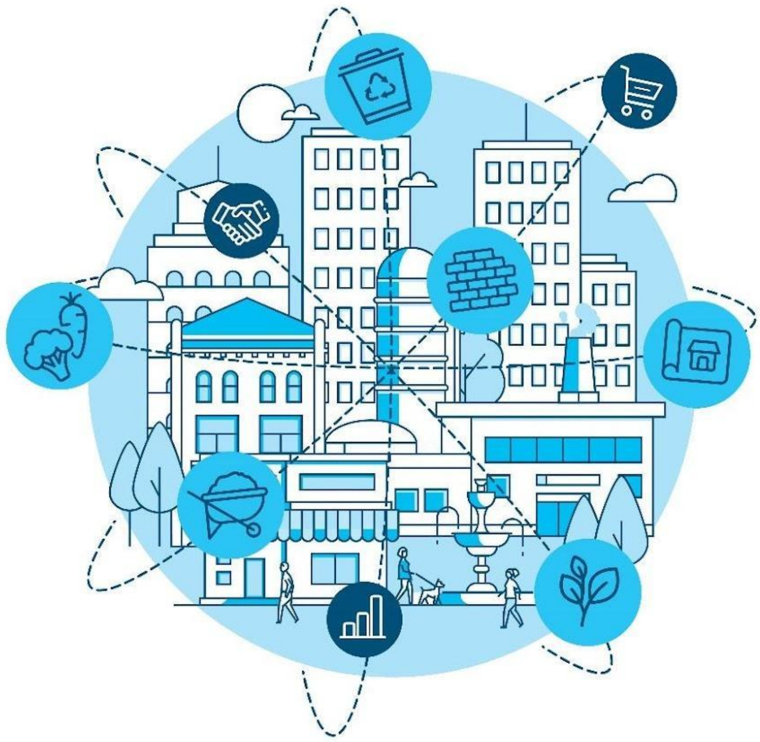
Guide for recycling concrete

Crushing and recycling concrete in new concrete on-site

Municipality of Roskilde, Denmark



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Briefly about the project behind the guide

As part of a new property strategy, the Municipality of Roskilde has decided to focus on circular economy. This means that the management of resources needs to be more sustainable.

This is no simple assignment. Therefore, the municipality participates in CityLoops with numerous development and pilot projects, which can generate knowledge and build experience for future projects.

"Recycling of concrete – from pilot project to a permanent change of practice" is one example of such a pilot project. And it has contributed with both hands-on experience with recycling of concrete and important knowledge of how circular economy can secure a more sustainable and environmentally friendly management of resources.

The project is part of CityLoops and the guide is developed in collaboration between the Municipality of Roskilde, Horten Lawyers and Pelcon Materials & Testing ApS – with contributions from a range of other actors in the construction industry. The project is based on a series of practical experiments with recycling of 1.000 tons of crushed concrete. All experiments are executed at Musicon in Roskilde where, amongst other, two slabs of recycled concrete have been casted and will be used as foundation for resources areas.


Application of curing membrane to the newly cast concrete. Photo: Torben Nielsen

About the guide

Purpose

If you as construction owner wishes to make requirements about recycling of concrete in your tenders, it is important that you are familiar with the practice, advantages, the legislation and complications connected to the processes behind recycling concrete. We hope that this guide will make you familiar with the required knowledge and create a foundation for more tenders with requirements for recycling concrete on site.

An increase in the amount of tenders with recycling requirements necessitates market involvement and volume. Both are fundamental for a transition to circular economy – when it comes to recycling of concrete and recycling in a broader sense. Many actors in the private sector already have experience in the field, but to create strong business models it requires that more companies dare to take on the transition to circular economy.

As a public construction owner, you are in the position to pave the way. Although many owners already make a big effort in the area, it is essential that experiences are shared with other owners. Experience and knowledge exchange are fundamental to the project in Musicon.

> This guide is meant as a step towards a common tender practice in this area amongst municipalities: A knowledge community that will develop and communicate results across municipalities and regions and thus support the transition to circular economy.

Content

The guide's main concern and focus is public construction owners, but it has been important to ensure that it is useful for different types of owners. Although the material in this guide specifically concerns the recycling of concrete, the described processes also address the transition to circular economy in a broader public authority context.

A CO_2 calculator is included as part of the guide, which provides the opportunity to assess the environmental gain by recycling concrete in specific projects. This means that you can assess whether the recycling of concrete makes sense in an environmental context already before the tender.

The guide also includes specific tender texts as appendices that you are welcome to use when you wish to make a tender with requirements for recycled concrete.

Please be aware that the guide describes recycling of crushed concrete in strength categories cf. DS/EN 206 DK NA. The guide does not replace legislation on the subject but is solely meant as a supplement.

Enjoy the reading.

The Sustainable Development Goals

The 25th of September 2015, world leaders adopted UN's Sustainable Development Goals at the UN summit in New York. This enactment marks a comprehensive and ambitious development agenda, which requires us all to take on a global responsibility and zoom in on those subjects where we as a global society can work for sustainable development.

The 6th of September 2019, the Danish parliament made a broad political agreement on a climate law that shall ensure Denmark reaches its goal of reducing greenhouse gases by 70 % (compared to 1990) by 2030. To succeed, it is important that all industries are on board – including the construction industry.

The construction industry can make a difference

Construction materials are responsible for a big part of the global CO_2 –emissions – both when they are produced and disposed of. The production of concrete alone produces more than 8 % of the world's total CO_2-emissions. At the same time, we are well on our way to use up some of Denmark's natural resources: The gravel pits are being emptied with a speed so great that e.g. the Capital Region of Denmark is expected to run out of gravel in 2027 if we do not reduce the consumption significantly. In short, construction is using up our resources in Denmark and globally. With the Sustainable Development Goals, we are required to think an extra time when constructing. What we build today must not limit the possibilities for future generations.

A common effort to reach specific goals

If we are to handle the challenge that follows the 17 Sustainable Development Goals, it is necessary to focus on specific solutions and results. Together.

In the project:" Recycling of concrete – from pilot project to a permanent change of practice", the Goals 8, 12 and 17 have set the direction and been decisive for a set of specific sub-goals in connection with the project.

SUSTAINABLE DEVELOPMENT GOAL 8, SUB-GOAL 4:

Resource efficiency in consumption and production and endeavor

Improve progressively, through 2030, global resource efficiency in consumption and production and aim to decouple economic growth from environmental degradation, in accordance with the 10-year framework programs on sustainable consumption and production. The developed countries must take the lead.

SUSTAINABLE DEVELOPMENT GOAL 12, SUB GOAL 2:

Sustainable management and use of natural resources

By 2030, achieve sustainable management and efficient use of natural resources.

SUSTAINABLE DEVELOPMENT GOAL 12, SUB GOAL 5:

Substantially reduce waste generation

By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

SUSTAINABLE DEVELOPMENT GOAL 12, SUB-GOAL 7:

Sustainable public procurement practices

Promote sustainable public procurement practices in accordance with national policies and priorities.

SUSTAINABLE DEVELOPMENT GOAL 17, SUB-GOAL 17:

Effective partnerships that build on experience and resource strategies

Encourage and promote effective public, public-private and civil society partnerships that build on experiences and resource strategies from partnerships.

Potential and challenges

The potential of recycling concrete – where crushed concrete makes up part of the aggregate – is obvious: Demolished concrete structures are already recycled in roads and similar today. But concrete can be recycled far better. The crushed material can replace new materials in concrete such as stone, gravel and sand, that Denmark will soon be running short on. While the gravel pits are being emptied, the transportation between pit and construction site increases, and so will the CO_2-emissions. By using crushed concrete in the production of new concrete on the construction site, we can avoid an upcoming resource shortage and reduce our CO_2 footprint.

So why is recycled concrete not a common practice? The potential is significant. This is due to several reasons. One being a question of time. The idea of recycling concrete as part of new concrete is still new and needs time to catch on and become an obvious choice similar to the none-recycled concrete.

Then, it also requires more of the owner. When working with recycled concrete you cannot simply order a truck with standardized concrete that can be used in all types of constructions. You need to stop and consider if you need the strongest type of concrete that can be acquired or if less is sufficient. This means you must make a deliberate choice. And you likewise need to take more responsibility in the process as you do not simply get your concrete delivered from the nearest factory.

Is it a disadvantage that recycled concrete makes the process more complicated? Yes, of course. But is it enough to erase the potential? Not at all. Recycling concrete increases the awareness of materials, reduces CO_2-emissions in connection with transportation, and is a sustainable solution to the steady increasing shortage of raw materials.

Before you begin

Processing the concrete on site

When you follow this guide, it is a central precondition that it is recycled locally – this means that the processes leading to the concrete being recycled all take place on the same location. There are two important reasons for this:

- It results in an environmental advantage because the concrete does not need to be transported over long distances.
- The crushed concrete will be classified with End-of-Waste instead of becoming classified as waste or a construction product because it is processed locally.

Identifying potential

When you as an owner consider whether it is suitable to recycle concrete in a specific project, you must assess it from an environmental, economic and time perspective. All three factors are more or less dependent. To do so, you may, for instance, use the CO_2-calculator that is described further on in the guide.

The role of the construction owner

To complete projects with requirements to use recycled concrete there is a need for a set of special qualifications. These qualifications will, in many cases, have to be found outside of the construction organization or included as requirements in the tender material.

It is not a standard requirement to request recycling of concrete in a public tender. As an owner you must therefore follow the tender process more closely than is normally required. This is due to the fact that tenders with requirements for recycled concrete are dependent on materials that must first be extracted by demolishing concrete structures. In other words: Your planning must include a mapping of your existing concrete structures with recycling potential, an overview of the need for aggregate materials, and an assessment of the time frame for the undertaking.

The owner also has a responsibility

Traditionally, the responsibility of the construction process lies with the advisor and contractor, but in projects involving recycling it can be a good idea to include smaller steps in the process where you as the owner take part. These steps can be aligned with the need for temporary storage of materials in intermediate depots and with different test samples. In this way, the owner gains the responsibility for the recycled material in one or several intermediate processes, which means the advisor and contractor may operate with a significantly lower risk. This will likely result in reduced costs.

As an owner it can thus be an advantage to take part in the construction process. It is also important to involve the authorities before the project begins. The better they are informed about the process beforehand, the more likely it is to avoid surprises during the project. At the same time, it is of course necessary to introduce potential project leaders to the different processes, enabling them to manage the project with that in mind.

Front loader fills aggregate in the mobile mixing plant. Photo: Torben Nielsen

Recycling levels A, B and C

Crushed concrete can be sorted into different categories of aggregate materials and may in that way replace new stone - and sand materials from a gravel pit – in different mixing ratios. The understanding of the mixing ratios is crucial to understand how crushed concrete can be recycled and become new concrete structures. In the following, you have an overview of the three recycling levels, which will be used as examples in this guide.

A

Level A

100 % of the stone fraction and 50 % of the sand fraction is replaced by recycled materials.

B

Level B

100 % of the stone fraction and 0 % of the sand fraction is replaced by recycled materials.

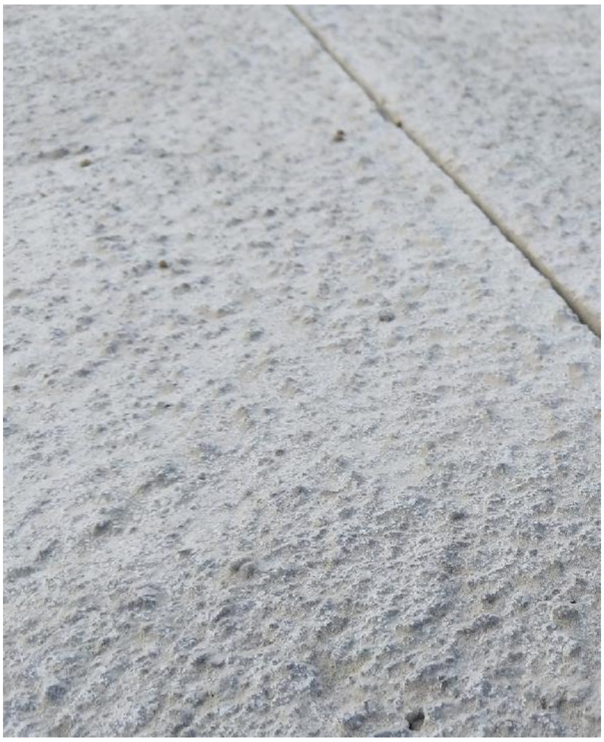
C

Level C

20 % of the stone fraction and 10 % of the sand fraction is replaced by recycled materials.

Sorting the demolished concrete in the three recycling levels – A, B, and C – requires knowledge of the quality of the demolished-concrete and its content as well as knowledge about advising and managing demolition and sorting processes to ensure no material is included that do not fit into one of the three levels.

Both level A and B introduce concrete compositions with a new level of ambition in the context of recycling crushed concrete. From 2021, both levels are covered by the DS/EN 206 DK NA.



Types of construction contracts and managing responsibility

Choosing the construction contract

The project group assesses that the two most suitable types of construction contracts in connection with recycling of concrete are subcontracting and main contracting. In the following pages you will read about the relevant differences between the two types.

Subcontracting

It is most appropriate to divide subcontracting in the following categories:

- Crushing, sieving and storage of concrete (on-site)
- Production of recycled concrete.

Every subcontractor is accountable to the construction owner within the boundaries of their own contract. The division with several subcontractors means that the work of the first subcontractor can affect the one who follows – and ultimately your legal position as owner. Therefore, it is important that you during the process ensure that the concrete is handled as agreed.

Advantages using subcontractors

Subcontracts may secure a more intense competition for the individual contracts because the number of actors in the field are greater. At the same time, the division into subcontracts can be suitable for projects where the concrete cannot be recycled right away but is in need of secure storing, until it can be recycled at a later point.

Disadvantages using subcontractors

Subcontractors require more from the construction owner. It requires more control of how the concrete is handled – and requires that the construction owner can control more subcontractors at once.

Soldering by particle size in the crushed concrete. Photo: Klaus Kellermann

Main contracting

A main contractor take care of the whole process including crushing, sieving, storage (temporary on-site storage) and production of recycled concrete.

The main contractor is responsible for all phases of the handling the concrete – from demolition to recycling.

This type of contract means there can only be one source of error if the handling of the concrete is insufficient.

It is therefore easy to place the responsibility, and it is not necessary for the owner to control every step of the process. Although the main contractor is responsible to the owner, the project team recommends that you carry out intensive supervision yourself, including with the fulfillment of the established outcome requirements (requirements for various tests to be performed).

Advantages with main contracting

The big advantage with main contracting is that only one actor is responsible for the fulfillment of the contract. This means there is no difficult legal or practical interfaces that may be challenging to handle. Often, you also need less resources in connection with the fulfillment of the contract (compared with multiple subcontracts).

Disadvantages of main contracting

This type of contracting may not be the best solution if the concrete is not to be recycled immediately after demolition, because the main contractor would then have to take responsibility (and risk) for the concrete for a longer period of time.

CO_2-calculator

When is recycling the right solution?

Recycling of concrete makes sense regarding several aspects: The use of crushed concrete in new constructions helps limit the need for new sand and gravel from our gravel pits. And recycling of crushed concrete helps reduce our total CO_2 emissions.

Driving with stones and sand from the gravel pits to the construction site emits large amounts of CO_2. The same is true when we drive crushed concrete away instead of recycling it.

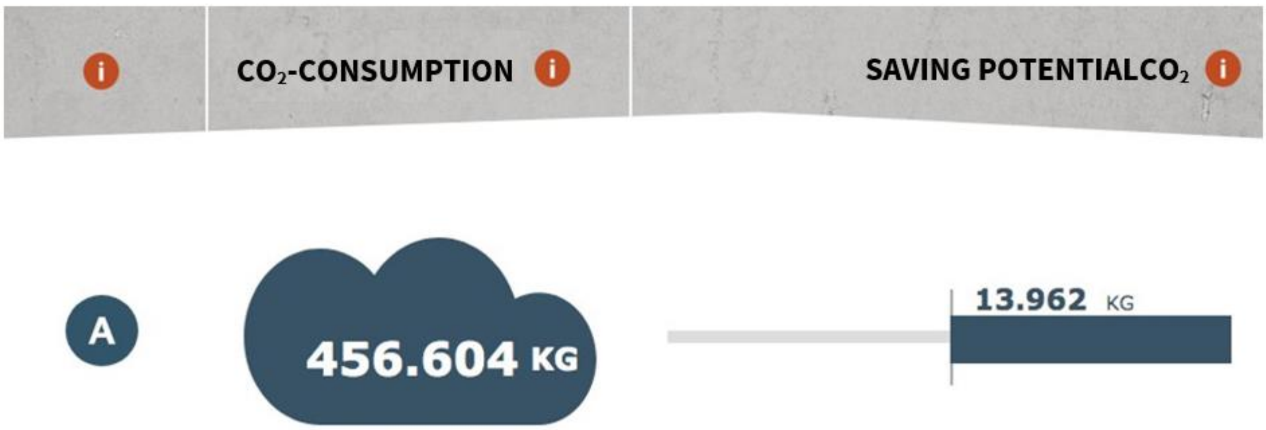
> 50 kilometers of driving with 1,000 tons of crushed concrete emits more than 4 tons of CO_2

The pilot project at Musicon has been accompanied by an online CO_2 calculator that can help you quantify the potential CO_2 savings associated with your specific project. This means that you can look at the potential of your own project to save CO_2 - instead of looking at average emission figures.

Tool for calculating possible CO_2 savings

In order to use the calculator to assess the environmental benefits from recycling concrete in a given construction project, you need to obtain a few informations. You have to quantify the amount of crushed concrete that is available - or can be expected to be available - and you have to find the distances to the gravel pit, place of landfill, recycling site and concrete supplier. Once this data is in place, you can use the online CO_2 calculator to calculate the amount of CO_2 emissions you can save if you choose to recycle concrete in your construction project.

The calculator is based on the three recycling levels, A, B and C, as described earlier, and compares the three recycling levels with the use of traditional mobile concrete for in situ casting as a reference value for CO_2 emissions. During the development of the CO_2 calculator, we have focused on providing a sufficiently uniform database for the two different processes (in situ casting with recycled aggregate material vs. the more traditional process with allocated concrete production



An example from the CO2-beregner.dk on a saving potential of recycled concrete level A.

and transport to the construction site for in situ casting with new concrete). The concrete recipe (the content of cement and aggregates) has therefore also been the same in both processes.

As this is a tool for calculating the CO_2 saving potential, the CO_2 calculator does not take into account the entire life cycle of each of the two processes but concentrates only on the elements that separate the two processes. It is therefore important to emphasize that the CO_2 calculator does not replace the need to make LCA calculations with dedicated tools, such as LCAbyg. LCAbyg is the market standard for LCA calculations in Denmark and can be downloaded free of charge at https: //www.lcabyg. dk

Preconditions of the calculator

It is a prerequisite for the CO_2 calculator that it not only uses generic data from different sources but is equally based on project-specific data such as distance to the landfill and the amount of crushed concrete. This means that the comparison between recycled concrete and mobile concrete - and their respective CO_2 emissions - is not static and can therefore never be seen as a general recommendation. Thus, it is only when you include the project-specific data in the calculation that you can use the result to assess whether recycling is the right solution.

Producing recycled concrete

On the following pages you can find a chronological review of all the processes associated with the production of recycled concrete. Each process is described as simply as possible.

Management and monitoring

The process behind the production of recycled concrete - including crushing, sieving and pile building - requires special skills. It is important that the work is managed and monitored by actors who have experience in this exact subject - and not just experience in industrial concrete production. Many things can go wrong, and it does not take much: A wrong surface, a soil-contaminated sieving plant, or 10 minutes of incorrect handling with a front loader is enough to destroy an entire production with recycled aggregate. Crushing 1,000 tons of concrete only takes half a day and the subsequent soldering takes about the same. The time spent monitoring the process is thus quite limited.

Examination of concrete before demolition

Before demolition, the concrete structure should be examined so that the condition and any damage are known. At the same time, it is a good idea to divide the concrete into different construction parts. Then, the task of examining the quality of the concrete may begin. This is done by extracting drill cores, examining the quality, and determining the recycling potential.

Also remember that environmental conditions during demolition, such as dust and noise, must be handled in accordance with the Executive Order on Environmental Activities - including the established rules and norms in the municipality in question. In the section "Examination of waste types" you can read more about contamination surveys of the concrete to be demolished.

New edition of DS / EN 206 DK NA

On 1 January 2021 the new Danish edition to the EU standard for recycling concrete came into force: DS / EN 206 DK NA: 2020. According to this standard, provided that certain requirements are met, it is now allowed in Denmark:

- to replace 100 % of both fine and coarse aggregate with recycled aggregate.
- to use recycled concrete in all exposure classes.

From 1 January 2021, a dispensation from the municipality is no longer necessary. Recycled aggregates that meet the requirements can be used in the same way as traditional aggregates.

The most important requirements for recycling aggregate are described in DS/ EN 206 DK NA:2020, section E.3.3 – see box below.

E.3.3 Recycled aggregate

The requirements of this sub-item include recycled aggregates. In addition, they include crushed process aggregates used by a group of concrete producers in quantities > 5% of the total aggregate quantity, as specified in point E.3.2.

General requirements:

b) Can only be used for concrete in normal or enhanced control class.

c) Can only be used in exposure classes XO and XC1, unless the aggregate manufacturer's production control system follows documented procedures, which ensure that the aggregate originates exclusively from concrete in exposure classes corresponding to the desired use in the aggregate. For recycled aggregates for which there is no prior knowledge, frost resistance and alkali reactivity must be documented for relevant exposure classes by supplementary studies in the form of frost/thawing-test as well as concrete prism test or petrographic documentation of content of alkali-reactive particles.

Supplementing requirements:

d) the aggregate must be sorted into fine and coarse.

e) density, absorption and chloride content must be determined by testing with the same methods and frequency, and requirements for continuous control as applicable to natural aggregate, cf. EN 12620 and this national annex.

h) E-modulus, creep and drying shrinkage of the concrete are documented, when applicable, and it is proved, to the appropriate extent, that the specific E-module, creeping and drying shrinkage are justifiable in relation to carrying capacity and construction safety. Methods and term are indicated in table DK NA-E.3.10.

i) coarse recycled aggregate shall meet categories from Table 20 of EN 12620: Rcu95, Rb10-, Ra1-, FL0,2- and XRg0,5-. Provision must be documented at least once per. year.

j) coarse recycled aggregate must meet categories (Rcu95, Rb10-, Ra1-, FL2-, XRg1-). Provision must be documented at least once a year.

(Extract from the DS/EN 206 DK NA:2020)

Table DK NA-E. 9 – Requirements for use of recycled aggregate.

Use in % by weight of the total aggregate amount

≤5%	>5%	
	Strength category ≤ C35/45	**Strength category > C35/45**
b. - c. -d. - e. - j. *	Requirements: ≤ 10 % fine and ≤ 20 % coarse t e s t : b. - c. -d. - e. - i.	Requirements: ≤ 10 % fine and ≤ 10 % coarse t e s t : b. - c. -d. - e. - i.
	Requirements: > 10 % fine and/or > 20 % coarse. Test: b. - c. -d. - e. -h. - i.	Requirements: ≤ 20 % fine and ≤ 50 % coarse. Test: b. - c. -d. - e. -h. - i.

* In this group recycled aggregate from concrete can be used, except from concrete from construction concrete, e.g. pipes and concrete products

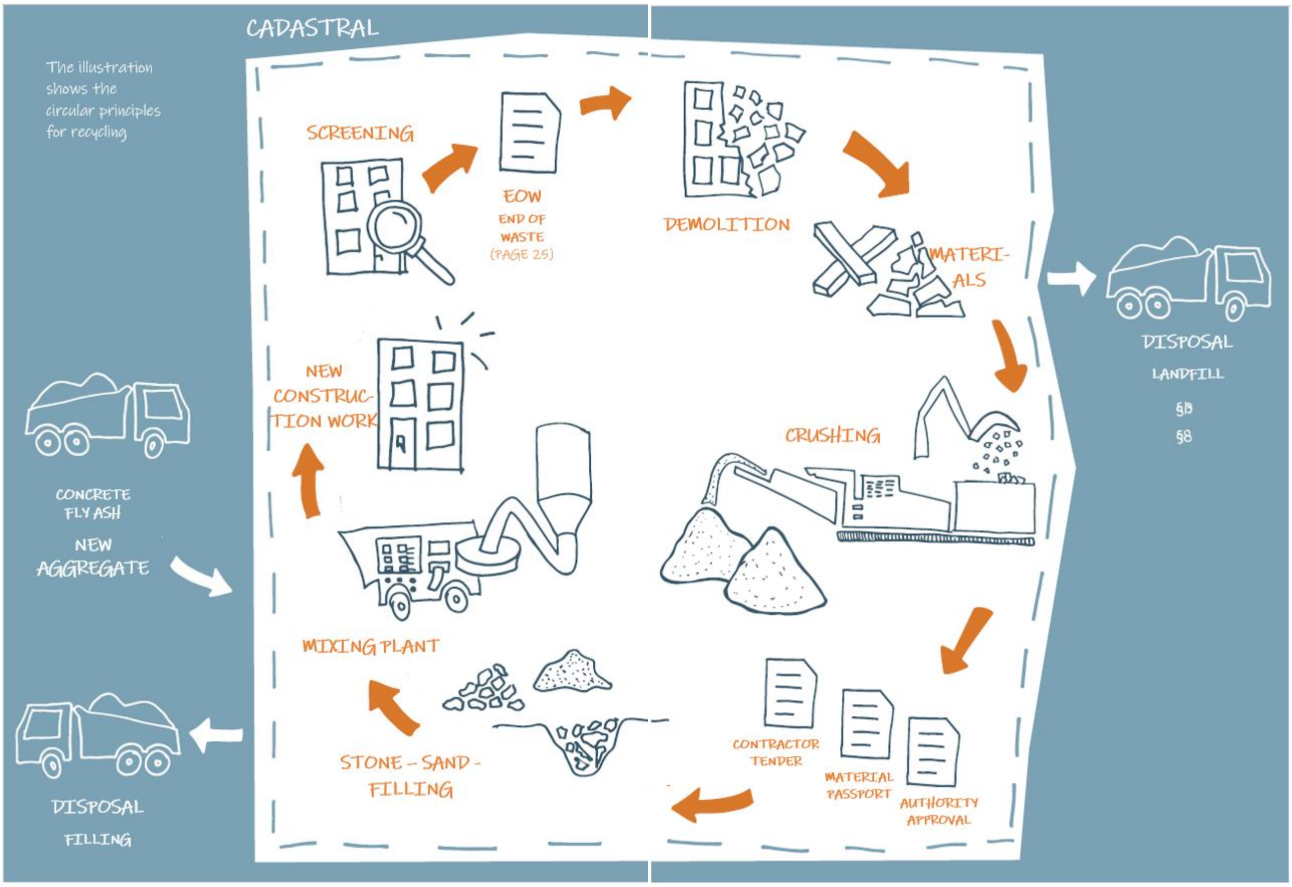
Recycled aggregates must originate from concrete for construction purposes. Aggregates from concrete products such as pipes, paving stones, lightweight concrete blocks, plaster and mortar from masonry constructions must not be used in the production of recycled concrete. However, concrete for construction purposes with cement and aggregates that meet this standard may be used. In case of doubt, it must be documented that the concrete is composed as construction concrete.

Table DK NA-E.10 – Testing methods and testing deadlines

	E-modul*	Creep*	Drying shrinkage and autogenous shrinkage *
Testing method	EN 12390-13	ASTM C512 or EN 12390-17	EN 12390-16
Term	28 days	7 – 56 days	7 – 56 days

*Testing is performed on the specific concrete composition.

(Extract from DS/EN 206 DK NA:2020)


CADASTRAL
The illustration shows the circular principles for recycling
SCREENING
EOW
END OF WASTE
(PAGE 25)
DEMOLITION
MATERI-ALS
DISPOSAL
LANDFILL
§19
§8
CRUSHING
NEW CONSTRUC-TION WORK
CONCRETE
FLY ASH
NEW AGGREGATE
MIXING PLANT
CONTRACTOR TENDER
MATERIAL PASSPORT
AUTHORITY APPROVAL
STONE – SAND – FILLING
DISPOSAL
FILLING

Aggregate materials for recycled concrete

Crushed concrete is an excellent aggregate material for new concrete production as long as the material is "healthy", well-documented, declared (according to DS / EN 12620) and meets the applicable requirements for recycled aggregate in accordance with DS / EN 206 DK NA.

When the desired maximum stone size, D_{max}, has been clarified in relation to the use of the concrete, reinforcement, cover layer, etc., crushing and sieving can begin, and piles of recycled sand (0-4 mm) and stone (the traditional fractions or a wide fraction, for example 4-25 mm), respectively, can be built. The piles can then - when they are ready and documented - be used in concrete production in the exact same way as natural aggregates.

Crushing

The actual crushing of the concrete takes place with a cone or jaw crusher. The optimal size of the crushed material is 0-32 mm. Then it can be categorized as stable gravel KVII according to DS401.

It is crucial that the chosen operator has knowledge of handling crushed material to be used as new aggregate. Some operators prefer crushing and soldering to take place at the same time - using crushing plants with separate soldering - but most operators choose to solder the material afterwards as it provides the opportunity to dispose of parts of the crushed material as e.g. road fill.

Sieving

Sieving of the crushed concrete can be done on 6 mm sieving and 28 mm sieving, respectively. In the pilot project at Musicon, the use of these sieves resulted in the 1,000 tons of crushed concrete (0-32 mm) being divided into three piles of 0-4 mm, 4-25 mm and 25-32 mm. The pile of 25-32 mm sieve was not used in the concrete production at Musicon.

After soldering, representative samples must be taken from the piles to be used in the concrete production (at Musicon: the piles of 0-4 mm and 4-25 mm), so that a general aggregate analysis can be made in accordance with DS / EN 12620. It is important to carry out density and absorption determinations according to a modified method (see Appendix 2), but all other testing of the recycled aggregate can be performed according to the methods specified in DS / EN 12620.

Experience shows that new concrete with recycled aggregate often has improved fresh concrete properties due to better grain shape and lower density. When crushing concrete, it has also been shown that the aggregate material almost automatically is divided into stone fractions that can be used directly in new concrete. No further soldering is thus required, and in the later concrete production you can make do with a single silo for stone aggregate.

Water saturation of aggregate materials

Recycled aggregates have a higher degree of absorption than natural materials. This is due to the content of cement paste. The finer the crushed concrete, the lower the content of natural stones among the grains - and the higher is the porosity and thus the absorption. Crushed concrete therefore takes significantly longer to become water-saturated - often days - than natural materials. This means that recycled aggregate (crushed concrete) that is not water-saturated will absorb moisture from the concrete during mixing. If this happens, the workability of the concrete will be considerably reduced in quite some time after the mixing, which can cause serious problems with both casting and durability.

The crushed material to be used as aggregate in the recycled concrete must be water-saturated before the concrete production is started.

The Danish autumn weather is usually a guarantee of abundant rain and thus water saturation of the material piles, while production in dry periods (and especially in summer) requires that the piles should be watered thoroughly in the days before use – e.g. with a garden sprinkler. As with all other concrete production, the content of free moisture in the aggregate materials must be determined, before the concrete production begins.

Remember that crushed concrete must be dried out for a significantly longer time than natural aggregate to determine the moisture content.

Mobile mixing plants

Normal/small mobile mixing plants have a significantly smaller production capacity than ready-mixed concrete. Therefore, ready-mixed concrete is always used at large castings. But for productions under 25 m^3 concrete per. hour, normal/small mobile mixing plants can easily solve the task if there is sufficient space on the construction site, and if the work can take place without disturbing potential neighbors with dust and noise.

A mobile mixing plant requires handling and participation of minimum three people:

- A certified and experienced mixer
- A person with an excavator/front loader for continuously filling the open material silos
- A concrete laboratory technician who tests the fresh concrete for set dimensions, air content and temperature and then casts and forms items for pressure testing

Handling of concrete on mobile mixing plants

Overall, there is no difference between ready-mixed concrete and concrete made on a mobile mixing plant. On a mobile mixing plant, the concrete delivery must of course also be adapted to the casting technique and speed, so the contractor's expectations and production capacity are in line. In connection with handling the concrete, however, there are several conditions that are different:

The concrete is produced and delivered in small batches - typically 1m^3.

- The height for emptying under the mixer requires the use of a flat crane bucket without a sock and emptying device – in other words, the low crane bucket must be tipped when emptied.
- Transportation using belts directly into a traditional crane bucket is not recommended as handling concrete with a high slump may result in unmixing the concrete.
- The concrete in the low crane bucket must be transported and lifted by a separate vehicle – e.g. a front loader/Manitou.
- The flat crane bucket can fill the concrete directly into the pump for the casting of tall walls.
- Using two crane buckets (one flat and one traditional with a sock) makes it easy to fill the concrete into the cast for the casting of moderate low walls.
- Using two crane buckets (one flat and one traditional) makes the concrete easy to place when casting floors and terrain decks.

Optimizing the recipe and mobile mixing plants

In all concrete production, a usable concrete recipe must be established to ensure that the properties of the concrete - workability, strength and durability - are met. Of course, this also applies to recycled concrete. The determination of such a concrete recipe is based partly on experience and laboratory tests, partly on the casting of standardized test specimens and the demonstration of strength and durability properties. Because concrete takes at least 28 days to develop strength, the casting of test specimens must be started at least 1½ months before the concrete must be produced.

Setting up and calibrating a mobile concrete mixer takes at least half a day and transferring and running a concrete recipe takes about the same amount of time. During this preparation, 3-6 m^3 of concrete will normally be produced, which cannot be included in the production, and must either be disposed of or used as filling, if/where possible.

It takes significantly longer time to determine the moisture content of recycled aggregate material due to the cement paste. This is important to be aware of in order to be able to adjust the mixture of the day and ensure correct concrete strength and workability.

Note that mobile concrete mixers must be certified batch mixers.

From DS/EN 206 DK NA:

The requirements for production control have been prepared based on the concrete being mixed on batch mixing plants. Concrete that is mixed in a continuous process in a mixing auger is not covered by this national annex and will therefore not be able to comply with it.

Example

Example of the manufacturing process from the project at Musicon

For the casting the concrete was driven from the mobile mixing plant using a front loader. The front loader was fitted with a flat cement bucket. The time spent on transportation was generally the limiting factor, so the concrete production often waited with a load of mixed concrete ready for emptying. Since the mobile mixing plant only had one silo for sand, the sand for the eastern construction site (which was made with level A concrete) had to be premixed in the mixing plant before the actual concrete production could begin. Having an extra aggregate material (both natural sand and recycled concrete sand) resulted in a slightly higher CO_2 consumption: Partly due to the logistics becoming a bit more complicated because it increased the transport of materials on site, partly because it required extra space on the construction site.

The mobile mixing plant at Musicon

The mobile mixing plant used for the casting at the construction site was a 1.2 m³ computer-controlled batching plant from Fibo Intercon. The plant was equipped with two open concrete buckets - one for sand and one for 4-25 mm recycled stone aggregate. In addition, the plant was connected to a cement silo and a fly ash silo. Both silos were placed on weight-cells so a consumption control and a comparison with the produced amount of concrete could be made. The mixing vessel was mounted directly on three weighing cells. The plant was calibrated by and in accordance with the instructions made by Fibo Intercon, and chemicals that were dosed via three separate pumps were both labeled and calibrated.

Construction waste

From waste to recycling

The Danish Executive Order on Waste (Executive Order no. 2159 of 9 December 2020 on waste) states that it is the municipal council that determines whether a substance or an object is waste. It is also the municipal council that determines whether waste is suitable for material recovery, including e.g. recycling.

The definition of "waste" in the Danish Executive Order on Waste:

"By waste this Executive Order understands any substance or object which the owner disposes of or intends or is obligated to dispose of."

The Danish Executive Order on Waste defines recycling as being:

"Any recovery operation where waste materials are reprocessed into products, materials or substances, whether they are used for the original purpose or other purposes. This includes reprocessing of organic material, but not energy recovery and reprocessing into materials meant for fuel or filling operations."

Once a substance or object is classified as waste, the demolisher and owner are faced with several legal and technical barriers.

The waste must be collected, assigned, handled and disposed of via the municipal waste schemes.

According to the Danish Executive Order on Waste, waste-producing companies must sort their building and construction waste into a number of fractions, including a concrete fraction.

This requirement applies if the total amount of waste from the construction work in question exceeds 1 ton.

Waste-producing companies must sort their waste at the source. And this requirement of sorting waste at the source means that the waste must be sorted at the place where it has been generated.

If the waste is sorted at the source in such a way that the concrete is suitable for recycling in level A, B or C, the owner can use the sorted recyclable concrete instead of using it as filler or disposing of it.

In Denmark since 2010, source-sorted recyclable commercial waste has been exposed to market competition. The municipalities have therefore not had the opportunity to establish arrangements or offer the collection of recyclable commercial waste. The intention is that the waste producers themselves must bear the responsibility for handling the waste.

The concrete waste that, due to defects/impurities, cannot be placed in one of the three levels A, B or C and thus cannot be recycled in a given project, will be used as filler or disposed of and will thus be included in the municipal waste schemes, since the owner disposes of the waste.

Waste can cease to be waste

The project "Recycling of concrete - from pilot projects to permanent change of practice" has, as mentioned, shown that the waste concrete - after sorting in recycling levels A, B and C - can be used by the owner outside of the municipal waste scheme. But the project has also shown that concrete waste after sorting and numerous of recovery operations can be classified as End-of-Waste according to the Danish Executive Order on Waste.

End-of-waste means that the waste ceases to be waste and is therefore no longer covered by the waste rules.

In addition to the fact that End-of-Waste is a goal in sustainable development and a circular economy, the legal effect will also be that the developer will not be charged a waste tax.

Examination of waste types

Prior to certain construction work, the owner must, according to the Danish Executive Order on Waste, carry out a screening of the building to determine whether the building may contain problematic substances, including PCB. Screening must be carried out for demolition work that produces more than 1 ton of waste and for replacement of double-glazed windows that have been manufactured in a certain period of time. Based on the result of the screening, a mapping of the building is carried out.

The Danish Executive Order on Waste also contains a requirement that the owner must submit a report to the municipal council. The report must include information on the expected waste quantities and types, etc.

The mentioned requirements - on screening and mapping for e.g. PCB - imply and presuppose that the demolisher/construction owner cooperates with the relevant environmental authority to examine which types of waste the building that is to be demolished contain. The owner must examine the waste and - if necessary - make samples. If this requirement is not met, an accurate report cannot be made to the municipality.

Waste can cease to be waste and instead get status as End-of-Waste, if

- the substance or object has undergone a recycling operation or another recovery process
- the substance or object is used with a specific aim
- there is a market for or demand for such a substance or object
- the substance or object meets the technical requirements for the specific purposes and complies with applicable legislation and standards regarding products
- the use of the substance or object does not have general negative effects on the environment or human health.

The work is carried out by examining historical data about the building, including its components and use.

It is always a good idea to make an environmental report or a log that follows the demolition and sorting process closely. In doing so, you ensure that the concrete fractions that are suitable for recycling are identified and determined WITHOUT the risk of mixing with those fractions that are not suitable.

Crushed concrete in three fractions. Photo:Klaus Kellermann

The Roskilde model for handling construction waste

As part of the experiment with recycling construction materials at Musicon, Roskilde Municipality has developed a procedure on how to handle construction materials from demolition. The aim of the procedure is to prevent that demolished materials which can be reused or recycled are perceived as construction waste or construction products with associated labeling requirements in accordance with the Construction Products Regulation.*

The construction waste that leaves the material flow is handled in the usual way by the local waste authority as it is unsuitable for recycling.

The advantage of the procedure is that the material never changes hands. It is always the same owner and thus does not fall under the Construction Products Regulation. In addition, the responsibility for the process is divided into several chunks, which you as the owner control yourself.

Furthermore, when you write a tender with requirements for reuse or recycled materials, there is already sufficient documentation (material passport) on the material for a contractor to use it directly.

The crucial thing for you, as the construction owner, is that you are ready to take on part of the responsibility in the process. All sample documentation has been made and can therefore be risk assessed in connection with recycling, just as usual. This means an incentive for recycling can be created in the market when the construction owner takes on part of the risk and leaves only the risk of execution to the contractor – a risk that this actor may influence.


Casting of test field. Photo:TorbenNielsen

The procedure is as follows:

1

The municipality assesses - on the basis of an environmental report - whether there are building materials from the forthcoming demolition that have the potential for recycling/rebuilding in future construction. If this is the case, it will be added as a tender requirement for selective demolition, where the demolition will have an outcome requirement for the purity of the materials in question.

2

When the demolition is completed, the demolished materials are checked in relation to tender requirements. If they meet the described requirements, they can be further tested for suitability for recycling. It is typically a specialist consultant who tests on a request made by the owner

3

Once the test results are known, the owner can assess whether the disassembled materials are of a type that

- can be recycled directly without further examination
- must be further examined before the suitability for recycling can be determined
- must be categorized as construction waste and leave the material flow because they are unsuitable for recycling.

4

The result is entered in a local material passport, which follows the material further in the process. Here you can read whether the material has been approved for recycling or further examination, and you can add special restrictions for the use of the materials to be examined. In addition to environmental conditions, the technical suitability for building and limitation are also stated in the material passport, which, together with the image, certificate, and analysis results, constitute an overall documentation for the material.

5

The local building authority approves the re-installation of materials with the accompanying material passport, if the documentation is adequate in relation to what the material is to be used for.

The legal framework for recycled aggregate

Management and execution of concrete structures must take place in accordance with a number of requirements for norms and standards (DS/ENs) on building and concrete structures, properties, production, etc. They all appear in the Building Regulation (BR 18, § 345):

BR 18 § 345 – Specifically applying to concrete structures

Management and execution of concrete structures must take place in accordance with the general rules for all structures cf. BR 18, § 344 and are specified in the form of several DS/EN's. In addition, concrete structures must comply with the special requirements for such structures in BR 18, § 345, which are:

1. DS/EN 1992-1-1. Concrete constructions, General rules and rules for building constructions with DS / EN 1992-1-1 DK NA.

2. DS/EN 1992-1-2. Concrete constructions, Fire technical dimensioning with DS / EN 1992-1-2 DK NA.

3. DS/EN 1992-3. Concrete structures for storage of liquids and powders with DS / EN 1992-3 DK NA.

4. DS/EN 206. Concrete, specification, properties, production and conformity and DS / EN 206 DK NA Concrete - Materials - Rules for use of DS / EN 206 in Denmark.

5. DS/EN 1520. Prefabricated reinforced elements of lightweight concrete with light aggregates and open structure with load-bearing or non-load-bearing reinforcement with DS / EN 1520 DK NA for lightweight concrete structures with lightweight aggregates.

6. DS/EN 12602. Prefabricated reinforced components of autoclaved aerated concrete with DS / EN 12602 DK NA for constructions of autoclaved aerated concrete.

See also the section "aggregates for recycled concrete".

Recycling level	A	B	C
Recycled sand, %	50	0	10
Recycled stone, %	100	100	20

Dispose sorted waste from the soldering process. Photo: Klaus Kellermann

The relevance of the recycling levels

Recycled aggregate level A and B are relevant for the production of concrete at both mobile mixing plants and concrete factories, while Level C is primarily relevant for factory concrete.

Level A

Recycling level A is very ambitious, but absolutely practically possible to implement without major challenges. On mobile mixing plants, level A (50/50 mixture of natural and recycled sand, respectively) requires either an extra silo or that the two types of sand are premixed before the concrete production is initiated. It is quite doable.

The challenge at level A is in relation to factory concrete. This is because there is a need for two additional silos for crushed aggregate in the sand and stone fraction, respectively. In addition, there is a risk that the crushed concrete in the sand fraction forms lumps in the - often - high silos, which creates production problems. It is especially when crushing 0–1-year-old concrete that the problem arises. This is because newer concrete potentially contains a certain amount of unhydrated cement, which can react with moisture in the silo.

Technical requirements for documentation - Level A

The recycled aggregate must be tested and documented in accordance with the requirements of DS / EN 206 DK NA and DS / EN 12620:

- DS / EN 206. Concrete, specification, properties, production and conformity and DS / EN 206 DK NA Concrete - Specification, properties, production and conformity - Rules for use of DS / EN 206 in Denmark.

- DS / EN 12620. Prefabricated reinforced components of autoclaved aerated concrete with DS / EN 12620 DK NA for constructions of autoclaved aerated concrete.

For each fraction of sand and stone, a series of laboratory tests must be performed, and the materials must be declared in accordance with current regulations. Note that in the case of a major continued production of recycled aggregate, the materials must be kept in piles, each of which must be tested. The measurement of the absorption and density of the recycled materials (in the laboratory) should be carried out according to a modified version of the test method (see Annex 2). The recycled materials do not have to be CE marked if they are supplied by the owner itself - and therefore are not a commodity.

Level B

In principle, there are no major practical problems with Recycling Level B: On mobile mixing plants
level B does not require an extra silo, as you can get by with the usual two aggregate silos - one for sand and one for coarse aggregate. For concrete produced at the factory, the challenge at level B is less than at level A, but an extra silo is still needed for crushed aggregate in the stone fraction.

Technical requirements for documentation - Level B

The technical requirements for documentation for level B are the same as for level A.

Level C

At level C, a small amount of recycled aggregate is "sprinkled" in the existing, natural materials. Level C is therefore primarily the natural choice for ready-mixed concrete, where the solution can slowly but surely consume all factory waste without significant problems. However, the beneficial impact on resource consumption is limited and it does not provide any actual CO_2 savings.

For mobile mixing plants, level C is not an appropriate solution. The practical challenges of mixing the natural materials with small amounts of recycled concrete will most likely cost more CO_2 than can be recovered. In other words, both more work and a higher price for a lower CO_2 account.

Technical requirements for documentation - Level C

At Level C, the materials must also be tested in accordance with the requirements of DS / EN 206 DK NA and DS / EN 12620 - exactly the same as at level A and B.

Control checks for properties and strength

The production of recycled concrete is surrounded by the same requirements for documentation and control as all other concrete production in scope and frequency in accordance with DS / EN 206 DK NA:

- The fresh concrete must be tested according to the DS / EN 12350 series for set dimensions, air content and temperature, and the results must be approved before the concrete can be installed. Concrete that does not meet the requirements must be discarded and must not be built in.

Samples must be casted, demolded and stored for pressure testing. The strength of the hardened concrete must be tested on test specimens after typically 2 and 28 hardening days according to the DS / EN 12390 series.

Material from demolition. Photo: Klaus Kellermann

A thank you to all the contributors

This guide has been made in collaboration with:

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Casting of base plate. Photo: Torben Nielsen.

Word list

Absorption determination: Calculation of water quantity in aggregate materials.

Aggregate analysis: Common term for various analyses that can be made of aggregate materials, e.g. humus content, petrographic description and sieve analysis.

Aggregate material: The main component of concrete. Aggregates usually make up between 65 and 75 % of the volume of the concrete. Traditional aggregates consist of natural sand and stone materials and crushed rock.

Cone Crusher: Type of crusher that is primarily used to crush natural stone of various kinds.

Creep: When a concrete body is exposed to a force / load, a momentary deformation will occur, which over time will continue to grow, even if the force / load is unchanged. It is called creep.

Crushing: Crushing of material into smaller fractions that can be further processed.

Density determination: Calculation of the density / density of the concrete.

Drying shrinkage: Reduction of either the length or volume of a material due to altered moisture content. Drying wind can cause cracking.

E-module: Modulus of elasticity / E-module: A number that describes the ability of a material to withstand elastic deformation under strong influence.

End-of-Waste: The phase in which waste ceases to be waste because the cumulative provisions of the Executive Order on Waste have been met.

Exposure class: Cf. DS / EN 206-1. Replaces previous environmental classes.

Factory concrete: Common name for concrete produced at a concrete factory. Also called ready-mixed concrete.

In situ casting: Casting of concrete structure on site.

Jaw crusher: Type of crusher used primarily to crush natural stone, concrete, and rubble.

Mobile concrete: Factory concrete that is used for in situ casting on construction sites – e.g. with a concrete cannon.

Mobile concrete mixing plant: A mixing plant that is built on a frame with wheels and can therefore be transported.

None-hydrated cement: Cement that has not yet been in contact with water and therefore has not formed a shell of binder / cement paste that increases the density and strength of the material.

Process aggregate: Common name for different types of aggregate, e.g. washed out process aggregate, crushed process aggregate and recycled aggregate.

Rebuilding: Process in which crushed concrete is used as aggregate material in new concrete.

Recycling: Any recovery operation in which waste materials are reprocessed into products, materials, or substances, whether used for the original purpose or for other purposes.

Resource efficiency: Central part of the product circle in circular economy (together with increased recycling and reduced waste generation).

Resource strategy: Part of the management basis for waste management in Denmark.

Sand fraction: Fraction that typically covers material with a grain size of 0-4mm.

Sieving: Sieving of material into fractions of certain grain sizes.

Sorting at the source: Sorting of construction and demolition waste into different fractions at the place where the waste is generated. The majority consists of concrete, brick, asphalt, soil and stone, and the vast majority can be recycled.

Stone fraction: Fraction that typically covers material with a grain size of 4-35mm.

Strength class: The compressive strength class of concrete is an expression of the characteristic compressive strength in MPa at 28 days hardening. The strength class is stated as e.g. C20 / 25, where the first number indicates the cylinder compressive strength (fck, cyl), and the second number indicates the cube strength (fck, cube).

Appendix 1: Tendering

It is the project group's perception that, at present, there is so limited experience with recycling concrete that there will be very few - if any - actors who can meet a minimum requirement for previous experience in such tasks. It is therefore the project group's recommendation that minimum requirements are only applied if the construction owner has a clear expectation that the market players can meet it.

Tender texts

Note: The tender texts below are based on a precondition that the contract is put to competition in the process of obtaining tenders, in accordance with the Public Procurement Act[1].

The appendix has been prepared as an inspiration catalog. It is therefore not a requirement (and in some cases not appropriate) to incorporate all elements of the following in a tender.

The appendix is structured around the following legal procurement topics:

- Capability criteria
- Award and sub-criteria (competition parameters)
- Contract requirements.

Capability criteria

The term "Capability criteria" is used for the criteria established by the owner in order to be able to assess the companies' (general) capability to carry out a tendered task. The assessment of the companies' capability is based on documentation of the companies' experience.

Experience with the recycling of concrete can be brought into play in several phases of the capability assessment. See example 1.1 and 1.2. In example 1.1, the requirement for experience is described as a minimum requirement:

Example to use for filling in 1.1

It is a requirement that the applicant has performed at least [x] similar tasks within the last five years from the application deadline. In this context, "similar tasks" means tasks which include (a) crushing of concrete, (b) sieving of concrete, and (c) recycling of concrete. To be similar, a task must contain **[the elements (a), (c) and / or (c)].**

In limited tender processes (i.e. tender processes with pre-qualification), the owner must, on the basis of some pre-stated criteria, select the applicants who will have access to submit tenders. An example of a wording for selection can be found in Example 1.2, which makes it possible to "reward" an applicant who has relevant experience without setting minimum requirements. As an alternative to a restricted, competitive bidding, the owner may choose to use a tender invitation (i.e. where the owner selects the field of tenderers). In that case, it is important that the owner ensures that the invited tenderers have the necessary experience.

Example 1.2

In the selection, the owner will select the [number of deployed] applicants who have the most experience with similar tasks. In this context, "similar tasks" mean tasks which include (a) crushing of concrete, (b) sieving of concrete, and (c) recycling of concrete. An assignment must, in order to be similar, contain **[the elements (a), (c) and / or (c)].**

1 Legal Order 2007-12-07 no. 1410 on obtaining tenders in the building and construction sector.

Competition parameter

Competition parameters are those criteria set by the owner in the tender that determine which of the offered solutions best meet the selected award criterion. Within the Public Procurement Act, the owner must choose between the award criterion "the lowest price" or "the most economically advantageous tender", cf. section 8 of the Public Procurement Act. If the criterion "the most economically advantageous tender" is chosen, the owner must determine a range of sub-criteria (competition parameters). Example 1.3 contains a proposal for a qualitative competition parameter.

Example 1.3

When assessing the proposals in relation to the sub-criterion "Quality", the owner will emphasize the extent to which the offered measures support the fulfillment of the established outcome requirements.

For the purpose of the owner's evaluation of the proposals in relation to the above criterion, the tender must contain a description of the measures that the tenderer will initiate to achieve the agreed outcome requirements, including, for example:

- additional training
- control plans
- supervision / quality assurance.

In the evaluation, emphasis is solely placed on the measures that go beyond the requirements contained in the tender basis.

Contract requirements

In particular, the following categories of contract requirements will be relevant to consider - regardless of whether the contract is offered in subcontractors or main contractor:

- **Outcome requirements**
  To the extent that the tenderers have competed for the "robustness fulfilment" of outcome requirements (Example 1.3), it is important that the winning tenderer is contractually obliged to realize the offered solution, see Example 1.4.

- **Outcome requirements and documentation**
  Outcome requirements must be met, just as the contract basis must describe the relevant documentation requirements (sampling). The owner may consider penalties for non-compliance with outcome requirements. However, the project group finds it important that the owner does not prevent the recycling of concrete through too restrictive sanctions, and considers whether the owner, by getting involved in the project, can reduce the risk that outcome requirements are not met (see e.g. Example 1.5).

- **Education**
  Securing recycling requires special insight, and this insight is - right now - not common. The project group therefore recommends that the owner makes training in the recycling of concrete available as a deliverable of the owner. The deliverable implies that the owner undertakes the task to train the relevant crew, see Example 1.5. It is a crucial precondition for the owner to be able to undertake this training, that the teaching is done by competent persons.

- **Financial management instruments**
  To ensure that the Contractor fulfills the Contract in accordance with the agreed, the owner may consider making use of one or more financial management instruments, see Example 1.6 and Example 1.7.

Example 1.4

The contractor is obliged to the owner to realize the tender basis in accordance with their proposal.

Example 1.5

To ensure that the persons employed by the Contractor under the Construction Contract have a minimum understanding of the recycling of concrete, the owner conducts a **[basic introductory course in the recycling of concrete]**. All persons who are engaged in the fulfillment of the Construction Contract are obliged to participate in this course. With the teaching, the owner assumes no responsibility for the Contractor's correct fulfillment of the Contract. It is thus up to the Contractor to ensure that the Construction Contract is fulfilled in accordance with the agreed.

Example 1.6 [Plan for the payment]

The contractor's remuneration is due for payment in accordance with the following payment schedule:

Rate 1: Sampling of demolished concrete (purity and strength) []%

Rate 2: Sampling of concrete after installation []%

Rate 3: Delivery * []%

* It is a condition for "Delivery" in accordance with the Construction Contract that the Contractor has performed all work, including quality documentation, operating instructions, etc. is submitted to, checked and approved by the owner.

It is also a condition for "Delivery" that a delivery transaction has been carried out covering all work, and that no significant deficiencies have been identified in this.

Example 1.7 [Ongoing documentation for quality assurance]

It is crucial for the owner to receive documentation showing that the work has been carried out in accordance with the Construction Contract and its appendices.

The Contractor is therefore only entitled to payment for work for which the Contractor has provided documentation for the fulfillment of the agreed outcome requirements. The contractor must - before the invoice can be sent to the owner - submit a draft invoice as well as documentation for documentation of the work covered. Final invoice cannot be sent to the owner until the owner (or his advisor) has approved the Contractor's draft.

Appendix 2: Modified method for determining density and absorption

Determination of density and absorption

In DS / EN 12620 it is specified that density and absorption of aggregates must be determined in accordance with DS / EN 1097-6. However, in the case of crushed concrete aggregates, this method should be modified to give an accurate result.

Modified method for determining density and absorption for aggregate of crushed concrete

Unlike natural aggregate, which consists predominantly of particles with relatively comparable properties, crushed concrete consists of particles with very different properties - from almost pure stones to lumps of porous paste.

According to DS / EN 1097-6, coarse aggregate must initially be washed on the 4 mm and 32 mm sieves. In aggregates of crushed concrete, sub-grains (<4 mm) consist primarily of fragments of mortar and cement paste. These sub-grains are both lighter and have a higher absorption than the fraction > 4 mm, which to a greater extent consists of stones and stones with a little mortar.

If the aggregate is washed, the increased absorption and lower density of the lower grains will not be taken into account, and the measured density and absorption properties will therefore not be accurate to the material.

PELCON therefore recommends using the following alternative method in determining the density and absorption of crushed concrete aggregates:

1. The material is tested as received.
2. A representative sample (twice the normal amount of material, cf. DS / EN 1097-6) is brought to a water-saturated surface-dry state condition.
3. The sample is divided into two.
4. Each sample is weighed.
5. One sample is used for density determination, e.g. in a pycnometer as described in DS / EN 1097-6.
6. The second sample is used to determine the absorption, i.e. dry in a heating cabinet at 105 ° C to constant weight.

By using this method, you both avoid washing the sample, and thus changing the properties of the total material, and also avoid having to pour the water from the sample into the pycnometer. In the standard version of the density and absorption determination, there is a risk of losing some of the fine material when the water is poured off.

It is not a good solution to measure the density and absorption of lower grains separately and subsequently include this in the total absorption. The sand material must also be wet sieved in accordance with DS / EN-1097-6 before the measurement is performed. Thus, the presumed high absorption in the 0-63µm fraction, which consists almost exclusively of cement paste particles, is lacking.