Sustainable concrete

Designers manual to possibilities for more sustainable concrete

What is sustainability to us?

Concrete is the most commonly used building material in the world nowadays, while it contributes to 5% of the total production of carbon dioxide (CO_2). [1]
As designers we believe that concrete is an important point of intervention when looking at more sustainable building materials. The knowledge of the different possibilities to make concrete a more sustainable material can give designers and researchers the power to influence the concrete industry and as a result contribute to a more sustainable world.
The technologies reviewed can be included in the context of the 3R's of sustainability:

Reduce: produce concrete that needs less energy for production or use. Also reducing material with high performance concrete.

Reuse: reuse elements of concrete in the production phase or concrete as a whole in the use phase.

Recycle: recycle elements of concrete and use them in the production phase.

Acknowledgements

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Eleni Sionti, Michael Hermelijn, Vincent van den Aardweg
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Why is concrete not sustainable?

Concrete has two main disadvantages with regards to sustainability, which put it in the centre of regulatory parties and the public: The production of cement is high resources and energy demanding, contributing to the atmospheric pollution; and concrete deteriorates by time, which affects its service behaviour, design life and safety. [2]

Manuals focus

This manual is intended for future designers and researchers interested in new sustainable posibilities of concrete. Our focus is therefore not optimisation of concrete with conventional methods like prestressed or hollow core sections, but rather with a focus on sustainability.

The technologies reviewed are in different levels of development, from early stage, late stage research to fully developed products. The main scope is to show the possibilities and directions for future researchers and designers, rather than showing the exact research procedure that every technology follows.

To this end, the further reading section will provide further sources on the presented technology or researches that follow different approaches but have the same scope. To provide a wide range of possibilities, the sources used vary from technical reports and papers to manufacturing websites and website articles.

How to read this manual

The headers of each technology are repetitive, and are set up as follows:

Production process
In this part you will find information of what changes in the process or composition of the concrete.

Properties
After knowing what changes in the process the relevant properties can be read.

Advantages & disadvantages
This section gives a quick overview of the advantages and disadvantages of each technology.

Impact on design
Here the way the technology has influence on the design is shown.

Case references
To illustrate the new possibilities and to inspire designers a case reference is shown.

State of research
This icon indicates how far the research has progressed. One bar indicates the product is in the early research phase, two bars indicate that it is in the later research phase and three bars indicate that the product is available on the market.

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Production proccess	✓	✓	✓	✓	✓	✓	✓	✓	✓
Properties	✓	✓	✓	✗	✓	✗	✓	✓	✓
Advantages & disadvantages	✓	✓	✓	✓	✓	✓	✓	✓	✓
Impact on design	✓	✓	✓	✓	✓	✓	✓	✗	✓
Case reference	✓	✓	✗	✗	✗	✗	✗	✗	✓
State of research	✓	✓	✓	✓	✓	✓	✓	✓	✓

1

Basics

The main principles of how concrtete was invented, forgotten and reinvented are reviewed. The typical production process of concrete is presented, the main advantages of concrete are emphasised and the life cycle is introduced.

+ History
+ Conventional concrete production
+ Why concrete?
+ Following a lifecycle approach

History of concrete

1.1

A review of the main milestones of concrete are illustrated [21], [22], [29].

12.000.000 BC

A reaction between limestone and oil shale during spontaneous combustion occurred to form a natural deposit of cement compounds. This was the first formed concrete.

amount of use

3000 BC

Egyptians were developing lime and gypsum mortars for use in the construction of their pyramids.

300 BC

The Romans are arguably the most famous users of concrete in the ancient world. Volcanic ash as slacked lime was used as cement like material.

126 AD

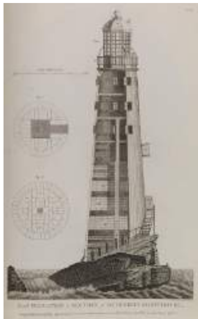
Romans create the Pantheon, a 42m unreinforced single span dome. Untill this day the largest in its class.

400 AD

They achieved great feats in architecture, some of which can still be seen today. After the fall of the Roman empire the art of concrete was forgotten.

1756 AD

John Smeaton rediscovers hydraulic cement for his Eddystone lighthouse design.

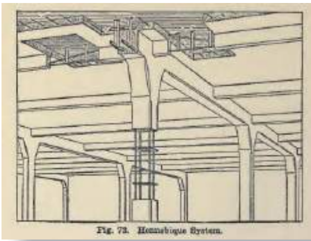


1824 AD

Portland cement is invented and named after the colour of a stone found on the Isle of Portland. This is still used up to date.

1889 AD

Alvord Lake bridge, the first reinforced concrete bridge. The pedestrian entrance to the San Fransisco's golden Gate park.



1892 AD

Hennebique, creates a reinforced-concrete construction system. Making columns, beams and floors a monolythic element.

1927 AD

Eugene Freyssinet invented pre-stressed concrete. Foto: Basilica of St. Pius X (1957)

1950 AD

Brad Bowman saw the potential of concrete as a decorative material instead of just a structural material. He used concrete as tiles, colored concrete and various other adaptations.

1970 AD

Fiber reinforced concrete invented.

1990 AD

Polished concrete developed.

What next ?

Conventional concrete production

Quarrying

Limestone and small amounts of sand and clay are extracted, usually from a quarry located near the cement manufacturing plant.

Raw materials preparation

The extracted materials are analyzed and blended with additional mineral components depending on the type of limestone available. Then they are finely ground for further processing.

Clinker production

The materials are heated in a kiln reaching a temperature of 1,470 C. The heat transforms the materials into a molten product called clinker, which is then rapidly cooled.

Cement grinding & distribution

The clinker is stored and then finely ground. Gypsum is added to control setting time, along with supplementary cementing materials, such as fly ash or slag, to obtain a fine powder called cement.

Mixing

Concrete is made by mixing sand, gravel, water, and cement.

Why concrete?

Durability

Concrete is highly resistant to heating and thawing. It's impermeable to air and wind-driven rain. As we can see in the examples of the Pantheon and the Collosseum in Rome, and pyramids in Egypt, concrete can last several millenia.

Energy-efficiency

Concrete provides a thermal mass that can store heat or cold, damping indoor temperature fluctuation.

Freedom of design

Unlike many other materials, concrete is not bound to fixed products and can be custom made to each project. The properties of concrete can be adjusted to meet the needs of a project, with the use of the adequate concrete class.

Freedom of treatment

Designers may also choose concrete for its adaptable color and surface. Besides the regular grey color the aggregate can be shown or a coloring agent can be added to the mixture to give the material as a whole a different color. These freedoms are a result of the production process.

Fire resistance

Concrete has low thermal conductivity, and a high thermal gradient. Sometimes it is used in hollow steel sections to improve fire resistance.

Life cycle approach

1.4

Getting familiar with concrete and changes suggested in this manual means knowing how the life cycle of concrete works. The three gray boxes in figure 1 show the main focus of this manual, how concrete can be made more sustainable in the production, multi use, and recycle & reuse phase.

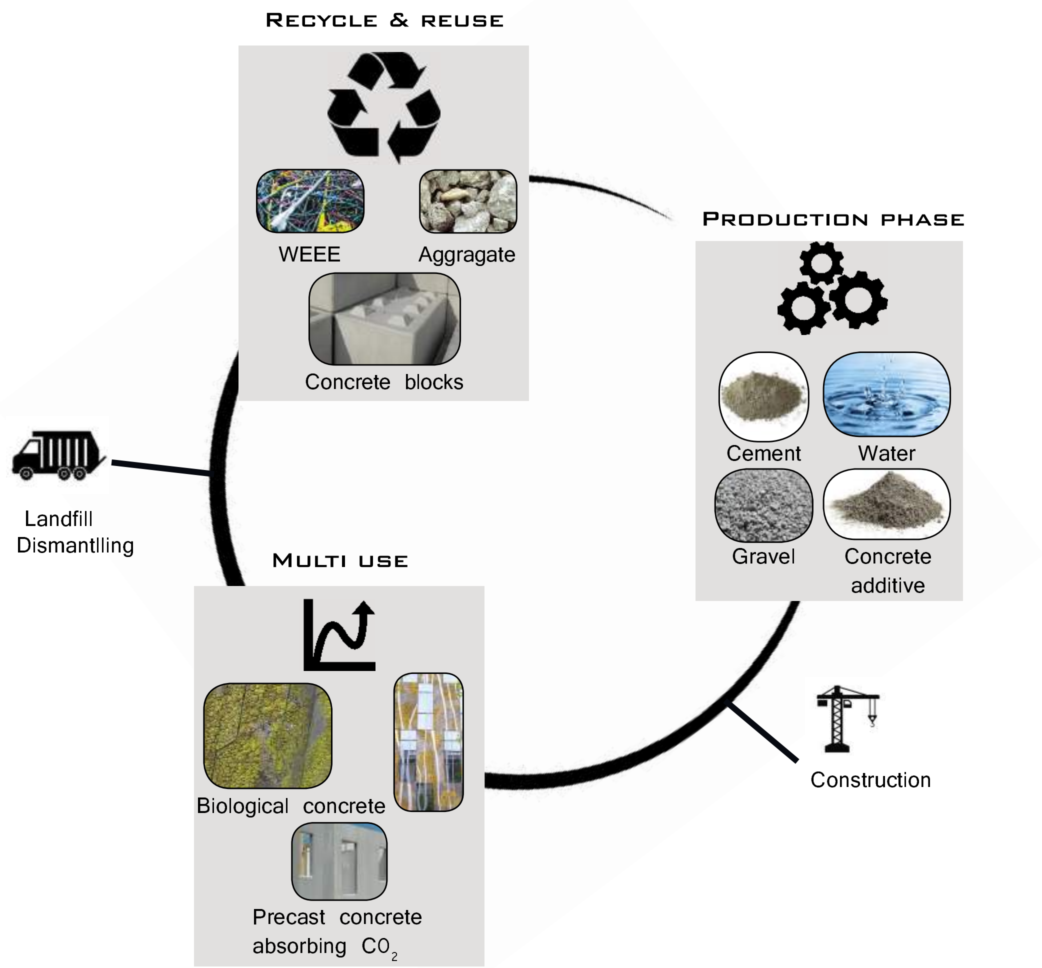


Figure 1: Life cycle of concrete, adapted from [8].

2

Production phase

The 5% of the industrial greenhouse – gas emissions is estimated to derive from the production of concrete. For this reason this phase is considered an important part of intervention. [1] The technologies presented in this section are related to concrete types that are produced with alternative methods than the conventional, giving a potential to sustainability of the concrete.

+ UHPFRC
+ Concrete with natural fibers
+ Greener cement
+ Self healing concrete

UHPFRC (Ultra High Performance Fibre Reinforced Concrete)

The first research activity related to Ultra high performance fiber reinforced concrete has started in early nineties. Several applications have been developed since then. The main features of this technology are summarized below.

Production process

The Ultra High Performance reinforced concrete is a high strength concrete reinforced with fibers. The concrete used has an improved homogeneity because fine sand is used instead of the coarse aggregates. [19] Specifically it comprises of: An ultra compact **cementitious matrix**, and **fibrous reinforcement**. These are illustrated in the following figure: [6]

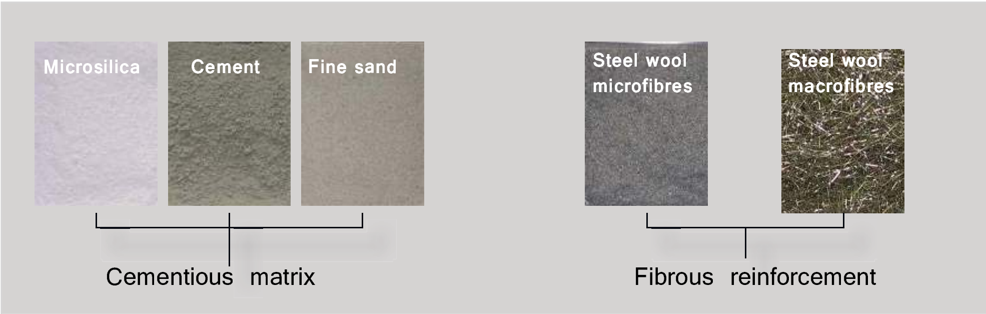


Figure 2: Ultra High Performance Fibre Reinforced Concrte ingredients adapted from [6].

Properties

Material characteristic	Range
Compressive strength (MPa)	180-225
Modulus of Elasticity (GPa)	55-58.5
Flexural Strength (MPa)	40-50
Density (kg/m3)	2440-2550

Table 1: Mechanical properties of UHPFRC.[7]

Advantages & disadvantages

The main advantages and disadvantages of this technology are illustrated in the following figure:

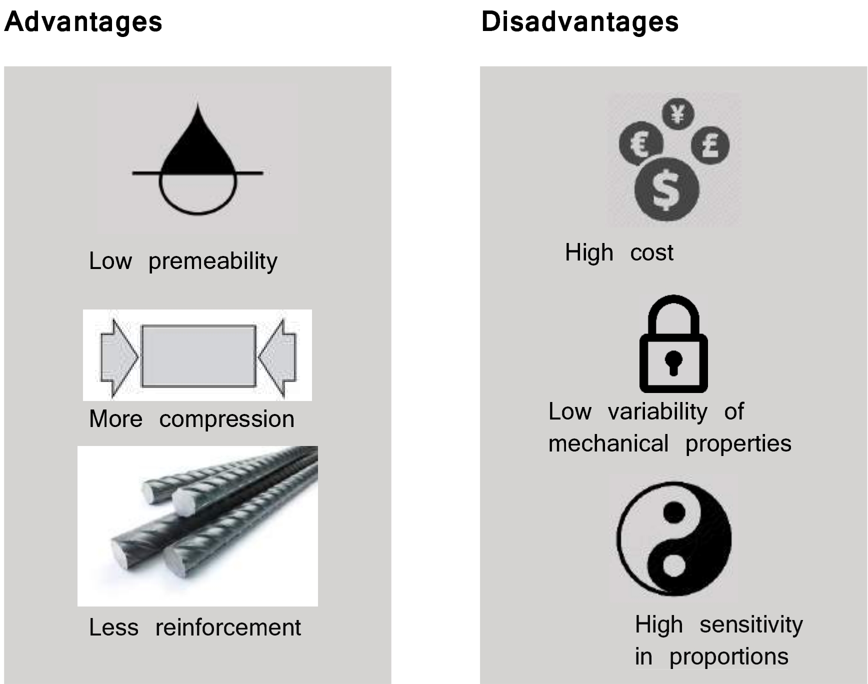


Figure 3: Advantges & disadvantages of UHPFRC adapted from [5].

Impact on design

The use of UHPFRC gives the possibility to reduces the structural **volume** by one fourth, by using less aggregate (-25%) and cement (-33%). The use of less material results in **bigger spans** offering **flexibility** to design. What limits this technology is the **high initial cost** which is not feasable in all projects. [19] The application of UHPFRC can be related to a number of fields, including [4]:

- Pedestrian and cycling bridges
- Traffic bridges
- Support beams for cooling towers
- Explosion resistant panels
- Shell structures (roofs)
- Strengthening existing structures
- Special application

Case Reference

The latticework of the **Jean Bouin Stadium** in Paris, designed by architect Rudy Ricciotti is an application of this technology. [47] The stadium is constructed by a UHPFRC envelope which is 30% perforated, with glass sealed in the gaps. This latticework has a number of advantages as it allows maintaining the unique character of the stadium, it offers a double curved morphology, is watertight and can provide a sound barrier.

Figure 4: UHPFRC application in Jean Bouin Stadium. [10]

Another application is the Museum of European and Mediterranean Civilizations MuCEM in Marcheille in France. The cladding is also made by UHPRC and designed again by Rudy Ricciotti. [49]

Figure 5: Cladding of the MuCEM in Marcheille in France. [49]

Figure 6: First standard UHPFRC bridge in Pijnacker, Netherlands. [50]

The first standard UHPFRC bridge in the Netherlands is opened to the public on October 2014. This is developed by the constructions engineers Pieters Bouwtechniek in collaboration with Hi-Con Netherlands.

State of research

As cost is considered the main disadvantage of this technology, research is focused on the optimization of cost parameters. In addition the re-arrangement of fibers in concrete to achieve better structural properties is also investigated. [51]

Further reading

- Toutlemonde, F., & Resplendino, J. (2011). Designing and Building with UHPFRC. State-of-the art and development. London: ISTE Ltd, John Wiley& Sons.
- Fardis, M. N. (2012). Innovative materials and techniques in concrete. Patras: Springer.

Concrete with natural fibres

Concrete is a material with high compressive strength but low tensile strength, showing brittle behavior. This means that concrete needs to be reinforced to improve its behavior in tension. This is usually done with steel reinforcement, which is expensive and high energy demanding. In this section the use of natural fibers in concrete is presented, as a more environmentally friendly approach.

Production process

Natural fibers can be used as **reinforcement** in the composites (cement paste, cement sand mortar and concrete). There are different types of natural fibers available, including coir, sisal, jute, eucalyptus grandis pulp, malva, ramie bast, pineapple leaf, kenaf bast, sansevieria leaf, abaca leaf, bamboo, palm, banana, hemp, flax, cotton, and sugarcane fibres. One of the most widely used is the coir fiber. [14]

Figure 7: Hemp, flax and coir fibres [42], [41], [40].

Properties

Properties vary according to the type of the fiber used. A full list of fibres can be retrieved from the relavant source. The properties of some fibers are illustrated in the following table [14]:

Fibre type	Diameter (µm)	Relative density (g/cm3)	Tensile strength (MPa)	Young's modulus (GPa)	Specific modulus (GPa×cm3/g)	Elongation at failure (%)
E-glass	<17	2.5-2.6	2000-3500	70-76	29	1.8-4.8
Abaca	-	1.5	400-980	6.2-20	9	1.0-10
Alfa	-	0.89	35	22	25	5.8
Bagasse	10-34	1.25	222-290	17-27.1	18	1.1
Bamboo	25-40	0.6-1.1	140-800	11-32	25	2.5-3.7
Banana	12-30	1.35	500	12	9	1.5-9
Coir	10-460	1.15-1.46	95-230	2.8-6	4	15-51.4
Cotton	10-45	1.5-1.6	287-800	5.5-12.6	6	3-10
Curaua	7-10	1.4	87-1150	11.8-96	39	1.3-4.9
Flax	12-600	1.4-1.5	343-2000	27.6-103	45	1.2-3.3
Hemp	12-600	1.4-1.5	270-900	23.5-900	40	1-3.5
Flax	12-600	1.4-1.5	343-2000	27.6-103	45	1.2-3.3

Table 2: Properties of natural fibres. [14]

Advantages & disadvantages

The natural fibers in concrete can improve a variety of **mechanical properties**, including flexural properties, impact resistance and fracture toughness. In addition, natural fibers are **cheap** and a **sustainable** alternative to metallic and synthetic fibers.

The main disadvantages of this technology include the **variability in properties** and the high moisture content and chemical absorption, leading to **less durability.** In addition volume changes can lead to **concrete cracking**, while an alkaline environment can lead to **weakening**, due to the poor interface between natural fibres and polymeric or cementitious matrices. [22]

Impact on design

The main impact of natural fibers on design is the contribution to a more sustainable approach in the use of concrete. This refers to the consumption of less energy, the decrease of gas emissions and the reduction of building cost and maintenance costs.

Case Reference

The use of coir (coconut) fibers in concrete has the potential for the development of sustainable concrete applications, for example roofing materials, wall panels/ boards and columns. Specifically, a Coconut Fiber-Cement Board (CFB) is developed by the PCA-Zamboanga Research Center, with the aim to replace traditional construction materials such as tiles bricks, plywood, asbestos and cement hollow blocks. [48] The application of the CFB is shown in the figure on the right.

Figure 8: Application of the CFB by the PCA-Zamboanga Research Center. [47]

State of research

As shown by experiments, both coir and flax fibers increase the ductility and therefore the load bearing capacity of the structure. What needs to be improved is the long-term durability in order to promote the application of these sustainable structures.

Further reading
- http://www.fiberreinforced.org/pages/applications.aspx
  Natural Fiber Reinforced Concrete, Presentation by Ben Davis, Retrieved at
- http://people.ce.gatech.edu/~kk92/natfiber.pdf

Greener cement

The parts of the production process that are responsible for the material's greenhouse-gas emissions are: the decarbonation of limestone and, the heating of cement. This is the reason why a number of research programs focus on the production of greener cement. There are different ways researchers try to produce greener cement. In this section a method developed by the Massachusetts Institute of Technology is presented as an indication. More possibilities can be found in the further reading.

Figure 9: Cement. [27]

Production process

The optimization of the **calcium to silica ratio** can be used to achieve a greener cement. Specifically, it is found that a ratio of 1.5 is the optimum in terms of sustainability. This was the result of a number of tests of cement with different ratios. In the conventional cement for example this varies from 1.2 to 2.2, where 1.7 is considered as a standard value. [18]

Properties

The material can achieve twice the **resistance** of conventional concrete. This refers to the mechanical resistance to fracture. [1]

Advantages & disadvantages

The main advantage of this technology is the reduction of emissions associated with the production of concrete, which for carbon emissions can be up to 60%. In addition, the produced cement is better and stronger. Specifically, the resulting material is more glassy and crystalline, which means there will be **no residual stresses**, therefore it will be more fracture-resistant. In addition, it will have an improved resistance to mechanical stresses.

This technology is still at an early stage of research and no disadvantages have been shown yet.

Impact on design

The increased resistance to mechanical stress has a particular interest for the oil and gas industries. This is due to the fact that cement around well casings is crucial to prevent leakage and blowouts.

Case Reference

No case reference is yet known for this technology.

State of research

The research is now at a molecular level of analysis. The forward steps are focused on assuring that the nanoscale properties can be translated to mesoscale. The findings have already been validated with a large amount of experimental data.

"Analysis of the material's molecular structure leads to a new formula that could cut greenhouse-gas emissions." [1]

Further reading

- http://www.scientificamerican.com/article/new-formula-could-cut-pollution-from-concrete/
- http://www.uspto.gov/about/ipm/calera.jsp
- http://www.smithsonianmag.com/science-nature/building-a-better-world-with-green-cement-81138/?no-ist=&page=1

Self healing concrete

Whenever concrete is under tension tiny cracks will appear and can cause reinforcement to to be exposed, wich can lead to structural failure. The only way to avoid this is to fill up these cracks. A special kind of concrete will be able to do that, self healing concrete. Inside the concrete bacteria react to air or moisture in the air and expand in the cavities of the tiny cracks. In that way the reinforcement stays protected. This technology is currently under research at the TU Delft.

Figure 10: Self healing concrete [52]

2.4

Production process

The maintenance of these cracks is costly but necessary. [52] In some situations the cracks aren't always accessible. To solve this problem self healing concrete was theorized. By adding a certain type of **alkaliphilic bacteria** to concrete it should be able to repair small cracks on its own.
The bacteria are added to the concrete mixture along with its standard ingredients of cement, aggregate and water.

Properties

The final properties of self healing concrete is not yet available as it is still in the early stage of research.

Advantages & disadvantages

Self healing concrete has 2 main advantages. Firstly the healing factor makes it **unnecessary to add extra steel reinforcement** or extra concrete as a redundancy to prevent the oxidation of the steel reinforcement when cracks are formed. Secondly the **reduced need for maintenance** allows for the use of concrete in areas which are no longer reachable after construction.

So far only 1 disadvantage has been implied. Since the bacteria, which are needed to fill up the cracks, can only survive within a certain pH range the surroundings should be monitored.

Impact on design

By making concrete self healing it is theorized that construction elements will become **more slender** as less redundant concrete and less redundant steel will be needed. This will **reduce material** and thereby costs. The decreased weight may also improve the maximum height which can be attained by concrete structures.

Case Reference

Self healing concrete is still under development thus there is no case reference available.

State of research

This technology is part of the self healing material program from the **TU Delft**. So far this technology is mostly based in theory. Since the **PH value** of concrete is not suitable for housing bacteria this has been a focus point. **Three particular kinds** of bacteria have been discovered to survive in the concrete mixture. For now the research team is focusing on how to optimize the bacteria's **calcite production** as well as creating the optimal conditions for bacteria in concrete.

Further reading
http://www.citg.tudelft.nl/en/research/projects/self-healing-concrete/

3

Multi use

In this paragraph all technologies that have an alternative use than the conventional are summarized. The new technologies introduced will also have a difference in the production process, but the designer here is interested in viewing the new possibilities in use.

+ Biological concrete
+ Precast concrete absorbing CO_2

Biological concrete

Biological concrete is a new technology developed by researchers from the Universitat Politècnica de Catalunya Barcelona with the focus to create concrete that capture the rainwater and provides green walls.

"Phosphate cements possess mechanical and chemical properties that are superior to those of ordinary hydraulic (Portland) cements, OPC, in general, thanks to innovations in their processing and microstructural handling and to compositional modifications" [46]

Production process

The biological concrete is produced with the use of **magnesium phosphate cement** (MPC). [13] The latter are chemically bonded ceramic materials with high performance. Specifically, they have a rapid setting, high early strength and high adhesive properties. [17]

Properties

To understand the properties of this technology, the structure is presented. This is a **multilayer panel** which consists of the following layers:

- **A structural layer**;
- **A waterproofing layer** on the top, which protects the latter from water infiltration;
- **A biological layer**, which allows water to accumulate and helps the colonization of organisms, including special families of microalgae, fungi, lichens and mosses. Specifically, it acts as a microstructure, helping retention, but also expelling the moisture. This layer can capture and store water, which also helps in the development of biological organisms.
- **A coating layer** with a waterproofing function. Specifically, it has a reversed function as it permits the rainwater to enter but it blocks it from escaping. This means that the water is always directed to where it can help the biological growth. It permits the entry of rainwater and prevents it from escaping. In this way, the outflow of water is redirected to where it is aimed to obtain biological growth.

Advantages & disadvantages

The main advantages of this technology concern **environmental**, **thermal** and **esthetic characteristics**. This concrete acts as natural support for the development of specific organisms, which means that concrete absorbs and therefore **reduces CO_2**. At the same time, it captures the solar radiation, regulating the thermal conductivity of the building. This vertical garden does not need any structural support, therefore it does not impose stresses on the building walls and it requires **less maintenance**. [43]

This technology is still at a research stage and no disadvantages are presented yet.

Impact on design

This material introduces a new concept of **vertical garden**, for both new buildings and the renovation of existing structures. In comparison to the current vegetated facades and vertical garden systems, this material supports the biological growth on its own surface. This means that complex supporting systems are not required and it is possible to determine the area of the façade on which the biological concrete will be applied.

> **"A new kind of concrete gives regular buildings living walls." [44]**

Case Reference

No case reference is yet known for this technology. Nevertheless the following simulations are developed.

Figure 11: Simulation of a vegetated façade at the Aeronautical Cultural Centre in El Prat de Llobregat.

Figure 12: Simulation of the vegetated facade, at the Ako suits hotel in Barcelona.

State of research

The biological concrete has already been patented by the Structural Technology Group of the Universitat Politècnica de Catalunya BarcelonaTech (UPC). Now the challenge is focused on the acceleration of the process, so that the mossy surface can be developed in under a year. A further aim is that the appearance of the façades can evolve over time, showing differences in color, according to the time of the year and the families of organisms developed. The company called ESCOFET 1886 S.A. hass reported to be interested in commercializing it.

Further reading

- Dezeen magazine: http://www.dezeen.com/2013/01/03/spanish-researchers-develop-biological-concrete-for-moss-covered-walls/
- Ding, Z., Dong, B., Xing, F., Ningxu, H., & Zongjin, L. (2012, December). Cementing mechanism of potassium phosphate based magnesium phosphate cement. 38 (8), pp. 6281–6288.

Precast concrete absorbing CO_2

There are different ways investigated by scientist to absorb CO2 by concrete. One possibility is presented in this section. Alternative ways of development are presented in further reading. This technology is developed by Carbon Sense Solutions.

Figure 13: Concrete absorbing CO_2. [11]

Production process

The technology is based on a natural process called **concrete carbonation**.
This technology is named **CO_2 Accelerated Concrete Curing** which accelerates the curing process and stores carbon dioxide at the same time in precast concrete. [11]

What is CO_2 Accelerated Concrete Curing?
"CO_2 accelerated concrete curing has been recently suggested as a carbon dioxide mitigation technology in which CO_2 is reacted with cement and stored as a thermodynamically stable carbonate in concrete construction products." [45]

Properties

There is no information available with regard to the exact mechanical properties of this technology. The further reading section can provide information about properties of alternative technologies that aim also at absorbing CO2, such as the Zeolite blocks.

Advantages & disadvantages

This technology promises a concrete that is more **durable**, more **resistant** to shrinkage and cracking, and **less permeable** to water. In addition it has the potential to sequester or avoid 20% of all cement-industry carbon dioxide emissions. The produced concrete meets all required **control standards**. [12]

As this technology is at an early stage of research no disadvantages are yet proven.

Precast concrete absorbing CO_2

Impact on design

This material has the potential to absorb CO2 and therefore contribute to a more sustainable design of concrete structures.

Case Reference

No case reference is yet known for this technology, as it is still at a research level.

State of research

Work is expected to begin on a **pilot plant** in the province of Nova Scotia in the summer of 2015, with preliminary results expected by the end of 2015. If it works and is widely adopted, it has the potential to sequester or prevent **20%** of all **cement industry carbon dioxide emissions**.

"Has the potential to sequester or avoid 20% of all cement-industry carbon dioxide emissions." [11]

3.2

Further reading

- Haselbach, L., & ASCE, M. (2009). Potential for Carbon Dioxide Absorption in Concrete. Journal of environmental engineering , 135, 465-472.
- More, B., Jadhav, P., Jadhav, V., Narule, G., & Mulani, S. (2014). CO_2 Absorbing Concrete Block. Journal of technology enhancements and emering engineering research , 2 (7), 147.

4

Recylce and reuse

In this chapter we discuss various ways of how to incorperate recycling and reuse in concrete.
Concrete is a project specifc material, which is usally discarded when the building is demolished. Recylced concrete is mainly used as aggregate or as blocks elements.

+ WEEE as a concrete aggregate
+ Recycling as aggregate
+ Reuse concrete elements

WEEE (**W**aste from **E**lectrical and **E**lectronic **E**quipment)

The waste from electrical and electronic equipment (WEEE) can be recycled, processed and then used as aggregate in concrete. In this way, the amount of non-biodegradeable materials in landfills is reduced and it can be added to a new development. This means replacing the regular aggregate used in concrete which in turn means a need to mine less new materials.

Production process

The following ingredients are used:

Figure 14: Composition of WEEE. [own image]

Properties

There are various ways of processing electronic waste. The method used influences how well the concrete and the material bind to one another [32]. The composition of the plastic aggregate also influences the compressive strength [33]. Since these factors can be seen as largely variable, the properties below are the results of the experiment with waste crushed with a “pulverized friction roller machine”.

Percentage of crushed waste	0%	4%	8%
Compressive strength after 7 days (N/mm²)	22.33	23.52	20.47
Compressive strength after 14 days (N/mm²)	32.67	33.65	28.59
Compressive strength after 28 days (N/mm²)	55.23	58.96	45.53

Table 3: Properties of the experiment results. [32]

Advantages & disadvantages

The main advantage that WEEE aggregate enables is the **reuse of waste** by trapping it within a structure instead of using it for landfill.

The main disadvantages is a clear **reduction in compressive strength** which is directly related to the kind of WEEE used, the way it has been processed and the % of its replacement. This means it is **not yet as reliable** as regular concrete for structural use.

Impact on design

WEEE aggregate concrete has various effects on the design. The WEEE material can **add color** to the aggregate when showing it for esthetic purposes, for example in tiles or walls. As it has a lower overall strength it is likely to result in **larger construction elements**.

Figure 15: Tile made with watste from electical and electronic equiment, waste from plastic and white cement. [32]

Case Reference

As WEEE aggregate concrete is still in early stage of research there are currently no projects that have incorparated this technology.

State of research

Using WEEE as an aggregate is still in its early stages. The research mainly focusses on how much of the aggregate can be replaced with WEEE and how this **effects the strength** of the resulting concrete. Research is also being done in how to process the WEEE and how this affects its usefulness as an aggregate. At the Nirma University, institute of technology the research is continuing by testing the **flexure strength and tensile strength** in proportion to the amount of WEEE added to the mixture. Another focus is attempting to increase the compressive strength by making the mixture more compact through powdering the waste material.[32]

Further reading

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Recycled aggregate

Concrete is considered unsustainable due to the sheer amounts of natural resources it consumes which are not normally recycled but are poured into landfills.

Production process

Concrete can be recycled by using it in the **production of new concrete**. Instead of using "virgin aggregate", old concrete is crushed and recycled to be used as aggregate. Research has shown that this does not significantly impact the tensile or compressive strength of this concrete as compared to freshly-made concrete. [24] In this case the ingredients are:

recycled aggregate [24]

sand[26]

cement [27]

Figure 16: Recycled concrete aggregate. [24]

Properties

% of replacement	Compressive strength	Tensile strength (MPa)	Young's modulus (GPa)	Abrasion test Thickness loss (mm)
0	59.3	3.85	35.5	1.96
30	57.1	3.65	34.2	1.86
100	54.8	2.95	28.9	1.37

Table 4: Properties of recylced concrete aggregate based on results of L. Evangelista and J. de Brito. [28]

Recycled aggregate

Advantages & disadvantages

Recycled aggregate concrete has the advantage of being **more environmentally friendly** due to a lower need for newly mined materials. Apart from this there are **no special advantages** to this material.

A disadvantage is the low amount of readily available recycled concrete. Due to the low amount of recycled concrete it is **not commercially feasible** to produce concrete with 100% recycled aggregate. Even though the margin is small, the strength of recycled aggregate concrete is smaller than of new concrete.

Impact on design

With the exception of a slightly **smaller load bearing capacity**, there are no consequences to the design as compared to regular concrete.

Case reference

Concrete with at least some recycled aggregate is widely used but there is no significant visual difference. Since this is the case there is no defining case reference.

State of research

Current research is focused on acquiring better quality recycled aggregate and therefore producing better quality concrete made with recycled aggregate. This research is being performed by various research centres such as the Department of Materials and Environment Engineering and Physics, Università Politecnica delle Marche. [24]

Further reading

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Reuse of concrete elements

One of the biggest contributors to concrete being unsustainable is its fixed design and its fixed connection. Concrete buildings are commonly designed for a specific purpose, leaving it as ill suited for other purposes. This means it cannot be assigned to another purpose resulting in demolition and ultimately landfilling. Yet there is a possibility to reuse concrete elements as a whole.

Production process

The idea is to create concrete elements which **can be deconstructed** and then **reused** for another project. To do this, various steps need to be taken starting from deconstruction, followed by a quality check and then reassignment. This is **labour intensive** but it does reduce the need for new raw materials and it reduces the change of releasing hazardous materials while crushing. [37]

"Making concrete on site requires 1830MJ/m3 while acquiring a reusable concrete element would only need about 90MJ/m^3." [37]

Properties

Reused concrete elements have their **original properties** which are dependent on the type of concrete. However elements that have been exposed to wheater conditions show a lower strength.

Advantages & disadvantages

Figure 17: Lifting of a section of a footbridge [37]

The use of reclaimed concrete elements has many advantages. First of all it is estimated that reusing concrete elements would cost only a fraction of the energy needed to produce new concrete. Making on site concrete requires 1830MJ/m^3 while acquiring a reusable concrete element would only need about 90MJ/m^3 [37]. Another advantage is that the reuse of old elements means there is no need for new raw materials in the production.

This technology also has various disadvantages. When it comes to deconstructing a building this process can last from a few weeks to some months while demolition takes a few days up to a few weeks. The costs are also significantly higher for deconstruction as opposed to demolition. One study suggests deconstruction of a building cost over €250.000 while demolition of the same building would cost less than €100.000. [37] It's likely that new connections will have to be made.

Impact on design

Concrete elements are not often reused which means they are not often designed to be deconstructed. In order to optimize concrete elements for reuse they have to be designed with that in mind. This means using a **predefined measurement set** or even using predefined elements. This would **lower the design freedom** which makes concrete an attractive material.
When concrete elements are not designed to be reused, it is often necessary to adjust the design in order to use the available pieces. [37] This means that **extra detailing** is needed such as alternative connections.

Case Reference

There are not many cases known where concrete elements were reused. One case which has been successful in the Netherlands is the dismantling of the upper levels of a flat in Middelburg. The elements retrieved from that flat were reused to build 114 new houses in the neighborhood by the name of Dauwendaele. The residences were set up in 3 blocks along the vrijheidstraat, the Rozenburglaan and the Buitenhovelaan[39]. The gallery flats consisted of 3 or 4 floors which shows it is possible to have a flexible design eve with predefined elements. The strength of the loadbearing walls was deemed to be of good quality, the floor edges had been damaged during the deconstruction, therefore the addition steel edges was suggested. In the end these were not placed.

Figure 18: Reuse of concrete elements in residential buildings Vrijheidstraat. [38]

State of research

The research in this field mainly focusses on creating pilot projects to better understand the deconstruction and reuse process for concrete elements. Such projects are planned to start in universities, such as the Delft university of Technology. [37]

Further reading

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