made by Willkomm, Wolfgang; Weber, Helmut: Recyclinggerechtes Konstruieren im Hochbau, Recyclingbaustoffe einsetzen, Weiterverwendung einplanen, Köln, p. 51 ff.; cf. Schießl, Peter; et.al.: Nachhaltigkeitsaspekte bei Neu- und Bestandsbauten, Guidelines, 2006, p. 22

Similarly, the basics and the design rules specified in VDI Guideline 2243 for "Recycling-oriented product development"[480] (recycling passport) are also of interest.

The requirements placed on the strategy for the development of recyclable structures in building construction are summarised in Fig. 10.2[481].

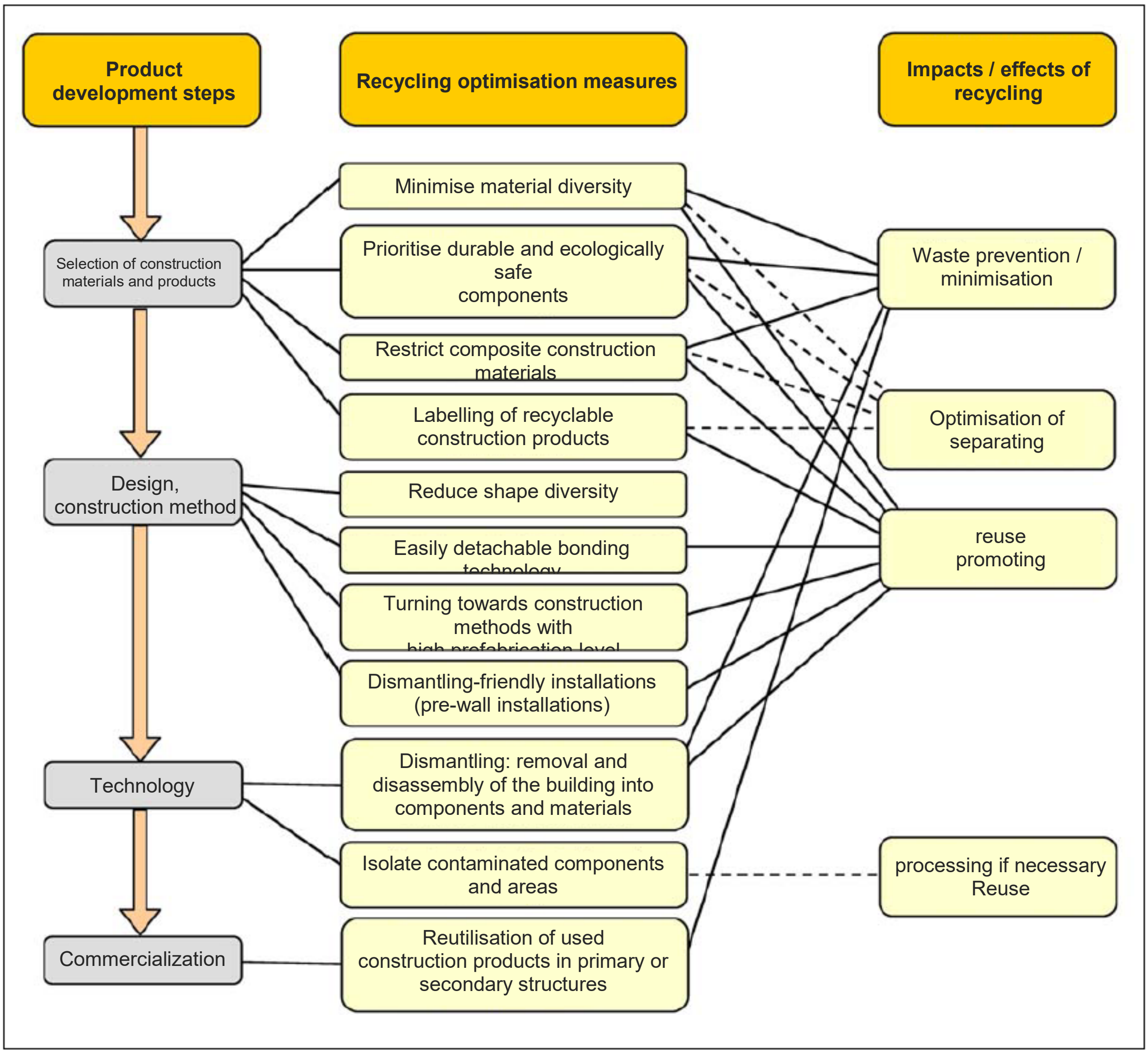

Fig. 10.2: Strategy requirements for the development of recyclable structures in building construction

Recycling-friendly constructions have to be planned in such a way that the construction can be easily disassembled into its individual parts, whereby the construction elements themselves remain undamaged and recycled materials are preferably used as an alternative or in addition to the primary construction materials and products, with a minimum proportion of residual materials in the entire manufacturing or fabrication process.

An additional requirement is that demountable constructions must not be more expensive than those manufactured according to the classic construction method.

[480] VDI Guideline 2243: 2002-07 Recycling-Oriented Product Development, VDI-Verlag Düsseldorf
[481] Fig. 10.2 was developed in line with the requirements for the recycling strategy for the development of plastic products according to KÄU-FER; see footnote 475, p. 103

The prototypes from the Netherlands have demonstrated that this is definitely achievable[482].

The decisive steps for recycling-friendly construction are taken – as mentioned above – in the planning phase with task assignment and co-responsibility of the client.

Finally, this chapter concludes with the description of sustainable recycling of mineral construction materials, which incorporates recycling-friendly construction (Fig. 10.3).

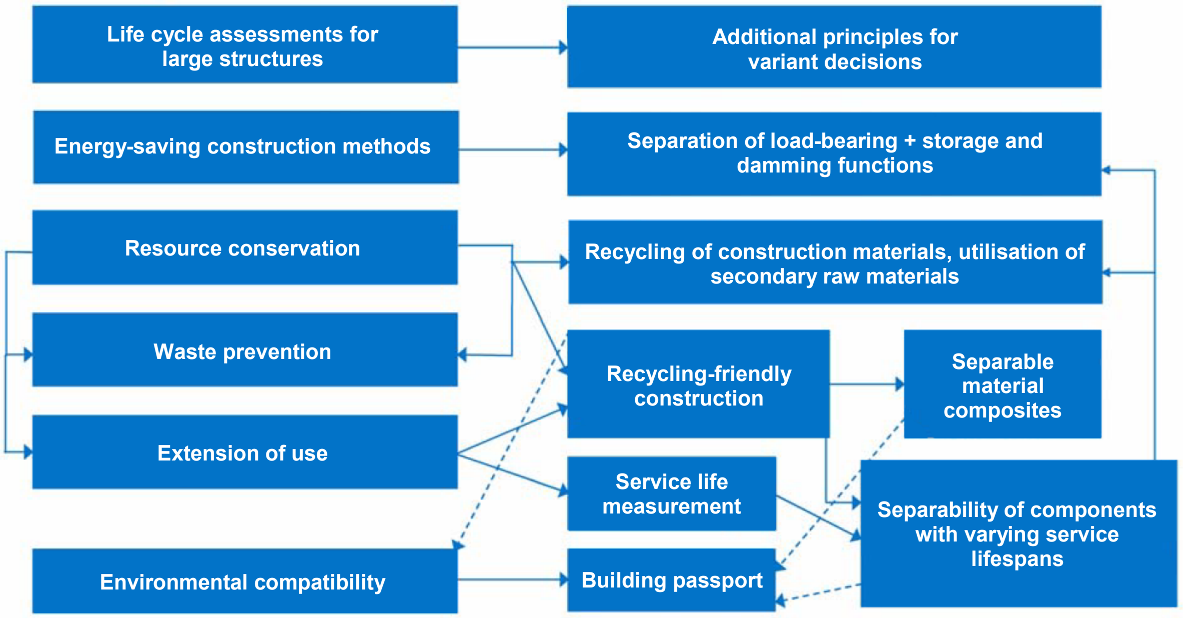

Fig. 10.3: Sustainable recycling of mineral construction materials[483]

10.4 Application examples – selection

Apart from Table 7.3, there are examples of reuse at various levels, which are mentioned below and serve as multipliers:

- **Reuse of historical components**

Example: Archaeological reconstruction of the Dresden Frauenkirche

A large number of the approximately 10,000 reusable sandstones salvaged from the rubble were reinstalled in the stone-facing area; the rest were used for background brickwork.

- **Component network Germany**

The component exchange centres in Bremen, Hanover, Giessen, Augsburg and Berlin-Brandenburg, headquartered in Luckenwalde, are networked under the umbrella organisation "bauteilnetz Deutschland".

The purpose of component exchanges is to preserve value and extend the service life of used components.

[482] Maes, Roland: Neuere Entwicklungen im Fertigteilbau in den Beneluxländern, in: Betonwerk und Fertigteiltechnik, Fertigteil-bauforum 14/84, 1984, pp. 6-8
[483] Schießl, Peter; Stengel, Thorsten: Nachhaltige Kreislaufführung mineralischer Baustoffe, PP-Presentation on the occasion of the Ecobuilding Conference, Fachgespräch Ökobau, 10.03.2008

Example: Bremen Component Exchange

Outer and inner doors, windows, tiles, floorboards, sanitary ceramics, etc. are available. Offers and enquiries are entered into a database; if a buyer is interested, the component can be inspected in the component warehouse or the component exchange can establish contact with the supplier.

(www.bauteilboerse-bremen.de)

Example: Berlin-Brandenburg Component Exchange

The product assortment ranges from historical construction materials to concrete elements.

(www.bauteilboerse-berlin-brandenburg.de)

Example: Thuringian Component Exchange

Concrete elements (walls, ceilings) as well as windows, doors, gates, lift systems and much more are procured via contact and/or request enquiries.

(www.bauteilboerse-thueringen.de)

- **Reuse of prefabricated timber construction systems**

There are demountable timber construction systems on the market, in timber frame construction, timber stud construction and timber panel construction. Reassembled houses can be completed with new elements from the same construction system.

- **Reuse of concrete components**

Example: Conversion of halls constructed by means of the assembly construction method

Although the concept of single-storey and multi-storey multi-purpose construction series has not been developed with the aspect of demountability in mind, but with the intention of minimising concrete work on the construction site, the requirement for full demountability has led to constructive solutions and bonding techniques which include aspects of demountability and which are largely considered to be easy to disassemble. Our own investigations are proof of this. For further information see Tab. 7.3.

- **Reuse of components from demountable buildings**

Thirty years ago, a three-storey office building in Vienna, which was constructed in line with the principles of demountability, was disassembled after only a short period of use (12 years) and reassembled 40 kilometres away in form of a smaller office building and two schools. The costs were approximately half the amount of the corresponding new structures.

The reuse of an office building in Essen resulted in cost savings of 42.6% in comparison to new construction. The primary utilisation period was 4 years[484].

- **Reuse of room elements (recycling-oriented construction)**

[484] Reinhardt, Hans Wolf: Demontabel Bauen mit Beton, in: Betonwerk und Fertigteiltechnik, Heft 5/1985, pp. 300-305

Example: Dismantling of a residential building constructed by means of the RE-Oranienburg method and reconstruction

The complete dismantling of a former residential building in RE-Oranienburg construction was trialled for the first time. The disassembly work began in December 1995. Merely the removal of supply lines and doors is necessary before the room cell(s) is (are) disassembled. The reclaimed room elements were reused to construct 2 two-storey and one single-storey building. This construction system should be further developed in terms of reuse of individual modules.

10.5 Interim conclusion

The buildings constructed by utilising used concrete components are currently not being planned with a view to further dismantling, since the secondary service lifespan is generally assumed to be at least 50 years. New assessment of secondary utilisation load as well as maintenance cycles and the resulting possible impact on the performance characteristics will require further evaluation of secondary utilisation – also in terms of new findings on the long-term behaviour of reinforced concrete structures and the controllability of environmental impacts.

The handling of large-format concrete elements is significantly more demanding in comparison to, e.g., disassembled elements. In the author's opinion, it would be crucial to document every construction project, but especially (re)constructions, and to exclude composite constructions as far as possible. This applies in particular to the installation of the required thermal insulation on outer walls. Currently, the thermal insulation composite system is predominantly used, which leads to increased expenses in subsequent dismantling measures for separating the materials from each other in preparation for their utilisation. This also applies to energy-related improvements to the existing building stock.

Another aspect of energy- and resource-saving construction with RC concrete elements is the complete utilisation of shape and performance properties. This means that the primary objective should not be centred on cutting to specific component dimensions or refinements. Rather, meaningful areas of application should be developed under the actual conditions.

According to the current state of knowledge, the primary utilisation cycle of concrete elements from non-demountable buildings (prefabricated buildings) can be extended by at least one and probably a maximum of two utilisation cycles.

The use of RC aggregates for the production of precast concrete parts is still an unexplored aspect of recycling. Activities are in place for stone production, but there is still some work to do in terms of industrialised construction and recycling friendliness.

11 Summary and derivation of conclusions

The presented study deals with product and material recycling in the construction industry – analysed by way of example on industrially constructed residential buildings – especially on the basis of prefabricated buildings that are scheduled for dismantling or demolition.

Since this building category is particularly affected by vacancy problems, it is the focus of measures within the Urban Redevelopment East programme. Vacant prefabricated buildings could therefore serve as a source of construction components for the coming years. If this potential for optimised recycling is not fully exploited, the various synergy effects will be lost.

The investigations are therefore centred on the reuse of concrete elements and product recycling. Component reuse is characterised by the preservation of shape and added value. The construction products remain in the economic cycle.

Alternatively, reutilisation, i.e. conventional recycling or material recycling, is evaluated. Recycling involves the return of reprocessed construction materials (RC construction materials) into the economic cycle. The analyses focus on the highest quality material recycling, the use of RC aggregates in concrete construction.

Since contaminants may be found in industrially constructed residential buildings, the study addresses the locations, periods of use, proper and safe handling and current recycling options for treated contaminated construction materials and products.

The sub-processes for reuse and recycling have been analysed and evaluated from a holistic perspective, i.e. according to construction material, technical, technological, legal, economic, ecological, social and logistical aspects - in accordance with the specific requirements profile for sustainable construction. Sustainable construction targets minimal consumption of energy and resources for all phases of the life cycle, including dismantling, demolition and disposal, in order to minimise the impact on the natural environment.

Detailed knowledge of the quality of the installed concrete elements and their secondary reutilisation as a component in its entirety or as RC aggregates to be manufactured therefrom have considerable influence on the costs associated with disposal.

The primary goal of the research work is to transfer knowledge and establish the foundations and requirements for product and material recycling for practical implementation. This provides the parties involved in these property life cycles with decision-making support.

The main results achieved can be summarised as follows:

- **Dismantling concepts in the housing industry**

    1. In view of the massive housing vacancy rate and the existing subsidy incentives, downsizing of industrially constructed buildings is currently focussed mainly on demolition measures that result in the destruction of assets.

    2. Partial deconstruction coupled with modernisation and/or refurbishment measures is assuming greater importance – at least in the context of upgrading.

- **Dismantling of prefabricated buildings**

1. The predominant construction system for industrially erected residential buildings is the wall construction method. Prefabricated construction with load levels of 5.0 t and 6.3 t, complemented by room cells of 9.0 t, is characterised by room-sized and room-high outer and inner walls, half-room-sized ceiling panels, large-format roof panels and several individual elements.

2. The a priori non-demountable, mass-produced buildings of the GDR era are demountable.

3. Partial dismantling offers several advantages, in particular:

   a) Preservation of the remaining stock (capital) usually accompanied by modernisation and refurbishment leads to a significant upgrading of the residential building and, depending on the measure, to different building variants (terraced house, city villa, etc.),

   b) Dissolution of the formerly monotonous structure of entire residential districts (loosening up the building structure, reducing the density of buildings, improving lighting conditions, etc.),

   c) Subsequent utilisation of the existing technical infrastructure (above and below ground) such as roads, paths, lighting, media supply,

   d) Recovery of the components in their entirety,

   e) Selection of contaminated construction materials and products, e.g., outer walls contaminated with synthetic mineral fibres.

4. "Key building figures" were determined as a guide for the calculation of disassembly and demolition times and the associated costs:

   The concrete mass varies between approx. 1.2 and 1.5 t/m² living space depending on the type of the building. Disassembly of a concrete element takes about 10 to 15 minutes; including the preparatory crane-independent work (chiselling out the joints, cutting the connections, creating alternative attachment options if necessary) which takes 36 minutes on average.

   Crane downtimes (calculated at 41% in the case of prefabricated buildings and 28% in the case of block construction) should be reduced in terms of cost-effectiveness. The preparatory, crane-independent work for disassembly requires detailed planning. Meticulous planning of the disassembly sequence is therefore particularly important.

   Scheduled reuse or subsequent utilisation of concrete elements has no significant influence on the disassembly time.

5. Alternative mounting options that have proven their effectiveness in panel disassembly:

   - the push-through system with support bolts for wall disassembly,

   - lifting straps for ceiling and wall disassembly

   and pliers for disassembly of wall blocks in the block construction method.

6. Plans for dismantling include

   - basic assessment (inventory / building analysis),
   - authorisation, implementation and contract award planning (regional differences and special features, e.g. with regard to legal construction framework conditions),
   - supervision of the construction process.

   Crane-guided dismantling is more complex and extensive than selective demolition. Both procedures cannot be compared with the construction of a new building.

   In many cases, complete plan sets are no longer available. Moreover, various pollutants inherent in the construction material are to be expected, depending on the year of construction.

   Detailed investigation of buildings, building components, construction materials and pollutants is therefore particularly important. Finally, the preparation of a construction-related dismantling/demolition concept is based on the qualitative preliminary investigation.

   Depending on the strategy selected for the removal, the stock situation and local environmental circumstances, it can be assumed that almost every partial deconstruction or demolition represents a prototype.

7. The disassembly costs per element are between € 133 and € 198.

   The costs can be offset by selling dismantled panels directly from the disassembly site to interested customers. For example, a used ceiling panel currently costs between € 33 and € 43. The disassembly costs could therefore be reduced by approx. 37 to 55% per element.

   The investigations have demonstrated that concrete elements are marketed directly via demolition companies.

   In addition, disposal costs are saved. For example, the tipping fee for delivery of a ceiling panel to an RC plant in its entirety is € 270; if it is pre-shredded, its is then approx. € 40, although it varies greatly from region to region.

8. Damage to the elements as a result of exposure from the bond can be avoided by properly opening the joints over the entire length/width of the component. The elements must not be torn loose.

   The same quality requirements are placed on the transport, transshipment and storage (TUL) processes for used concrete elements as for new concrete elements. Inadequate interim storage and unauthorised handling may result in damage or deterioration of the concrete elements.

   It is recommended that contracts are only awarded to qualified, experienced dismantling companies.

9. The energy required for disassembly of one tonne of concrete element is ~157 MJ when mobile crane is used and ~73 MJ in the case of tower crane utilization. This means that the use of an mobile crane requires ~53% more energy than that of a tower crane.

Approx. 106 MJ of energy is required for the production of one tonne of building rubble. Comparison of energy-related CO2 emissions demonstrates that demolition with ~7.9 kg CO2/t concrete element is lower in emissions than disassembly by means of mobile crane (~11.7 kg CO2/t) and tower crane (~12.8 kg CO2/t).

SO2 emissions are at the lowest level when disassembly is carried out by means of tower crane as compared to demolition and disassembly by means of mobile crane.

Whereas the deployment of a tower crane generates NOX dusts of ~12 g/t of concrete element to be dismantled, the deployment of mobile crane and the excavator do not release any nitrogen oxides.

The interim balance for this sub-process from the ecological perspective indicates that demolition is more favourable than dismantling.

- **Hazardous substances and their specific disposal**

1. Over the past few years, legislative bodies have issued regulations that stipulate bans or restrictions on production, use and disposal. Numerous regulations have since provided the legal framework for procedures regarding the handling and disposal of contaminated construction materials and products. Country-specific regulations for the disposal of hazardous waste are also decisive. There is the obligation to transfer/tender in some of the federal states. This means that the company takes over the management of material flows to the disposal facility.

2. Asbestos-containing materials, tar-containing roofing and barrier felt and synthetic mineral fibres (KMF) can be found in prefabricated buildings. Utilisation of the respective substance group varies greatly in terms of time and region; its use even varies within a residential building.

3. There is a ban on the manufacture and use of asbestos and asbestos-containing preparations (Annex IV, No. 1 Gef StoffV). The only exceptions are demolition and renovation or research work.

4. All asbestos-containing waste has been classified as hazardous since 1 February 2007. Depending on the declaration analysis, asbestos-containing waste has to be assigned to waste code 170601* "Insulating material containing asbestos" (weakly bound asbestos waste) or 170605* "Building materials containing asbestos" (strongly bound asbestos waste).

5. Hazardous waste must always be removed separately by professionally authorised companies prior to dismantling or demolition of the shell construction and disposed of separately in a professional/proper manner in line with the state of the art.

   The verification process for waste disposal was fundamentally reconceptualised in 2007. This principle consists of a prior check and a follow-up check.

6. The following asbestos-containing materials (outside and inside) can be found in prefabricated buildings: Morinol joint sealants, "Baufatherm" fire protection boards, "Sokalit" lightweight boards and "Neptunit" fire protection boards.

7. Evaluation of the health effects of asbestos: inhaled asbestos fibres may induce two main effects:

   - formation of scar tissue ("fibrogenic effect")
   - and cancerous tissue ("carcinogenic effect")

   what can lead to asbestosis (significant impairment of respiratory function), bronchial carcinoma (lung cancer) or, less frequently, pleural mesothelioma (cancer in the pleura or peritoneum).

   According to GefStoffV, asbestos-containing construction materials are classified as Category 1 - carcinogenic hazardous substance.

8. A number of treatment processes (mechanical conversion, thermal processes, chemical decomposition) have been developed and tested for asbestos-containing waste, which have been proven to destroy the harmful asbestos fibre structure and produce fibre-free initial products. Recycling options are primarily available in the cement, ceramics and concrete industry. Furthermore, the utilisation of thermal reaction products as fillers for stone mastic asphalt appears to be a viable approach.

   However, the treatment procedures are mainly subject to the following disadvantages:

   - high specific energy consumption,
   - high safety requirements (black area) and
   - higher treatment costs as compared to landfilling.

   Furthermore, sales of the treated discharge materials have to be ensured. However, they are subject to the applicable structural engineering requirements on the one hand, although acceptance also has to be guaranteed on the other hand.

   It has not yet been possible to implement the developed treatment processes on an industrial scale due to economic reasons.

9. Currently, asbestos-containing waste is almost exclusively deposited. The waste may only be deposited/landfilled in closed, labelled containers (e.g. big bags) in DK I or DK II landfills approved for this purpose under waste legislation in accordance with the AbfAblV or separately in waste disposal areas.

10. In prefabricated buildings, synthetic mineral fibres (glass, stone and slag wool) was mainly used for thermal and sound insulation marketed under the trade name "Kamilit", e.g. for impact sound insulation, as a thermal insulation layer above the top storey ceiling and/or in multi-layer outer walls, for insulating ventilation systems etc.

    Increased utilisation was observed between 1982 and 1989.

    They are therefore classified as 'old' mineral wool (biopersistent artificial mineral fibres according to Annex IV No. 22 GefStoffV) and are suspected to be carcinogenic.

Fibres with a carcinogenicity index of KI ≤ 40, manufactured before 01.06.2000, must be assigned to the AVV waste code 170603* "Other insulating material consisting of or containing hazardous substances" as a hazardous waste. This categorisation also applies to synthetic mineral fibres waste of unknown quality and with no RAL quality label.

11. Evaluation of the impact of synthetic mineral fibres on human health: synthetic mineral fibres of "critical fibre geometry" with a certain biopersistence are suspected of causing cancer when inhaled. Furthermore, skin irritation (fibres with a diameter > 5 µm) and temporary inflammatory irritation of the respiratory tract and eyes are possible.

12. The handling of "old" mineral wool insulation materials is only permitted in the course of disassembly, demolition, maintenance and repair work. Disassembled "old" synthetic mineral fibre products may not be reused and must be disposed of properly.

13. Synthetic mineral fibre products are non-flammable and have to be stored in closed, labelled containers. They are predominantly deposited in Class I or II landfills. The disposal costs are between 100 and 600 €/t.

    An environmentally friendly, newly developed treatment process (Woolrec process), in which crushed synthetic mineral fibre waste is mixed with clay minerals and natural binding agents, then compressed and finished, is used in the brick and tile industry and is the only one that has been put into practice so far. The acceptance price for mineral wool waste is 165 €/t.

    Another treatment process based on multiple-mode microwave technology is being trialled on a laboratory scale. The advantage over the aforementioned process is that the hazardous substance is first slagged and ground afterwards. Areas of application for the discharge material are expected in the construction materials industry (in the cement industry, for concrete production, for brick production, in asphalt).

14. The safest way for detaching outer walls contaminated with mineral wool from the structure without releasing fibres is by means of crane-guided dismantling.

    By separating the outer wall into its individual layers (weather and base layer = uncontaminated) and the synthetic mineral fibre insulation layer (= hazardous waste), the amount of hazardous waste to be disposed of from an outer wall of 6 t, for example, can be reduced to approx. 50 kg TM of synthetic mineral fibre insulation wool. This reduces the volume to be disposed of as well as the amount of disposal costs.

15. The removal of the synthetic mineral fibre insulation wool from outer walls in the installed state (in the building) will be limited to individual measures, as the manual effort required to remove the uncontaminated weather shell and the mineral wool is too time-consuming.

16. Roofing membranes containing tar are likely to be found in buildings in eastern Germany until around 2020 due to their production period up to 1990 and their predicted service life. PAHs, phenols and other aromatic and aliphatic hydrocarbons are considered to be the main components of the several thousand individual chemical substances contained in tar.

17. Assessment in terms of health: chemical substances contained in tars can trigger acute reactions (characterised, for example, by skin, eye and respiratory tract irritation), chronic

effects (skin changes, liver and kidney damage, damage to the central nervous system) and secondary effects (skin, throat and lung cancer).

18. Roofing membranes are categorised as hazardous waste on the basis of the PAH test parameter in accordance with EPA, in compliance with the country-specific reference and limit values. Due to the varying permissible PAH concentrations, the categorisation does not apply uniformly throughout Germany. Hazardous waste is to be assigned to AVV 170303 * "Coal tar and tar-containing products".

19. Rapid tests for the detection of tar and PAHs (tar gun, paint spray test, test paper, etc.) can only be used as guidance for damage potentials. This is no substitute for quantitative statements.

20. Roofing felt containing tar is suitable for thermal utilisation due to its relatively high calorific value of 20,000 kJ/kg. They can be materially recycled for the production of asphalt in cold mixed material. Only roofing membranes containing bitumen are permitted for use in a hot-mix process.

    In preparation for energy recovery or material recycling, processing in specially authorised pre-treatment plants is required to separate foreign substances (e.g. metals).

    The thermal and material recycling of tar-contaminated roofing membranes reflect the state of the art.

- **Quality features of used concrete elements**

<u>Assessment of structural properties</u>

1. Generally, it should be noted that the compressive strength classes of the concrete elements are minimally fulfilled according to the project planning, but are usually increased.

   The measurements on 160 tested, 15 to 30 year old WBS 70 ceiling panels in C 50/60 demonstrate a 4-fold increase as compared to the minimum requirement according to the valid DIN. The prestressed ceiling panels of P2 type, projected in B 300 (C 25/30), fulfil the new, stricter requirements for C 30/37 (proven on 83 prestressed concrete ceiling panels).

   The 172 inspected inner walls of building type P2 exhibit an increase of 1 strength class as compared to the data from the project planning.

   The inner walls of WBS 70 fulfil the projected concrete strength class.

   The results of the compressive strength test can be summarised as follows:

- WBS 70:	Prestressed concrete ceilings	C 50/60
	load-bearing inner walls	C 20/25
- P2:	slack reinforced	C 20/25
	Prestressed concrete ceilings	C 30/37
	load-bearing inner walls	C 20/25

2. The analysed ceiling panels and inner walls of WBS 70 and building type P2 fulfil the requirements of exposure classes XC 1 - XC 3 if the minimum concrete strength is taken as basis. The prestressed ceiling panels in the P2 series achieve XC 4. In terms of reuse of the analysed dismantled concrete elements, this primarily means that environmental requirements that go beyond the primary requirements are complied with.

3. Investigations into concrete cover have shown that the range of ceilings and inner walls of the P2 building series complies with the minimum concrete cover if the secondary use remains unchanged. The prestressed concrete ceilings of WBS 70 do not fulfil this requirement.

   Analyses in terms of carbonatisation lead to the conclusion that, if environmental conditions in secondary use remain unchanged in comparison to primary use, there is sufficient corrosion protection for the entire range of the investigated concrete elements. In this respect, the statement made under 2. that higher exposure classes are also complied with in the case of unprocessed concrete elements is once again relativised.

4. The analysed range of elements from residential construction is classified as dense. The permeability values are $k_f = 10^{-10}$ to 10^{-11} m/s and are comparable to clays that have $k_f = 10^{-8}$ to 10^{-12} m/s.

   The total porosity of 12.5% < 16% indicates durable concrete. The determined water penetration depth of 1.3 cm to 2.4 cm < 3 cm confirms their water impermeability.

5. Untreated concrete elements from the residential construction series do not comply with the requirements against frost with and without the effect of deicing agents.

<u>Assessment of load-bearing capacity</u>

The arithmetical verifications of the load-bearing capacity of the ceiling panels were partly supplemented by experimental load tests in order to obtain a reliable assessment of the load-bearing capacity.

1. The existing load-bearing reinforcement of the tested ceiling panels is sufficient for live loads in living spaces (1.50 kN/m²). The slack reinforced ceiling panels of P2 type can even be used in offices (live load 5 kN/m²).

2. Load tests on prestressed concrete ceilings revealed an almost linear relationship between load and deformation, which was maintained up to around 1.5 to 2 times the service load. The deformations increased disproportionately only with further increases in load. High elasticity of prestressing steel and excellent adhesive bond between steel and concrete have been proven.

   Neither the prestressed nor the slack reinforced ceiling panels failed in the concrete compression zone or due to steel flow.

3. In the investigated application case, where the inner walls are installed in 3-storey residential buildings, there are no concerns from a structural point of view.

4. The arithmetical and experimental investigations confirm that there are no objections to the reuse of the analysed range of components from a structural point of view.

Evaluation of building physics properties

1. The investigated non-refurbished prefabricated building type P2 does not meet the current sound insulation requirements. The only exception is the flat ceiling with tensioned matt. Construction and processing deficiencies as well as structural correlations were identified as causes.

2. The P2 type does not comply with the current thermal insulation requirements due to the insufficiently dimensioned thermal insulation layers. Merely the apartment partition walls and the top storey ceiling (due to insulating wool layer) comply with the minimum DIN requirements.

   The lack of thermal insulation is generally found in all industrially constructed residential buildings.

3. The fire resistance calculations and the fire load tests have proven that the load-bearing capacity of prestressed concrete ceilings of the P2 type is maintained for > 30 minutes under load. The load-bearing capacity of reinforced concrete panels was maintained for > 90 and 85 minutes, respectively.

   Therefore, the unprocessed elements can only be reused in residential buildings with a height of up to 7.00 metres.

The results of the tests performed on selected element groups of WBS 70, P2 and PN 36-NO panel construction types confirm that the concrete elements exhibit high performance properties. The underlying comparative studies on load-bearing capacity are based on the assumption of an unchanged utilisation purpose in secondary use as compared to primary use. The repeated utilisation in residential construction has been checked in accordance with current regulations.

Supplementary load-bearing tests were used to confirm the arithmetical verifications and to demonstrate the load-bearing capacity reserves of a specific range of ceiling panels.

On the other hand, the arithmetical verifications also revealed that certain ceiling panels of the jamb storey (PN 36-NO) are not suitable for reuse for the same purpose if not refurbished. However, it is possible to upgrade the concrete elements subjected to bending, e.g. by means of slotted carbon fibre lamellae.

The reuse of concrete components in house construction requires upgrading measures to improve the building physics parameters. There are various solutions available on the market in this respect.

In terms of fire resistance, non-refurbished ceiling panels can be used in high-rise buildings up to building class 3.

- **Reuse options / product recycling**

1. Dismantled concrete elements can be reused in a variety of ways, for example

   - in residential and multi-purpose construction,

   - in landscape and park construction,

   - in environmental protection structures (noise barriers, dyke construction),

- in agricultural construction (silos, etc.).

The technical feasibility of both the reuse and subsequent use of old concrete elements in residential and multi-purpose buildings (single-family houses, semi-detached houses, city villas, community centres) as well as in the design of outdoor areas (climbing rocks, seating elements, fencing elements, artistic decorations) was demonstrated in implemented pilot projects.

However, the largest part of the existing potential in the building stock remains unexploited in terms of product recycling.

In order to address the initial issues of acceptance of the panel, we are currently conducting our own research into the use of old concrete elements for dyke structures (underground application).

Furthermore, cross-border subsequent utilisation is being investigated in preparation for practical implementation.

2. The conducted investigations prove that disassembled concrete elements from prefabricated buildings are ready for use when properly dismantled.

   Ceiling panels and former load-bearing inner walls are particularly suitable for reuse, outer walls are also suitable.

   Roof cassette panels, staircase elements and bathroom cells are reserved for special areas of application or the same areas of application as in primary use due to their component geometry and shape and are therefore considered to have limited reusability.

   Basically, jamb and loggia elements can be reused. This range has been rated as conditionally suitable for reuse due to the low number of installed jamb elements (in the case study P2 ~3%) as compared to the total number of installed elements. Although the loggia elements account for ~ 11% of the total amount, the parapet panels are made of different materials and, what is more, the building condition assessments exhibit considerable fluctuations, so that subsequent use in residential and multi-purpose construction is only possible to a limited extent. However, it can still be utilised without restriction in subordinate applications, e.g. for the construction of climbing rocks.

   Only the partition walls (insufficient component thickness of 7 cm) and the contaminated outer walls insulated by means of mineral wool are not suitable for secondary use as construction components/products.

3. The following parameters were used as decision criteria for suitability for reuse - in consideration of the self-developed decision model - based on the decision stages (systematic processing of test criteria as part of the suitability, main and additional tests):

   - quality of concrete elements,
   - quantity/availability of concrete elements,
   - their geometry and shape,

- the disassembly process (incl. TUL transport, transshipment and storage) for obtaining the components,
- reconditioning and processing options,
- architectural design spaces,
- economic and ecological assessment/importance of reuse and recycling.

4. Assuming that the ceiling panels and inner walls e.g. of a 5-storey P2 building are reused, the reuse rate amounts to ~38% in relation to the total number of installed elements. This amounts to 50% in terms of mass. If the non-loaded outer walls are also reused, the reuse potential increases to ~45% in terms of elements and 68% in terms of mass. If only half of the outer walls can be reused, the reuse rate is still 41% in terms of quantity and 59% in terms of mass.

   Assuming that the concrete elements with limited reusability are also subsequently utilised, the reuse rate could increase to 82% in terms of quantity and ~95% in terms of mass.

   Due to the different component dimensions, the quantity-related reuse rate may differ for other building types.

5. Since no generally recognised rules of technology are available for the utilisation of used concrete elements, the effort required for approval is currently too high and too time-consuming. Usually, approval is granted in individual cases.

6. Construction involving used concrete elements in structural engineering generally results in a cost advantage of 10 to30 % for the shell when compared to conventional solid construction methods.

   The amount of cost savings is mainly influenced by

   - the surface area constructed with reusable concrete elements (wall surface, ceiling surface), i.e. the reuse rate,
   - professional, careful planning and
   - the number of handlings of concrete elements.

   Reuse and subsequent utilisation are most cost-effective when the donor and recipient buildings are close to each other in terms of time and space.

   Nonetheless, cost calculations indicate that there is a cost advantage in the provision of used concrete elements at a distance of ~ 2,000 km from the disassembly site. Savings of between 30 and 40 % were calculated. The economic advantage results primarily from local energy and raw material prices. However, the actual amount of the economic advantage can only be proven in a pilot project planned for 2010.

   If the costs for disassembly of concrete elements, including testing and transport costs, are taken into account, savings of € 216 for a ceiling panel and € 281 for an inner wall are achieved in comparison to new precast concrete elements in Germany.

Currently, the buyer pays ~€ 50 for the provision of an inner wall on the disassembly site and around € 57 for a ceiling panel. If dismantling costs are excluded, this results in savings of € 472 for an inner wall and € 407 for a ceiling panel when compared to new part prices. A transport distance of 30 km is included, however, unloading of the elements is excluded. This means that up to this sub-process, the costs are approx. 1/10 of the new price from the customer's perspective.
The apparent cost advantage is eliminated or at least limited if the used concrete elements have to be cut or adapted to geometries and the scope of reconditioning measures is large.

7. The ecological benefits of component recycling are primarily due to the high potential for the preservation of raw materials and energy. Life cycle assessment comparisons were used to determine that the savings vary in terms of reuse rate, transport distance and, above all, the deployed means of transport and intended use. Energy savings of ~88 % are achieved in comparison to new production, even with a transport distance of over 2,000 km.

   The production of reinforced concrete elements is particularly energy-intensive. The production of 1 tonne of precast concrete requires ~3,080 MJ of energy. In terms of heating oil consumption, ~72 litres are required for 1 tonne of precast concrete.

   The provision of used concrete elements for reuse or subsequent utilisation – resulting from disassembly – requires only 3.7 litres of heating oil per tonne of precast concrete element. This results in savings in heating oil of almost 95 %.

   Since energy consumption correlates with the release of climate-relevant pollutant emissions, a reduction in pollutants through the reuse of concrete elements is demonstrable.

   The energy-related emissions for new production of 1 tonne of precast concrete are reduced by around 97 % in comparison to the provision of 1 tonne of recycled precast concrete. The CO2 emissions are reduced from 394 kg/t to less than 12 kg/t. Furthermore, natural resources are conserved. The ratio of raw material consumption to the production of 1 tonne of reinforced concrete is around 6:1. For example, 21 t of natural raw materials are not required for the production of a single prestressed concrete ceiling of P2 type.

   At the same time, land consumption is reduced. Furthermore, the material flows are reduced.

8. If the use of old concrete components for dyke stabilisation is structurally suitable (developed dyke construction variants; proof has not been provided yet), there are cost savings of ~10% for new construction of dykes with inner sealing and ~20 % for the construction variant with surface sealing. The cost advantage in comparison to the standardised construction of a homogeneous dyke with a slope inclination of 1:3 results from the deliberately chosen steeper slope inclination of the dyke with 1:2 and the resulting lower earth mass movements.

   Land consumption can be reduced by nearly 30%, the earth mass saving is approx. 27%.

   The construction of overflow sections by means of used concrete elements leads to cost savings of 50% in comparison to the standardised dyke construction with a slope inclination of 1:10. The earth masses to be moved in order to construct the supporting structure are reduced by approx. 75%.

In view of dyke construction and upgrading measures still required in the Federal Republic of Germany and the environmental policy objective of the German sustainability strategy to reduce land consumption from the current 118 ha/d to 30 ha/d by 2020, the developed alternative dyke construction variants imply an interesting approach.

Compared to conventional dyke construction, the energy expenditure for the surface sealing variant is reduced by ~17%, for example, if the old precast concrete parts to be delivered are transported over a distance of 100 km. The energy consumption is reduced by 20% for a distance of 25 km. The transport of the concrete elements and the deployment of the crane for installation of the elements (on the waterside dyke embankment) only take up around 10% of the energy consumption for a transport distance of 100 km.

The construction of a new dyke with an inner sealing is 37% to 43% more energy-intensive than conventional construction due to the installation of a strip foundation. Reuse of used concrete elements in earthworks, especially in dyke construction, has proven its effectiveness. The surface sealing variant is suitable both for new construction and for upgrading of the existing dykes. The inner sealing variant cannot be recommended for new dyke construction due to ecological reasons. The suitability for upgrading must therefore be analysed in the following.

Bentonite should be tested as joint material.

- **Construction elements/material recycling**

1. Construction waste (excavated soil, road rubble, building rubble, mixed construction and demolition waste) accounts for the largest proportion of total waste generated in Germany at nearly 60 %.

   Approx. 55.1 million t (70.1 %) of the 78.6 million t of construction and demolition waste generated annually from the fractions of construction waste, road demolition waste and mixed construction and demolition waste were processed/recycled in RC plants, while 14.6 million t (18.6 %) were directly recycled and 8.9 million t (11.3 %) were disposed of in landfills. This results in an average recycling rate of almost 89%.

2. An average of ~10% of the primary raw materials (aggregates) could be replaced annually with RC construction materials made from building rubble, road rubble and construction site waste. However, an average of around 10–11 million t were still withdrawn from the economic cycle each year due to disposal in landfills.

3. RC construction materials are mainly used in road, earth and path construction. Over 40% was incorporated into supporting layers and frost protection layers, while around 45% was utilised in earthworks and landscaping. Approx. 4.9% was used as aggregates in concrete construction.

4. Recycling must be carried out properly and harmlessly and must therefore be oriented towards constructional and environmentally compatible requirements in line with the intended use and area of application. A nationwide system of regulations is in place with regard to structural engineering requirements, including quality assurance.

There are no standardised national regulations regarding the elutriability of recyclates. Apart from the different federal state-specific requirements, the majority of the federal states comply with LAGA M 20.

In this respect, the verification process varies in terms of the scope and frequency of the analyses to be conducted. In extreme cases, it is possible to disqualify mineral waste from recycling if a parameter is exceeded, whereas this waste would not even be tested in the neighbouring federal state.

In this context and in consideration of the current statutory requirements for soil and groundwater protection, the Federal Ministry for Environment is working on a substitute construction materials ordinance which aims at harmonising the regulations at federal level in order to create legislative consistency in terms of recycling requirements and prevent unfair competition.

5. High-quality material recycling of RC aggregates, such as for the production of RC concrete, requires qualified demolition with separation of the material types at the demolition site, their selective processing and separate storage.

   The requirements placed on the composition of recycled aggregates in accordance with delivery type 1, DIN 4226-100 (≥ 90 M-% concrete chippings) are not complied with even by construction waste generated from prefabricated buildings by means of selective demolition. This is why it is particularly important to ensure proper segregation during processing.

   By contrast, crane-guided dismantling enables absolute uniformity of the source material for processing to be provided at the dismantling site - insofar as subsequent utilisation as a component is not required.

6. The quality of the recyclates can be controlled by the treatment process in such a way that there are no deficits in relation to primary raw materials.

   For example, the cement paste adhering to the aggregates can be treated by means of abrasion.

7. Since crushed sands < 2 mm are generated in relatively large quantities (approx. 35–40 %) during processing of the building rubble, utilisation in concretes is excluded according to DIN, however there are only a few utilisation possibilities, a series of experimental investigations have been performed on ultra-fine crushing in order to use them, for example, as a raw material component for the production of cement, as an additive for lightweight concrete and in self-compacting concrete. The test results reveal promising areas of application.

   In terms of recycling practice, this means integrating ultrafine grinding into the reprocessing process. However, an investment is only worthwhile if there is demand for the product. Alternatively, it is possible to grind cement clinker together with crushed sand to produce Portland composite cement.

8. The normative basis for the production of RC concrete has been available in Germany since 2004. Nonetheless, RC concrete still has not become widely accepted in Germany.

Apart from economic reasons, the main reason for this are the modified properties of RC concretes in comparison to (standard) reference concretes. These include:

- decline in compressive strength of 10–30 % depending on the composition of the aggregate, maximum grain diameter, cement content, w/c ratio, etc.,
- reduction of the elastic modulus by 20–50% depending on the composition of the processed aggregate,
- mostly decrease but also increase in tensile strength; recycled sand < 4 mm clearly causes a reduction,
- creep and shrinkage increase of 30–40 % due to the higher deformation behaviour of crushed sand.

9. Environmental studies on RC concrete clearly demonstrate that there is no significant environmental impact as compared to reference concretes. RC concretes have a slightly higher energy consumption and a higher global warming potential. This is due to the increased cement content, as 95% of the global warming potential is attributable to cement, 2% to RC aggregates, 1 % to gravel/sand and 1% each to the transport of aggregates.

   However, utilisation of RC aggregates conserves natural resources (at a rate of 24–44 % per m³ of concrete, depending on the proportion of recycled material and cement content) and consequently reduces land consumption.

11.1 Conclusion

- **For product recycling**

In the context of maximising resource productivity, the reuse and subsequent utilisation of concrete elements is a genuine alternative and complementary solution to conventional construction.

This result is a consequence of the assessment of material efficiency and sufficiency.

The reduction in environmental pollution associated with the conservation of resources is achieved by economising on the energy-intensive building material concrete.

Facts

- The increase of crane-guided dismantling measures for the reduction of vacancies in prefabricated buildings in conjunction with upgrading of the remaining stock,
- the available potential of secondary components that can be recovered and reused in the course of vacancy elimination in the coming years, and
- high utilisation properties of concrete elements,
- improved utilisation of the lifespan of concrete components,
- implementation of the highest priority objective of waste prevention by means of reuse in accordance with the German Waste Management Act (KrW-/AbfG) and the Waste Framework Directive,

- flexible application scenarios,
- substitution of primary raw materials and thus reduction of energy consumption for new concrete production of 95%, including the reduction of climate-related by-products of ~97%,
- cost savings for the shell construction of 10 to 30 % and the resulting cost advantages in comparison to new construction

speak for themselves.

Despite the economically attractive components – and this is the reason for the successful spread of the subsequent utilisation concept – the available potential or the source of these components in existing buildings is not even close to being fully exploited.

Particularly with regard to the discussion on climate protection, the use of anthropogenic raw materials in high-grade recycled form is not receiving the attention it deserves in connection with the transformation of prefabricated buildings in the course of urban redevelopment.

Therefore, it is necessary to set the course for the future by improving

- the legal framework for construction,
- the government incentives by offering differentiated subsidies for disassembly and demolition, and
- the logistics processes in terms of optimising the marketing of used concrete elements.

- **For material recycling**

The remarkably high recycling rates achieved over the years have made a significant contribution to the conservation of resources. Considerable quantities of mineral recyclates were used in road, path and landscape construction in particular, instead of the primary raw materials that would have been required otherwise.

However, there is a general deficit with regard to the level of utilisation. This applies in particular to concrete rubble from building construction, which can only be recycled to an equivalent extent through repeated use in the form of RC aggregates in concrete construction.

Considering the limited recycling possibilities in the foreseeable future due to the stricter limit values for pollutant concentrations in recyclates for preventive protection of groundwater and soil, it is necessary to continue supporting the use of RC aggregates in bound form, in concretes.

Particularly the concrete demolition rubble from prefabricated buildings provides a qualitative and quantitative starting point.

Assuming that approximately 350,000 industrially constructed flats in eastern Germany will become surplus by 2016 and therefore need to be demolished, around 28 million t of concrete demolition rubble will be generated. This would correspond to an average of approx. 3.5 million t of demolished concrete per year up to 2016. While this would merely correspond to a substitution rate of natural aggregates in concrete products of ~2.5% (~140 million t of aggregates are required annually for concrete production), recycling would be maintained at the same level.

At the same time, it can be assumed that the concrete structures constructed throughout Germany in the 1950s, 1960s and later will significantly increase the proportion of concrete demolition waste in future.

Overall, it can therefore be assumed that the volume of concrete rubble will remain stable or even increase.

In this respect, the current obstacles to the use of RC aggregates in concrete construction need to be reviewed and communicated in detail.

One starting point for optimising RC concrete production is to reduce the cement content to minimum level.

The results presented here are primarily intended to encourage the reuse of concrete elements and, secondarily, to prioritise the recycling of RC aggregates in concrete construction as part of the discussion on sustainable management in the construction sector.

Further development of the organisation and management is required in order to achieve improved marketability and acceptance.

11.2 Final conclusions

The primary objective of the thesis was to clarify the holistic nature of product and material recycling, to recognise specific problem areas and to identify further fields of activity. These include, among others

- **for concrete element recycling (product recycling)**
  - the development of normative principles to reduce the effort involved in obtaining authorisation for the reuse of concrete elements, depending on their intended use,
  - the development of practical and cost-effective measurement methods for determination of the type of insulation material in outer walls in installed condition,
  - the development of a platform (e.g. construction element exchange) to promote the supply and demand of concrete elements,
  - the development of reutilisation projects, e.g. for structures in disaster prevention,
  - further development of the areas of application for used concrete elements, e.g. in dyke construction and others,
  - development of further pilot projects;
- **For material recycling**
  - the analysis of the demolition/dismantling process chain up to the recycling of RC aggregates in concrete in order to determine the sales conditions for high-quality recycling and identify weak points with regard to the potential exposure of cost increases and/or quality reductions,
  - development of standardised federal recycling requirements in technical structures in non-bonded form;

- **For product and material recycling**
    - development or expansion/standardisation of quality assurance systems, e.g. RAL for crane-guided dismantling.

Disassembly and recycling-friendly construction methods need to be developed in the future.

Education and training at colleges and universities must be orientated towards the new concept of sustainable construction. The curriculum needs to be adapted to the latest developments and modified practical conditions. The sustainable management of the existing building stock is an economic and environmental imperative.

List of abbreviations

Fig.	Figure
AbfG	Waste Management Act
Par.	Paragraph
AK	Labour force
gen.	general
AVV	Waste List Ordinance
AW	Outer wall
W	Width
BBodSchV	Federal Soil Protection and Contaminated Sites Ordinance
BBodSchG	Federal Soil Protection Act
BE	Concrete element
BHW	Design flood
bspw.	for example
bzgl.	regarding
BZS	Construction status
bzw.	or
ca.	approximately
ChemG	Chemicals Act
D	Thickness
Def.	Definition
i.e.	in other words/this means
DFG	German Research Foundation (DFG)
DG	Top storey
DH	Semi-detached house
DIN	German Institute for Standardisation
div.	diverse
DKP	Roof cassette panel
DP	Ceiling panel
E	Energy expenditure
EfbV	Ordinance on Specialised Waste Management Companies
EFH	Single-family house
EG	Ground storey
EgRL	Waste Management Association Directive
incl.	including
EK	Installation class
EM	Emissions
acc. to	according to/corresponding
EU	European Union
FG	Expert group
FZK	Mobile crane
GefStoffV	German Ordinance on Hazardous Substances
acc.	according to
GFS	no effect level
ggf.	If applicable
H	Höhe
Pub.	Publisher
i. Allg.	In general
i. d. R.	generally/as a rule
i. M.	on average
IEMB	Institute for Conservation and Modernisation of Buildings e.V.
incl.	including
IW	Inner wall
K	Costs
Chap.	Chapter
k.A.	no information/not specified
KEA	Cumulative energy consumption/expenditure
KG	Basement storey
KI	Carcinogenicity index
KMF	synthetic mineral fibres
kW	Kilowatt
KWTB	Working Group Circular Economy Carrier Construction
L	Length
lfdm.	running metre
LGBW	Lightweight storey construction Cottbus
li.	left
LS	Professorship
lt.	according to
max.	maximum
MFH	Multi-family dwelling or apartment house
min.	minimum
min.	Minute
mln	millions
MP	Measuring point
bn	Billions

EP	Corner point	MW	Brickwork/masonry
et.al.	et alterae (and others)	n	Quantity
etc.	et cetera	n.a.	not accomplished/not complied with
NachwV	Verification Ordinance	Var.	Variant
NG	standard storey	cf.	compare
o.a.	listed above	VwVws	Administrative Regulation of Substances Hazardous to Water
OG	Upper storey	WBK	Housing construction association
OK	Top edge	WBS	Housing series
PAK	polycyclic aromatic hydrocarbons	WE	Residential unit
PEI	Primary energy content	Wfl.	Living space
Pkt.	Point	WGK	Water hazard class
PVC	Polyvinyl chloride	WHG	Water Resources Management Act
RAL	German Imperial Committee for Terms of Delivery, today the "German Institute for Quality Assurance and Labelling e.V."	WV	Reuse
RC	Recycling	e.g.	exempli gratia (for example)
approx.	approximately/around	z.T.	partly/partially
Re	Reassembly		
RE	Room element		
re.	right		
resp.	respectively		
RH	Terraced house		
RoRo	Roll-on/Roll-off		
s.	see		
p.	Page		
SBB	Special waste company Berlin/Brandenburg mbH		
sog.	so called		
spec.	Specific/special		
pcs.	piece/pieces		
Std.	hour		
Tab.	Table		
TDK	Tower crane		
teilw.	partially		
TGL	Technical quality and delivery conditions in the GDR		
TgV	Transport Authorisation Ordinance		
TM	Dry mass		
TS	Dry matter		
TUL	Transport, transhipment and storage		
u.a.	and others		
u.ä.	and similar		
u.v.a.	and many more		
etc.	etcetera		
v.a.	especially/ particularly		

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