Sustainable building with concrete – Practical guidance from German Committee for Structural Concrete (DAfStb)

1 General

Increasing scarcity of raw materials, limited landfill space and the need to reduce CO_2 emissions are the global requirements that sustainable buildings, among others, demand a low consumption of raw materials and energy as well as the greatest possible flexibility of use and reusability or durability of the function in the building. Sustainable buildings have to meet ecological, economic and socio-cultural requirements, at the same time offer a high technical quality and have to be aligned to the processes of construction. Furthermore, the buildings should be comfortable for the user and must not impair their health. The specific requirement profile of the client therefore determines the main points with which the numerous criteria of sustainability, such as for example in the certification system of the Federal Ministry of Construction [1], are anchored, should be weighed against each other. All measures in this practical guidance are based on the following key sustainability goals:

- An immediate and drastic reduction in CO_2 emissions as a measure for climate protection,
- Take precautions for the already existing consequences of climate change,
- Resource conservation and material optimization.

When considering whether to preserve a structure or to dismantle it, the preservation approach must always be followed in the interests of sustainability and the service life extended through appropriate maintenance.

Since the value of a building in terms of sustainability does not only depend on its production costs, the planned service life and the pure property value, a large number of criteria must be checked and incorporated into the design, construction or maintenance of the building. This results in sensible habit planning, aesthetic architecture, optimized structural design, efficient building technology, a suitable choice of materials and a reasonable implementation process.

The following practical guidance from DAfStb for buildings of common high-rise construction (residential buildings, administration buildings, event buildings, shopping centers, industrial halls, etc.) serves investors, clients, designers, contractors and representatives of the building supervision for decision-making processes in sustainable construction with concrete. The guidance is understood as a preparation step for a possible sustainability certification and show how sustainable design and construction can be carried out with the existing technical specifications and authority regulations in concrete construction. The basic documents for this guidance were [2], [3], [4] and [5] for clause 3.3.

2 Guidance for design

2.1 General planning principles

Sustainable construction requires all those involved in construction to work together as partners. Basics are

- The duly definition of the essential goals,
- Holistic planning over the entire foreseeable life cycle as well as
- efficient quality management with the definition of tasks, responsibilities and communication processes.

Architects, building physicists, structural engineers and company technicians develop a holistic building concept together with the client, which, in addition to the current usage requirements and property-specific environmental effects, should realistically assess possible future changes in usage. In principle, particular attention must be paid to the interactions between the various criteria of sustainability considerations, because very often several criteria are influenced by one decision. This can also have opposite effects.

⇄ This symbol within the practical guidance indicates possible interactions.

The advantages of each building material can be optimally used if the relevant specialists (property planners, structural engineers, building physicists, etc.) are involved in the planning phase in good time. Concrete construction has considerable advantages for sustainable construction, especially in terms of economic quality, the possibility of predominantly using regional resources, technical quality and process quality through intensive communication (see also [6]). There are hardly any limits to the freedom of design through the variety of shapes of buildings and components made of concrete.

2.2 Influences on individual sustainability aspects

2.2.1 Resource conservation and climate protection

Resource-saving optimization can take place in concrete construction under various aspects:

- A static optimization of the structures or components made of reinforced concrete with simple, straight load paths without detours through contradicting planning processes or rescheduling leads to material and weight savings (less concrete, less reinforcement). In general, the design should be "appropriate to the material". Overpressed solid structures react significantly more resiliently to the building load and are correspondingly more durable than building parts under tensile or alternating load. Concrete in cross-sectional areas without function should be avoided.
- In the case of concrete structures, the optimization of the technical manufacturing process can be used to reduce waste and ensure a shorter production time (e. g. production of as many identical component cross-sections as possible or optimization of individual components of the structure).
- Optimizing the concrete composition leads to a reduction in CO_2 emissions without any loss of resistance or durability, so that usually no coatings are required and surfaces with little cleaning and maintenance efforts are created.

In the Joint Research Project "Sustainable Building with Concrete" of the DAfStb [7] it was found, among other things, that in multi-storey buildings the environmental life cycle assessment (LCA) of the entire supporting structure can essentially be improved by clever planning of the storey-ceilings. The amount of concrete used has a greater influence on the ecological balance than the strength class of the concrete. In order to ensure an optimal transfer of the loads, all load-bearing elements should be on top of each other. This measure can reduce the amount of concrete and concrete steel.

⇄ *Interactions:* The static optimization of the component cross-sections with the aim of using less material influences the ***flexibility and convertibility*** of the load-bearing structure, as load-reserves may be dispensed with. The decision as to which focus is to be set for optimization depends individually on the specifications and requirements of those involved in the construction. ⇄

2.2.2 Area and volume efficiency

The available floor space should not only be optimally used from an economic point of view, but also from the perspective of sustainability in order to cover existing space requirements with the least possible consumption of space.

Column-free floor plans or as few vertical support members as possible over several floors increase the ***space efficiency*** and also serve the ***functionality*** of the building.

The ***volume efficiency*** is significantly influenced by the thickness of the floor slabs. This can be optimized by choosing a support system with appropriate spans.

Example 1: By using prestressed components and high-strength concretes, even wide-span ceiling systems with a reasonable slab thickness may be realized. Optimizations are to be carried out here in accordance with the foreseeable possible uses.

Example 2: Storey-frames can also be used as a static system in an efficient and balanced manner with regard to the stress, which generally require less reinforcement.

Example 3: With slender column cross-sections, e. g. optimized through the use of high-strength concrete or butt-joints, the floor area can be used just as efficiently.

Interactions: By using slender, highly-utilized component cross-sections, on the one hand the use of resources is optimized, and at the same time – as already mentioned above – the ***flexibility and convertibility*** of the building can be improved. Particularly in the case of generous, free floor plans, the effects on the assessment of the fire compartments must be observed.

2.2.3 Flexibility and convertibility

For the sustainable use of real estate, the flexibility and convertibility of the structure are of great importance. For this purpose, it should be possible to adapt to changed usage requirements with the lowest possible cost and resource consumption.

Column-free floor plans offer maximum flexibility for interior design. Floor ceilings can be constructed with a span of up to 20 m [8], industrial halls with girder spans of up to 60 m. In the case of main and secondary girder ceilings, a flexible arrangement of the supports along the main girder increases the flexibility of the usable areas on the ground floor [7].

Load bearing reserves for later changes of use can be planned in advance in an appropriate framework. For example, buildings in mixed areas on the lower floors could be designed for increased working loads of 3.5 to 5 kN/m² in order to enable variable usage options. In addition, reserves for changed expansion loads, e. g. for lightweight partition walls, should be considered. In the case of industrial/commercial use, dynamic traffic loads and, if necessary, additional load cases such as "lift truck impact" or the subsequent installation of a crane runway can be taken into account for later functional changes or expansions.

With an appropriate design of the bagle frames and eaves supports, subsequent hall expansions are possible without any problems. In this context, modular concepts can be important because they contain reproducible interfaces and (re)combination options. When separating the facade from the supporting structure and using detachable connections, facade panels can be dismantled in the event of expansion and reassembled at another location. In multi-storey buildings, the possibility of adding a later floor can be planned in advance through structural details and taking the corresponding loads into account.

Interactions: The consideration of a subsequent working load change or extension usually requires larger, initially unused cross-sections as well as corresponding connection details and thus greater material expenditure in the manufacturing phase. They therefore have an effect on the life cycle assessment (LCA) of the manufacturing phase.

2.2.4 Thermal comfort

The concrete core activation makes use of the thermal storage capacity of the concrete and stabilizes the interior temperatures in summer and winter. It not only ensures an extremely comfortable room climate – without air turbulence, but also reduces the energy required for heating and cooling the building. The thermal properties of the concrete have a positive effect on the room climate in summer heat protection; Thermal energy can also be specifically stored. Further information is available in e. g. [7].

Interactions: For a most flexible floor plan possible, office rooms in particular are usually designed with light weight interior finish, double floors and suspended ceilings. Due to these constructions, there is often a lack of thermally effective storage mass in such rooms, especially when there are no solid inner walls available for thermal use. Information on the combination of the requirements “high flexibility of use” and “thermal storage mass” is given in [10]. The effect of concrete surfaces on the room acoustics must be taken into account in the planning.

2.2.5 Sound insulation and room acoustics

Due to their heavy weight, concrete components offer ideal conditions for optimal sound insulation.

To improve the room acoustics on unclad surfaces, suspended ceiling sails, baffles or other plane absorbers can be arranged. Special concretes or structured concrete surfaces can also contribute to a better room acoustics.

Especially with regard to thermally activated reinforced concrete ceilings (see 2.2.4), absorber strips concreted into the ceiling can be used, which achieve practical absorption spectra for office use with very little influence on the thermal performance. Further information is available e. g. in [11].

Interactions: Sound-absorbing materials on concrete surfaces can reduce their thermal effectiveness.

If cavities are specifically arranged in the ceiling cross-section for reasons of resource efficiency, the sound insulation properties must always be checked.

2.2.6 Thermal protection

Heat and moisture protection properties of the building envelope influence the energy demand, the comfort and the durability of a building. With appropriate detailed planning and training, concrete structures can be constructed with practically no thermal bridges and with a high-quality appearance. Buildings can be thermally optimized in particular with reinforced concrete sandwich facades. Guidance on this sustainability aspect as well as an extensive collection of details is provided in [12]. However, greater attention must be paid to the recyclability and sustainability of the thermal insulation materials used. Interesting alternatives can also arise with new concepts of graded or open structures concrete cross-sections, especially in ceiling systems.

Interactions: In the event that the supporting shell of reinforced concrete sandwich facades is used as a load-bearing outer wall, additional supports can be omitted. However, this affects the flexibility, since, for example, the facade panels cannot simply be exchanged or reused in the event of an expansion of the structure.

2.2.7 Fire protection, durability and robustness

To ensure durability, the effects from the environment and the ***requirements in use*** must be realistically assessed. The concrete is composed to match the resulting stress (exposure classes). A high, constant quality is guaranteed by controlled manufacturing conditions and permanent self-control.

The required ***fire resistance time*** of components made of concrete can be achieved simply and cost-effectively by choosing a suitable cross-section, depending on the requirements in use. Concrete does not increase the fire load and does not develop toxic gases or strong smoke in the event of a fire.

Concrete structures are practically ***maintenance-free*** due to the durability and resilience of the building material.

Interactions: The consideration of maintaining or dismantling a building is always "***PRO value retention***" in terms of sustainability. When considering existing buildings, however, the so-called *"Replacement building"* with a durable, robust and flexible new concrete structure can also be a sustainable solution [13].

2.2.8 Recycling and reusability

The subsequent dismantling at the end of the life cycle of the structure must be taken into account at the planning stage.

Whenever possible, in the interests of sustainability, the aim is to reuse the entire building or individual components. For this, e. g. reusable precast concrete parts, which can be dismounted nondestructively if detachable connections are used, allows for a planned dismantling of the building and contribute to reducing the amount of waste and the consumption of resources. In the case of innovative concrete construction methods with non-metallic reinforcement, the questions of recyclability and reusability must be considered in the planning. In some cases, with these concrete construction methods, the pure separation of concrete and reinforcement is not yet technically or economically possible.

Crushed concrete has proven itself as a coarse aggregate in concrete or as an unbound filling material in road construction, where it replaces primary raw materials. In 2018, the recycling rate of crushed concrete was over 90 % [14]. Reinforcement that is separated from the concrete is 100 % recycled as steel scrap.

The use of coarse recycled aggregates in load-bearing components is regulated in [15]. Depending on the exposure class and type of recycled aggregate, up to 45 % by volume (concrete components inside buildings) of the coarse natural aggregates can be replaced by coarse recycled aggregates without the need for a separate or significantly more difficult design and construction of the components compared to the Technical Building Regulations is. It should be noted that recycled aggregate is currently only available regionally for the production of concrete for load-bearing components. A comprehensive supply of concrete manufacturers with suitable recycled aggregates is not yet given1).

Interactions: The use of recycled aggregates in concrete influences its ***workability*** due to the increased water requirement and the rather angular and rough surface of the crushed grains of the recycled aggregate. This must be taken into account in the concrete composition and concrete production.

3 Notes on the building material

3.1 Environmental product declarations for concrete

First and foremost, Environmental Product Declarations (EPDs) provide information about the environmental impact of a product (see also comments on Section 3.1). They serve the ***exchange of information*** and are used as a basis for the life cycle assessment of buildings in the course of the sustainability assessment. EPDs are not suitable for comparing building materials. The declarations apply to one cubic meter of unreinforced concrete produced in Germany for structural components (walls, ceilings, beams, stairs, etc.), underground engineering (components in contact with the ground, foundation elements, etc.) and civil engineering works (e.g. bridges). It does not matter whether these components are cast and concreted on site or delivered to the construction site as precast concrete parts.

---

1) The DAfStb will shortly begin work on technical rules to expand the use of recycled aggregates (other aggregate types, larger exchange quantities).

In the environmental product declarations, all ***life cycle phases*** of the concrete from the extraction of the raw materials to the deconstruction/demolition of the building and its reuse are taken into account (**Fig. 1**).

Product stage			Construc-tion stage		Use stage							End of life stage				Benefits and loads beyond the system boundary
Raw material supply	Transport	Manufacturing	Transport to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport	Waste processing	Disposal	Reuse-, Recover-, Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
x	x	x	x	x	x	MND	MNR	MNR	MNR	MND	MND	x	x	x	MND	x

Fig. 1: Overview of the declared life cycle phases for one cubic meter of unreinforced concrete

(x: included in life cycle assessment; MND: module not declared; MNR: module not relevant at product level)

Download the EPDs for concrete in compressive strength classes C20/25 to C50/60 as a PDF file at: https://www.beton.org/wissen/nachhaltigkeit/umweltproduktdeklarationen. Extensive background information on the concrete EPDs as well as assistance for the use of the data is contained in [16].

3.2 Transfer to the building

With the environmental product declarations for concrete, independently verified building material values are available in order to determine the environmental impacts that can be assigned to the concrete used in order to assess the ecological pillar of sustainability of a building. The ÖKOBAUDAT platform [18] provides all actors with a standardized database for the life cycle assessment of buildings. The total concrete volume of the construction (as far as known, differentiated into different compressive strength classes) only needs to be multiplied by the LCA-values per m³ of concrete.

The amount of reinforcement that is usually present must also be recorded. In addition to the data records in ÖKOBAUDAT [18], *ift* Rosenheim published environmental product declarations for reinforcing steel and welded wire mesh in June 2013 [19]. For more precise consideration of prestressing steel, EPDs already exist in Northern Europe, which can be used for simple comparative calculations. The life cycle assessor has to make appropriate assumptions on the basis of approximate degrees of reinforcement, since the amount of reinforcement has a significant influence on the balance, but is still subject to changes in the early planning phases.

An example building is presented in the comments to Section 3.2.

3.3 Notes on choosing and optimizing building materials

“A sustainable” building material doesn´t exist per se. The choice of building material, however, influences numerous criteria for sustainability considerations. At the same time, however, there are also many aspects that are independent of building materials, so that considering the sustainability of a building solely on the basis of the building materials used is inappropriate and wrong. This relates in particular to the results of the life cycle assessment (LCA).

As a rule, the environmental impact of an ***individual*** building product / building material is not a relevant factor for the sustainability of a building – the primary aim must be the optimizing of a building with respect to sustainability in a ***holistic*** sense.

In addition to the currently used concrete compositions, the cement and concrete industries are developing ***optimized cements and concretes*** with the lowest possible environmental impact. CO_2-efficient cements and concretes with a ***reduced content of Portland cement clinker*** can already be used in Germany. Clinker is the most important component of cement and ensures the strength of the concrete. In addition to clinker, other raw materials – so-called main constituents – are also used, depending on the type of cement. The composition depends on the type of cement and the proportions defined in the cement standard. The cements have different performance characteristics depending on their application in concrete. These are important from a structural engineering point of view because they can be used to produce concretes for different applications. In addition to these structural features, the CO_2 content has also been of great importance for a number of years. Reducing the clinker content is a lever to reduce the CO_2 footprint of cements and concretes.

The challenge is to further improve the CO_2 balance of the concrete or a component ***without losing sight of the technical performance***. Depending on the field of application, durability is the focus of considerations in addition to robust fresh concrete properties and practical strength development. Depending on the ambient conditions, the designer specifies the component-related exposure classes (see **Fig. 2**).

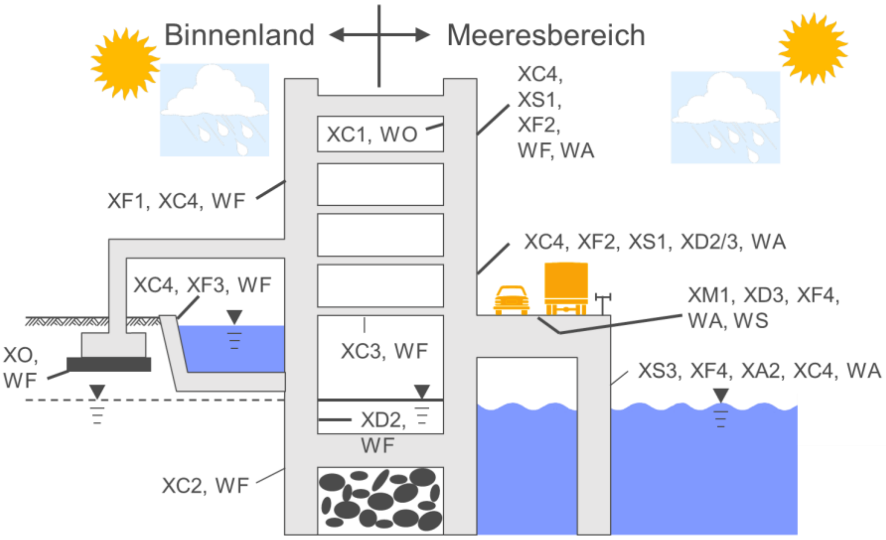

Fig. 2: Exposure and moisture classes on concrete component samples

As described above, the types of cement mentioned in the comments to Section 3.3 of this practical guidance can be used for concretes in normal building construction (internal components XC1 and external components XC4/XF1) (see page 15). The strength development of concretes with CEM II and CEM III/A cements, which is important for curing, is comparable under practical building conditions.

In principle, different cements with comparable technical performance are available for a construction task, for the production of which a different amount of CO_2 is released per tonne. Thus, it is already possible today to check whether a concrete based on a more CO_2-efficient cement has comparable technical properties for the specific application. The question of which type of cement is used in a ready-mixed concrete plant, a precast concrete plant or another application with comparable technical performance also depends largely on the availability of the raw materials. When specifying the concrete raw materials or concretes to be used, the locally existing and available resources must therefore always be taken into account. As consequence, it depends on good communication between those involved in the construction.

Interactions: The ***choice of building materials*** and the material-optimized design of the individual components, taking into account the suitability for conversion, improve the ecological balance of the supporting structure.

Resource conservation and a reduction in CO_2 emissions can also be achieved by using industrially produced or recycled aggregates (see 2.2.8). The use of recycled aggregates for concrete is already recommended for some of the state's own construction projects.

Interactions: When using industrially produced or recycled aggregates, care must be taken that they do not have any negative ***effects on the soil and groundwater*** and that they meet the legal waste requirements. In the case of recycled aggregates, this can be proven by compliance with the German standards [21] and [22].

The ***effects of the use of building materials on the local environment*** is another sustainability criterion in certification systems. The environmental compatibility of concrete is determined by the environmental compatibility of the constituents, for which either no separate verification is required on the basis of experience or for which corresponding verification must be provided, see [23].

4 Effects of planning decisions on execution

In the course of the planning and design of concrete structures, it should be considered that decisions about the structural design and the specification of building material properties always have an impact on the possible and necessary methods of execution.

In this respect, the designer must bring together the various aspects and consider the corresponding effects in the area of tension between dimensioning/structural design, choice of building materials and execution. With the German “BBQ approach” in the new German standard DIN 1045, a corresponding tool is available for this (BBQ = **B**eton**B**au**Q**ualität, see also [6]). Effects of the specifications of the planning are for example:

- The further reduction of the clinker content in the cement or the reduction of the cement content in the concrete leads to a slower development of strength and thus in some cases to significantly longer curing times and longer service times of the formwork. This additional effort must be taken into account when considering the total efforts to be made.
- An optimization and reduction of cross-sections always means that the concrete placement is only possible with increased effort. When optimizing mass in terms of reducing the amount of concrete, it is always important to consider the amount of work involved in building. The use of external vibrators may be necessary because the use of internal vibrators is ruled out for very slim and highly reinforced components.
- The use of recycled aggregates presupposes that they are available locally in the required quality and uniformity – however, this is beyond the sphere of influence of the contractor. When used, there may be increased transport and producing costs on the part of the building material production, which must be taken into account in the overall balance.
- In the case of recycled material (aggregate) that has only been homogenized to a limited extent and accordingly variating properties, unexpected fluctuations in the properties of the fresh concrete may

result, which require greater attention when placing the concrete and thus lead to greater efforts in the execution.

Depending on the construction task, further questions can arise in which specifications in the planning and in the selection of building materials limit the field of action of the execution and lead to increased expenditure there. In the case of sustainable construction with concrete, these interactions are considered together and in the sense of an overall balance.

5 Summary

The above statements show that in the complex weighing process, a decision to build with concrete has predominantly positive effects on the sustainability of buildings. This practical guidance supports the designer in making optimal use of the potential of concrete construction in terms of sustainability, without having to wait for new climate-friendly regulations.

An early coordination of all those involved in the construction is indispensable due to the requirements for sustainable buildings, so that suitable materials and construction methods are taken into account as early as the preliminary planning phase.

The environmental product declarations for concrete and reinforcing steel enable the designer to assess the environmental impact of concrete buildings already in the early planning phases, regardless of the different components, using the expected concrete cubic form and the amount of reinforcement.

This practical guidance was developed by the DAfStb board as the first concrete measure to implement sustainable building with concrete. The planning aid is embedded in a roadmap of the DAfStb, which – supported by research and guideline projects in the various committees – aims to make the concrete construction method climate neutral by 2045 [24].

6 References

[1] Leitfaden Nachhaltiges Bauen. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit. Berlin, Februar 2016.

[2] FDB-Merkblatt Nr. 10 zum nachhaltigen Bauen mit Betonfertigteilen, Ausgabe Juli 2019.

[3] Deutscher Ausschuss für Stahlbeton. Grundsätze des nachhaltigen Bauens mit Beton, Gelbdruck Juli 2014, unveröffentlicht.

[4] Graubner, C. A. et al.: Der Stadtbaustein im DAfStb/BMBF-Verbundforschungsvorhaben „Nachhaltig Bauen mit Beton“ / Dossier zu Nachhaltigkeitsuntersuchungen – Teilprojekt A – In: Schriftenreihe des Deutschen Ausschusses für Stahlbeton, Heft-Nr. 588 (2014).

[5] Müller, Chr.; Mohr, M.: Wie gelingt die Dekarbonisierung des Betonbaus in der Praxis? Beitrag für die Baukammer Berlin, 2/2021.

[6] DIN 1045-1000, Tragwerke aus Beton, Stahlbeton und Spannbeton – Teil 1000: Grundlagen und Betonbauqualitätsklassen (BBQ), erscheint voraussichtlich in 2022.

[7] Verbundforschungsvorhaben „Nachhaltig Bauen mit Beton“, Ressourcen- und energieeffiziente, adaptive Gebäudekonzepte im Geschossbau – Teilprojekt C. DAfStb Heft 585. Beuth Verlag, Berlin 2010.

[8] Betonfertigteile im Geschoss- und Hallenbau – Grundlagen der Planung. FDB e.V., Bonn 2021.

[9] Energieeffizienz im Hochbau. BetonMarketing Deutschland, Erkrath 2013.

[10] Wirksame Speichermasse im modernen, nutzungsflexiblen Bürobau – Leitfaden. Hofer, G.; Varga, M.; Grim, M.; Amann, S.: Nachhaltigkeit massiv AP 7. e7 Energie Markt Analyse GmbH, Wien 2009.

[11] Integrale Akustiksysteme für thermisch aktive Betonbauteile – Akustik in Betondecken. Drotleff; Wack. Forschungsinitiative Zukunft Bau F 2738. Fraunhofer IRB Verlag 2011.

[12] Planungsatlas Hochbau, InformationsZentrum Beton, Düsseldorf, s. www.planungsatlas-hochbau.de, zuletzt abgerufen am 19.10.2021.

[13] Bestandsersatz als ökonomische und ökologische Alternative zur energetischen Sanierung. Studie im Auftrag des Bundesverband Baustoffe – Steine und Erden e.V. April 2010.

[14] Bericht zum Aufkommen und zum Verbleib mineralischer Bauabfälle im Jahr 2018. Kreislaufwirtschaft Bau, Berlin 2020.

[15] DAfStb-Richtlinie Beton nach DIN EN 206-1 und DIN 1045-2 mit rezyklierten Gesteinskörnungen nach DIN EN 12620, Ausgabe September 2010.

[16] Nachhaltig bauen mit Beton – Begleitbroschüre zu den Umweltproduktdeklarationen Beton. Informations-Zentrum Beton GmbH, Düsseldorf, August 2020.

[17] Umwelt-Produktdeklarationen für Beton. InformationsZentrum Beton GmbH, Düsseldorf 2018.

[18] Baustoffdatenbank des Bundesministeriums des Innern, für Bau und Heimat (BMI); Version 2021-II vom 25.06.2021, s. https://www.oekobaudat.de/, zuletzt abgerufen am 19.10.2021.

[19] EPD Betonstahl (Kurzfassung). Badische Stahlwerke GmbH. ift Rosenheim, Juni 2013.

[20] Abschlussbericht „Auswirkungen der erweiterten europäischen Basisanforderungen für Bauwerke auf die Regelungen der harmonisierten technischen Spezifikationen“. Forschungsinstitut der Zementindustrie: TB-BTe B2275-A-2/2011. Auftraggeber: Bundesinstitut für Bau-, Stadt- und Raumforschung im Bundesamt für Bauwesen und Raumordnung (BBSR).

[21] DIN 4226-101, Rezyklierte Gesteinskörnungen für Beton nach DIN EN 12620 – Teil 101: Typen und geregelte gefährliche Substanzen.

[22] DIN 4226-102, Rezyklierte Gesteinskörnungen für Beton nach DIN EN 12620 – Teil 102: Typprüfung und Werkseigene Produktionskontrolle.

[23] Erläuterung des DAfStb zum aktuellen Regelungsstand der Umweltverträglichkeit von Beton (September 2020), s. http://www.dafstb.de/application/DAfStb_Umweltvertraeglichkeit_Beton_2020-09-07.pdf, zuletzt abgerufen am 19.10.2021.

[24] Nachhaltig bauen mit Beton – Roadmap des Deutschen Ausschusses für Stahlbeton (DAfStb) für einen klimagerechten und ressourceneffizienten Betonbau, Berlin im September 2021.

[25] Liste der Anwendungszulassungen für Zement des Deutschen Instituts für Bautechnik, s. https://www.dibt.de/fileadmin/verzeichnisse/NAT_n/vSVA_3.htm, zuletzt abgerufen am 19.10.2021.

[26] Concrete Sustainability Council, Hintergrundbericht zum CO_2-Modul, erscheint voraussichtlich Anfang 2022, s. a. https://www.csc-zertifizierung.de/, zuletzt abgerufen am 19.10.2021.

Comments on the practical guidance

To Section 3.1 Environmental product declarations for concrete

For cast in-situ concrete structures in building construction, concretes with compressive strength classes from C8/10 to C30/37 are predominantly used. **Table E1** gives extracts from the life cycle assessment values for a C25/30 concrete.

Table E1: Extract from EPD Concrete C25/30 – Results of the life cycle assessment for 1 m³ of concrete [17]

Environmental impact	Unit	A1-A3	A4	A5	B1[2]	C1-C3	D
Global Warming Potential (GWP)	kg CO_2-Eq.	197[1]	3,9	1,08	-10,0	21,11	-21,40
Depletion potential of the stratospheric ozone layer (ODP)	kg CFC11-Eq.	5,36E-8	0,77E-12	4,71E-12	0	1,61E-11	-1,32E-10
Acidification potential of soil and water (AP)	kg SO_2-Eq.	0,287	0,0099	1,60E-3	0	0,073	-0,047
Eutrophication potential (EP)	kg $(PO_4)^{3-}$-Eq.	0,0535	0,0024	2,57E-4	0	1,64E-2	-8,86E-3
Formation potential for tropospheric ozone (POCP)	kg Ethen-Eq.	0,023	-0,0034	1,11E-4	0	-6,95E-3	-2,79E-3
Potential for abiotic depletion of non-fossil resources (ADP_{el})	kg Sb-Eq.	0,64E-3	0,41E-6	5,36E-7	0	3,57E-6	-8,60E-6
Abiotic depletion potential for fossil fuels (ADP_{foss})	MJ	900,0	52,50	10,5	0	273,1	-227,00
Use of resources	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C1-C3**	**D**
Total renewable primary engery (PE_{ern})	MJ	190,0	3,5	5,89	0	34,5	-94,10
Total non-renewable primary engery (PE_{nern})	MJ	999,0	52,70	13,66	0	282,6	-279,0
Use of secondary materials	kg	23,0	0	0	0	0	2.400,0
Renewable secondary fuels	MJ	183,0	0	0	0	0	0
Non-renewable secondary fuels	MJ	348,0	0	0	0	0	0
Use of freshwater resources	m³	0,80	0,02	0	0	0	-1,28

[1] This does not include 29 kg CO_2-Eq. from the incineration of waste in the production of cement clinker. For further explanations see EPD text.

[2] Through carbonation, concrete components absorb carbon dioxide during their service life. For further explanations see EPD text.

For precast concrete components, concretes with compressive strength classes C35/45 to C50/60 are usually used. **Table E2** gives extracts from the life cycle assessment values for a C45/55 concrete.

Table E2: Extract from EPD Beton C45/55 – results of the life cycle assessment for 1 m^3 of concrete [17]

Environmental impact	**Unit**	**A1-A3**	**A4**	**A5**	**B1[2]**	**C1-C3**	**D**
Global Warming Potential (GWP)	kg CO_2-Eq.	286,0[1]	29,10	1,08	-10,0	21,11	-21,40
Depletion potential of the stratospheric ozone layer (ODP)	kg CFC11-Eq.	7,72E-8	5,75E-12	4,71E-12	0	1,61E-11	-1,32E-10
Acidification potential of soil and water (AP)	kg SO_2-Eq.	0,406	0,072	1,60E-3	0	0,073	-0,047
Eutrophication potential (EP)	kg $(PO_4)^{3-}$-Eq.	0,081	0,017	2,57E-4	0	1,64E-2	-8,86E-3
Formation potential for tropospheric ozone (POCP)	kg Ethen-Eq.	0,035	-0,024	1,11E-4	0	-6,95E-3	-2,79E-3
Potential for abiotic depletion of non-fossil resources (ADP_{el})	kg Sb-Eq.	1,02E-3	3,11E-6	5,36E-7	0	3,57E-6	-8,60E-6
Abiotic depletion potential for fossil fuels (ADP_{foss})	MJ	1.360,0	394,1	10,5	0	273,1	-227,00
Use of resources	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C1-C3**	**D**
Total renewable primary engery (PE_{ern})	MJ	282,0	26,5	5,89	0	34,5	-94,10
Total non-renewable primary engery (PE_{nern})	MJ	1.500,0	395,8	13,66	0	282,6	-279,0
Use of secondary materials	kg	11,0	0	0	0	0	2.400,0
Renewable secondary fuels	MJ	264,0	0	0	0	0	0
Non-renewable secondary fuels	MJ	502,0	0	0	0	0	0
Use of freshwater resources	m^3	0,88	0,01	0	0	0	-1,28

[1] This does not include 42 kg CO_2-Eq. from the incineration of waste in the production of cement clinker. For further explanations see EPD text.

[2] Through carbonation, concrete components absorb carbon dioxide during their service life. For further explanations see EPD text.

Beyond the information in the EPD, there are no environmental impacts or use of resources in the use phase (B1 to B5) due to the concrete during the reference service life of 50 years [1]. The recycling potential of concrete (D) compensates for most of the environmental impacts that arise at the end of life through the demolition of the building and the processing of the recycling material (C1 to C3). Some even by a wide variety.

The main environmental impacts arise in the production phase (A1 to A3). The most important influencing factors for a concrete of the compressive strength class C45 / 55 are shown in **Fig. E1**.

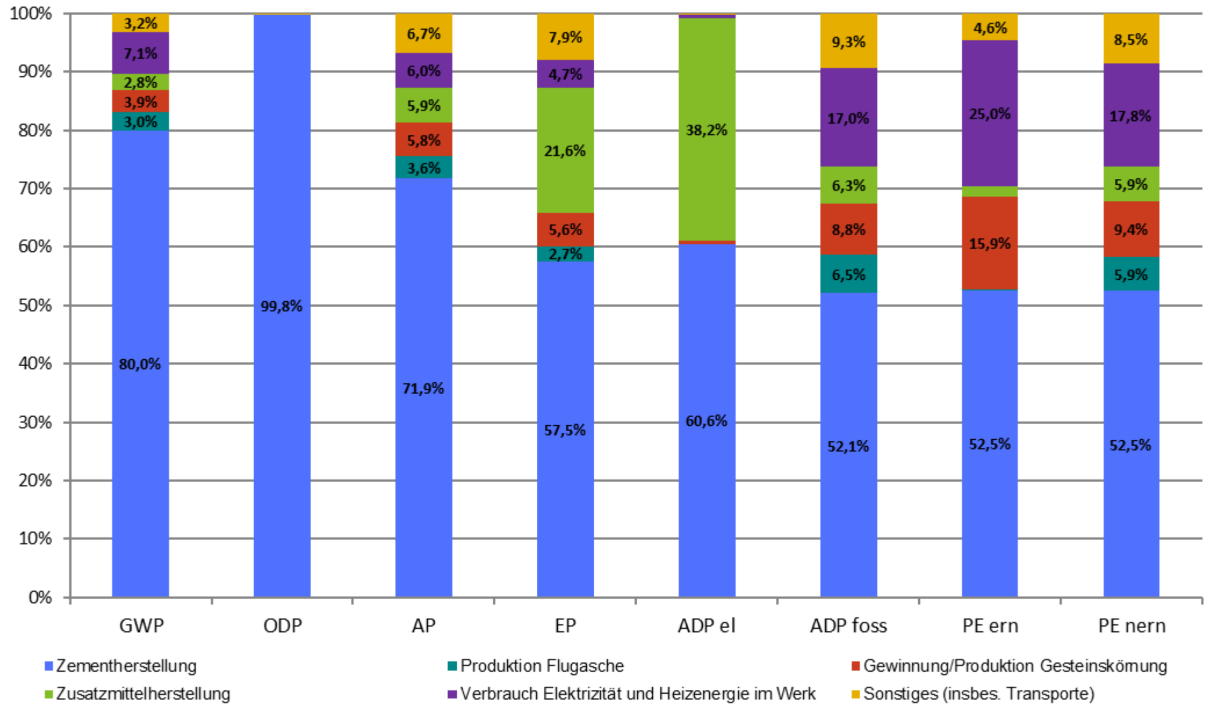

Fig. E1: Influential factors on the impact and life cycle inventory analysis for the production of concrete of compressive strength class C45/55 (A1 to A3) [17]

Used abbreviations:

GWP: Global warming potential,
ODP: Depletion potential of the stratospheric ozone layer,
AP: Acidification potential of soil and water,
EP: Eutrophication potential (overfertilization),
POCP: Formation potential for tropospheric ozone,
ADP$_{el}$: Potential for abiotic depletion of non-fossil resources,
ADP$_{foss}$: Abiotic Depletion Potential for Fossil Fuels,
PE$_{ern}$: Renewable primary energy, PE$_{nern}$: Non-renewable primary energy.

Translation of the explanations:

Zementherstellung = Production of cement,
Produktion Flugasche = Production of fly ash,
Gewinnung/Produktion Gesteinskörnung = Production of aggregates,
Zusatzmittelherstellung = Production of admixtures,
Verbrauch Elektrizität und Heizernergie im Werk = Consumption of electricity and heating energy in the plant,
Sonstiges = Others (especially transports).

On Section 3.2 Transfer to the building

In the following, the determination of the environmental impact is explained using an industrial hall made of prefabricated components. To determine the life cycle assessment of a building, the life cycle assessment data sets (**Table E3**) are applied to the total masses used. Exemplary determination of the ecological balance values for the precast concrete parts (girder, bars, columns, foundations) of an industrial hall (length = 47 m, width = 28 m, height = 10 m, approx. 1,326 m² net floor area) see **Table E4**.

Table E3: LCA data sets for 1 t of reinforcing steel B 500 and 1 m³ of concrete C45/55 (modules A1 to A5)

Environmental impact	Unit	1 t reinforcing steel [19]	1 m³ concrete C45/55 [17]
GWP	kg CO_2-Eq.	280	316
ODP	kg CFC11-Eq.	1,02E-04	7,72E-8
AP	kg SO_2-Eq.	0,766	0,480
EP	kg $(PO_4)^{3-}$-Eq.	0,0991	0,098
POCP	kg Ethen Eq.	0,0397	0,0112
ADP_{el}	kg Sb Eq.	3,71E-05	1,02E-3
ADP_{foss}	MJ	4.320	1.746
PE_{ern}	MJ	960	314
PE_{nern}	MJ	7.920	1.909

Table E4: Exemplary determination of the environmental impacts for an industrial hall (precast concrete parts only; modules A1 to A5)

Environmental impact	Unit	Industrial hall Amount of reinforcing steel 32.489 kg[1]	Industrial hall Amount of concrete 52,5 m³ C45/55	 Amount of concrete 154,4 m³ C35/45	Total per m² net floor area
GWP	kg CO_2-Eq.	9.096,9	16.590,0	39.245,4	49,0
ODP	kg CFC11-Eq.	3,31E-03	4,05E-06	1,05E-05	2,51E-06
AP	kg SO_2-Eq.	24,887	25,200	57,514	0,0811
EP	kg $(PO_4)^{3-}$-Eq.	3,21966	5,145	10,9898	0,0146
POCP	kg Ethen-Eq.	1,2898	0,588	3,4340	0,00401
ADP_{el}	kg Sb-Eq.	1,21E-03	5,36E-02	1,27E-01	1,37E-04
ADP_{foss}	MJ	140.352	91.665	187.488	317,1
PE_{ern}	MJ	31.189	16.485	37.548	64,2
PE_{nern}	MJ	257.313	100.223	206.581	425,4

[1] incl. prestressing steel.

On Section 3.3 Notes on the choice and optimization of building materials

The environmental impact of cement, which has a significant impact on the eco-balance of concrete, only accounts for 0.4 to 1.2 % of the sustainability certification of a fictitious office building [20]. On the one hand, this is due to the fact that the concrete does not cause any additional environmental pollution. The contribution to the environmental pollution from cement/concrete cannot simply be neglected due to the small share in the life cycle assessment of the building, it is foreseeable that the importance of the manufacture of the building and the building materials used will increase in the eco-balance due to increasing demands on the energy efficiency of the building during service life. Clinker-efficient cements have been used in Germany for many years, also because they can reduce the CO_2 emissions from cement production. The average clinker cement factor has been reduced from 86 % (1997) to 71 % over the past 25 years. As result, cement producers in Germany have made a significant contribution to reducing CO_2 emissions. The current concrete standards DIN EN 206-1 and DIN 1045-2 contain the application rules for standard cements depending on the exposure classes. If the concrete standards for a cement contain no or a very restricted application, the proof of suitability for use in certain exposure classes was and still is in these cases by a national technical application approval (az) from the “Deutsches Institut für Bautechnik (DIBt)”. Currently (as of June 2021) there are 27 of these approvals [25]. The following types of cement can therefore be used in all exposure classes:

- Portland cement CEM I,
- Portland slag cements CEM II/A-S and CEM II/B-S,
- Portland-burnt shale cements CEM II/A-T and CEM II/B-T,
- Portland limestone cements CEM II/A-LL,
- Portland fly ash cements CEM II/A-V and CEM II/B-V,
- Portland composite cements CEM II/A-M with S, LL, T, V or D[2)],
- Portland composite cements CEM II/B-M with S, T, V or D[2)],
- Portland composite cements CEM II/B-LL, CEM II/B-M and possibly CEM II/C-M with abZ (application approval az),
- Blast furnace cements CEM III/A[3)],
- Blast furnace cements CEM III/B[4)].

The new Portland composite cements CEM II/C-M, for which the first national technical approvals have been available for a few months, can be used at least for all exposure classes except XF2, XF3 and XF4. This regulation will also be included in the next edition of the concrete standard DIN 1045-2 for CEM II/C-M (S-LL) cements in about two years. Concretes for normal building construction (internal components XC1 and external components XC4/XF1) can be produced with all of the cements mentioned above, depending on availability. This is important insofar as around 65 % of in-situ concrete in Germany is used in these exposure classes. With a technical approval, these cements are allowed to be used in XF2, XF3 and XF4. Such approvals are also available.

Table E5 shows in line 5 the average CO_2 emissions associated with the production of one cubic meter of concrete today – expressed as Global Warming Potential (GWP) in kg CO_2 equivalents per cubic meter of concrete, based on the environmental product declarations for concrete (for more information see [17]).

As a guide, the table also contains values for concretes that would be 20 % or 30 % better than the average or up to 20 % above the current average with regard to the greenhouse gas emissions required for their production.

In addition to a classification based on the unit “kg CO_2-Equivalent per m^3 of concrete”, **Table E6** shows a representation taking into account the performance of the concrete, i.e. “CO_2-Equivalent per (m^3 concrete x MPa)”. This illustration shows the following:

- In the higher strength classes, the performance-related greenhouse gas emissions are lower than in the lower strength classes.
- This performance-related consideration makes sense if the higher strength is used by reducing the component dimensions, i.e. if the building is slim and CO_2 is saved in the production of the component.
- If higher strengths are justified for static reasons or due to the exposure class, without any material savings being possible, the CO_2 efficiency of the concrete can be described on the basis of these values.

[2)] (D-V) not in XF2/XF4.

[3)] Exposure class XF4: CEM III/A of strength class ≥ 42.5 N or strength class 32.5 R with up to 50 % by mass of blast furnace slag.

[4)] CEM III/B may only be used in XF4 for the following applications:
a) Seawater components: w/c ≤ 0.45; Minimum strength class C35/45 and c ≥ 340 kg/m^3
b) Scraper tracks: w/c ≤ 0.35; Minimum strength class C40/50 and c ≥ 360 kg/m^3; Observance of DIN 19569-1
Artificial air pores can be dispensed with in both cases.

The applicability according to exposure classes according to DIN 1045-2, Tables F.3.1 to F.3.3 must be taken into account. The values in lines 4, 5 and 6 can in principle be used for all concretes or concrete components for normal building construction (internal components XC1 and external components XC4/XF1).

Table E5: Orientation values for greenhouse gas emissions from concrete

1	**Designation**	**C20/25**	**C25/30**	**C30/37**	**C35/45**	**C45/55**	**C50/60**
2		Greenhouse gas emissions in kg CO_2-Equivalent/m^3 concrete					
3	Concrete for example with CEM VI or similar	125	138	153	171	200	210
4	Concrete for example with CEM III/A, CEM II/C or similar	142	158	175	195	229	240
5	Concrete, current average 1)	178	197	219	244	286	300
6	Concrete with CEM I	213	237	261	286	312	325

1) GWP values without incineration of waste in clinker production; see also tables E1 and E2, modules A1 to A3 for concretes C25/30 and C45/55.

Table E6: Orientation values for performance-related greenhouse gas emissions from concrete

1	**Designation**	**C20/25**	**C25/30**	**C30/37**	**C35/45**	**C45/55**	**C50/60**
2		Performance-related greenhouse gas emissions1) in kg CO_2-Equivalent/(m^3 x MPa)					
3	Concrete for example with CEM VI or similar	4,3	4,1	3,7	3,5	3,4	3,3
4	Concrete for example with CEM III/A, CEM II/C or similar	4,9	4,6	4,3	4,0	3,9	3,8
5	Concrete, current average	6,1	5,8	5,3	5,0	4,8	4,7
6	Concrete with CEM I	7,3	7,0	6,4	5,8	5,3	5,1

1) Calculation of the values based on average compressive strength f_{cm}, cube: Example C20/25, line 3: 125/(f_{ck} + 4) = 125/29 = 4.3.

It should be emphasized again that when specifying the concrete raw materials or concretes to be used, the structural requirements and the locally available resources must always be observed. Thus, it depends on good communication between those involved in the construction.

As shown above, the environmental impacts caused by the cement can be reduced by reducing the proportion of clinker in the concrete. The availability on the market of the "substitutes" used, such as fly ash, must be taken into account, but also that ecologically optimized concrete compositions can only be compared with conventional compositions if they can also guarantee constant strength, durability and quality.

In the production of precast concrete parts, for example, the concrete has a high early strength in order to achieve the shortest possible stripping times. Precast plants therefore often use higher concrete compressive strength classes with which the cross-sectional dimensions can be reduced. The recipes can be further optimized from an economic and ecological point of view thanks to the production conditions in the precast factory under permanent quality control.

Fig. E2 shows that the greater the concrete compressive strength, the greater the global warming potential per m^3 of concrete. In relation to the concrete compressive strength, however, the specific global warming potential of concrete decreases with increasing compressive strength class (see also **Table E6**). Correct assessment of the environmental impact of a building material can therefore only be made in connection with the specific building task and the boundary conditions there – i.e. at the building level.

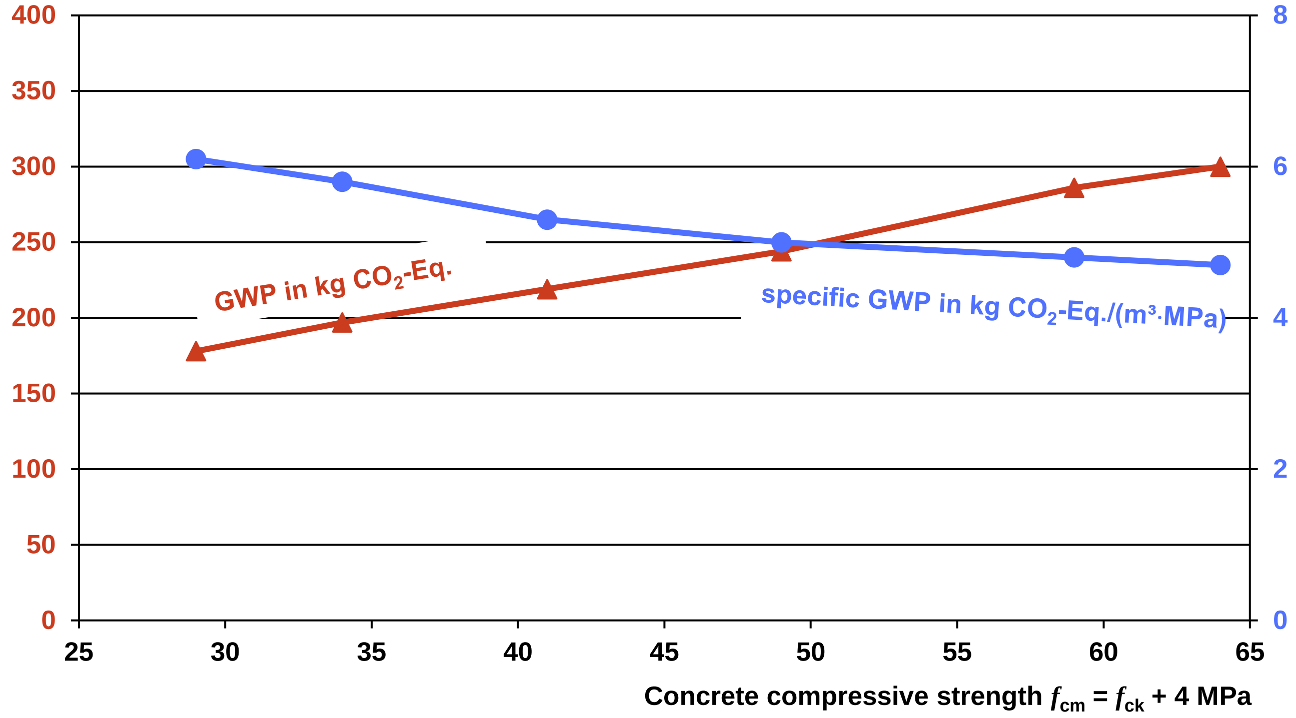

Fig. E2: **Relationship between concrete compressive strength and global warming potential (GWP) or performance-related global warming potential (specific GWP); Values from table E5, line 5 and table E6, line 5**

As part of the Concrete Sustainability Council (CSC), a global certification system was established, which is intended to provide companies in the concrete, cement and aggregate sector with information on the extent to which they are operating in an ecologically, socially and economically responsible manner in the production of concrete (CSC concrete certificate). The CSC works in the implementation with so-called regional system operators. In Germany, this task has been taken over by the German Ready-Mixed Concrete Association (Bundesverband der Deutschen Transportbetonindustrie BTB) and operates this system (source: www.csc-zertifikation.de).

A new “CO_2 module” as a voluntary, additional module to the CSC concrete certificate will soon be established. Its aim is to create transparency with regard to the greenhouse gas emissions associated with concrete production and to divide CO_2-reduced concretes into 4 CO_2-classes (see **Table E7**).

Table E7: **CO_2-classes according to [26]**

CO_2-class	**Description**
Level 1	Reduction of greenhouse gas emissions by at least 30 % compared to an average concrete with CEM I.
Level 2	Reduction of greenhouse gas emissions by at least 40 % compared to an average concrete with CEM I.
Level 3	Reduction of greenhouse gas emissions by at least 50 % compared to an average concrete with CEM I.
Level 4	Reduction of greenhouse gas emissions by at least 60 % compared to an average concrete with CEM I.

The CO_2 module is a certification at product level and does not replace an environmental product declaration (EPD) according to DIN EN 15804.

Today, CO_2-reduced concretes of levels 3 and 4 can only be applied in very few exceptional cases in accordance with the building regulations. Possible restrictions regarding the durability of the concrete, the construction and the availability of suitable constituents must be taken into account. The feasibility of each project must be clarified individually with the concrete producer.

Berlin, 2021-12-17

Translated from German by Udo Wiens
German Committee for Structural Concrete (DAfStb)
Budapester Straße 31
10787 Berlin, Germany
Mail: udo.wiens@dafstb.de