New Concrete Technology – New Architectural Form

Visions for a New Architectural Form using New Concrete Technology in giant structures

Anja Margrethe Bache
Ph.d.- The Aarhus School of Architecture, Aarhus Denmark
Sculptor – The Royal Danish Academy of Fine Arts, Copenhagen, Denmark
Master of Science Engineering –The Danish Technical University, Lyngby Denmark
Research worker at The Danish Building Research Institute, P&I, Hørsholm Denmark, (mail: amb@sbi.dk)

Abstract

A new Concrete technology with great architectural potential for new forms, Compact Reinforced Composite, CRC, has been invented. (1).(2). It has been used in many engineering projects, for example reinforcing bridges of steel in Holland, (3), but even after 20 years, not generally in an architectural context.
The explanation could be that the concrete and building sectors are at a deadlock and bound by tradition, but also that the architectural potentials for the new concrete technology are more or less unknown. This article is an introduction to this new concrete technology, a description of its design forum and a visual presentation of visions for its architectural potentialities for giant constructions illustrated by sketches and models.

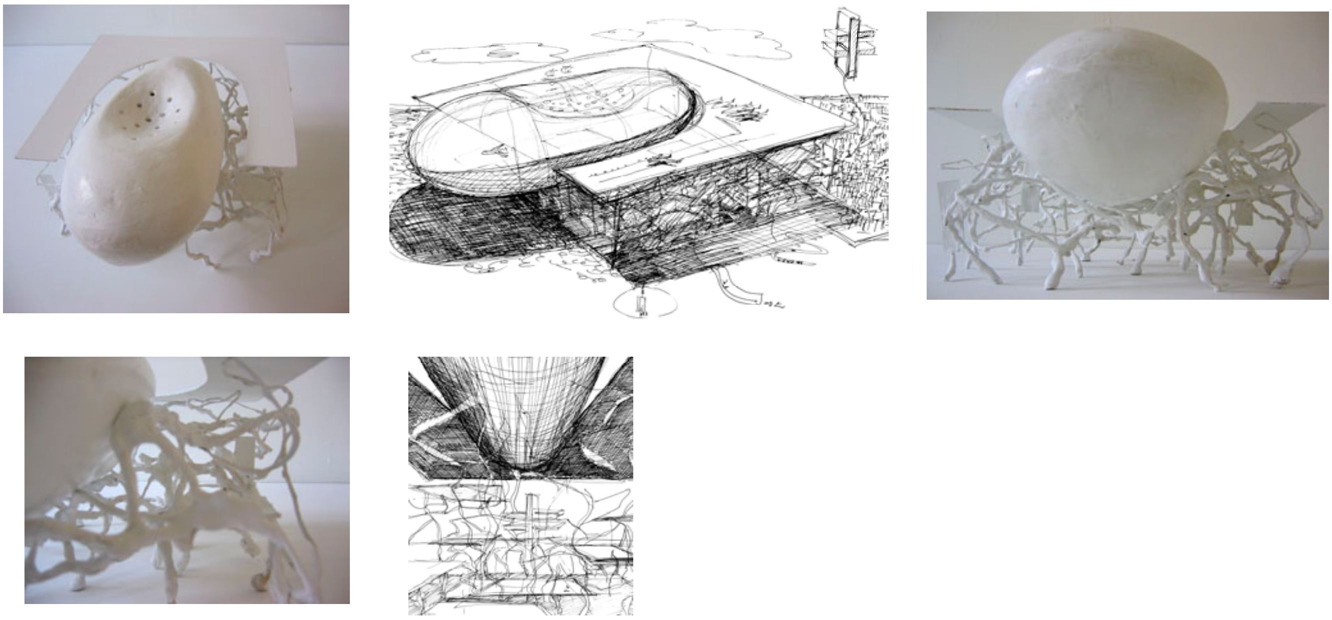


Figure 1. Model and sketches of one vision for a giant construction made of CRC, here an airport. The models in this article are shown on the homepage, (13):
www.dk/AAA/forskning/e-publishing/BETONS%20FORM:pdf

Materials science, the study of materials as a whole, rather than in their special chemical, physical and engineering aspects, is a fairly recent development. Indeed it has only lately become respectable… Naturally the first task was one of understanding the observed phenomena, why solids in general, and especially the familiar materials, behave in the way they do. Though there are still a good many loose ends, this stage can broadly be said to be accomplished. The problem now facing materials scientists is what to make use of their knowledge. The ambitious will want to apply materials science in radical ways, either by making substantial changes in the older materials, or else by inventing new and perhaps better ones. J.E. Gordon. 1984.(4).

Introduction

In 1978 senior scientist Hans Henrik Bache invented Densit, (5) - and in 1986, when he was a scientist at the Danish firm Aalborg Portland A/S, he invented Compact Reinforced Composite, CRC, (6), now called "The New Concrete Technology[1]. With the new concrete technology design of very large, relatively light and ultra ductile composite materials[2] can be realized.

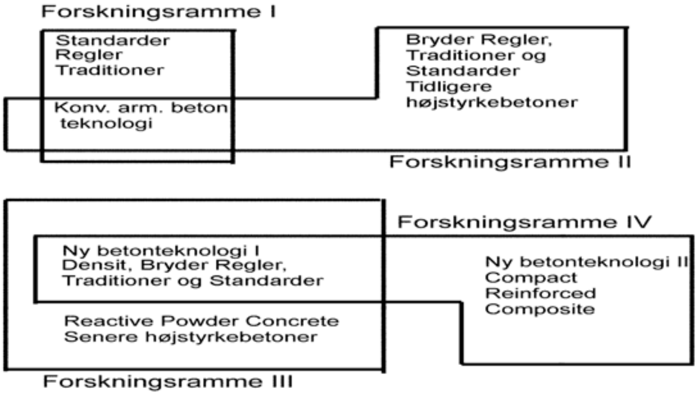


Figure 2. The new concrete technology, Compact Reinforced Composite, CRC, is with its overall fracture-mechanical concept, the different applied theories, its structure and its behavior, fundamentally different from existing concrete technologies, shown schematically in this figure.

The concrete technology has been used and tested in ceramic-, metal- and plastic composites, but most often with cement as a binding material, as a “New Concrete”. Popularly speaking the new concrete technology aims at designing materials in relation to the size of constructions, that even in very large scales, and subjected to relatively strong forces. It is very ductile, with no cracking, neither in the compression- nor in the tension[3] side of the construction.

The new concrete technology, CRC, has great architectural design potentials, not only for smaller constructions, as for example slender stairs and balconies, but also for very large constructions, as for example giant slender airport constructions, stadiums, and so on - and in constructions with spans of 500-1000 meter. (2).

With the new concrete technology it is possible to design and carry out conventional constructions and architectural designs, as we know them today using traditional, reinforced concrete. But the new technology offers a completely new freedom and a wider range of solutions and in scales not possible with conventional reinforced concrete. The new concrete technology, CRC, opens the way for a completely new world of architectural form. But even though it has been used in practice for 20 years in many projects[4], it is still by and large not used in an architectural context[5].

The structure of the new concrete technology, its mechanical properties and its present-day use is shortly introduced in this article. This is followed by a description of the design forum and a visual presentation of visions for the architectural potential for giant constructions.

For more specific and profound literature and relevant homepages look at the list after this article.

The structure of the new concrete, CRC

The new concrete-technology is based on theories such as Material Physics, Capillary theory, Colloidal theory, Chemistry, and other theories, but most important is the use of Fracture Theory, the science of how things breaks.

Materials are by nature neither ductile, nor brittle[6]. The way a material breaks depends among other things on the size of the constructions and the strength of the materials. A vase of glass has a brittle fracture form, while the fiber of glass with much smaller dimensions has a ductile fracture form. This is also true when it comes to steel. It is possible to use the very strong types of steels, with strength as high as 2000 MPa, for cables with relatively small diameters. But it can not be used for constructions with much larger dimensions, for example buildings - where it will change to a brittle, fracture form – dangerous in buildings. That’s why the CRC-materials are designed in relation to the size of the constructions. The aim is to obtain very strong materials from a fracture-mechanical overall design, which can be used for extraordinarily large constructions, loaded both in compression and tension and which at the same time are extremely ductile.

The CRC-technology is an overall design concept for design of both binder, concrete, fiber reinforced concrete and main reinforced concrete. The new concrete is made of a cement-based Densit-binder, aggregates, fibers and main reinforcement. The packing of the binder is more or less free of the binding surface forces, normal in conventional concrete binder. That’s why the CRC materials can absorb much larger density of the binder, (60-80 percentage per volume, versus 30-50 percentage per volume in conventional concrete binder). Much stronger aggregates can be used as well as main reinforcements, and it is possible to use much larger percentages per volume of fibers and main reinforcements than in conventional reinforced concrete. The mechanical properties and the way constructions of the new concrete are deformed are therefore fundamentally different from that known from conventional reinforced concrete.

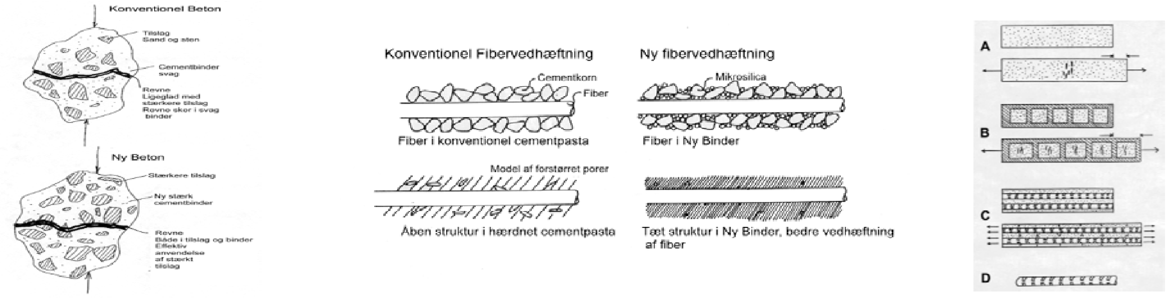


Figure 3. Densit is used as binder in the new concrete, CRC. It is very strong, that's why there effectively can be used much stronger aggregates than in conventional concrete binder. The packing of density in Densit is 60-80 percentage per volume, while it is 30-50 in conventional concrete binder. This gives a much stronger fixation of the fibers in CRC than in conventional concrete. Percentage per volume of fibers and main reinforcement are much larger in CRC than in conventional reinforced concrete. This leads to a global fracture zone in CRC with small microcracks all over the element when exposed to tension, where there in conventional concrete is a local fracture zone with large visible cracks, and therefore much smaller fracture energy. (2).

The mechanical properties of the new concrete

The new concrete technology, can be used to design magnetic concrete, fireproof concrete, (up to 1400 degrees centigrade), frost-proof concrete without air entrainment, (down to minus 50 degrees centigrade), and "Concrete" where 99 % of the cement is replaced with other binders. (1).

		Konventionel højkvalitets-beton	Ny beton			Sejt kvalitets-stål	Konventionel armeret beton
			Beton/matricemateriale		CRC		
			0-2% fibre	4-12% fibre			
Trykstyrke	MPa	80	120-270	160-400	160-400		4-60
Trækstyrke (f_t)	MPa	5	6-15	10-30	100-300	500	
Bøjningsstyrke* (f_b)	MPa				100-400	~600	
Forskydnings-styrke*	MPa				15-150		
Densitet (ϱ)	kg/m³	2500	2500-2800	2600-3200	3000-4000	7800	2500
E-modul (E)	GPa	50	60-100	60-100	60-110	210	17,5-30
Brudenergi	N/m	150	150-1500	5000-40000	$2\cdot10^5$-$4\cdot10^6$	$2\cdot10^5$	
Styrke/vægt-forhold (f_b/ϱ)	m²/sek²				$3\cdot10^4$- 10^5	$7{,}7\cdot10^4$	
Stivhed/vægt-forhold($^E/\varrho$)	m²/sek²				$2\cdot10^7$-$3\cdot10^7$	$2{,}7\cdot10^7$	
Frostbestandighed		moderat/god	absolut frostsikker — uden luftiblanding				
Korrosionsmodstand		moderat/god	korrosionssikker — selv med kun 5-10 mm dæklag			dårlig	Dæklag > 45 mm

Figure 4. The mechanical properties of CRC and other conventionally used building materials. (1).

With the CRC-technology materials strengths 5-8 times larger than conventional reinforced concrete can be obtained, comparable with the strengths of conventional construction-steels. CRC can obtain stiffness 2-3 times the stiffness of conventional reinforced concrete – and up to half the stiffness of construction-steels. CRC weighs more than conventional reinforced concrete, but typically a third to half the weight of construction-steels. (1).

An example of how a strong beam of the new concrete CRC deforms in a bending test is shown in figure 5. The beam is 95x150x2000 mm, the bending strength is 5-10 times that of conventional concrete, (the test could not continue to a collapse of the beam (not within the test machine's capacity). The strength given of the beam is therefore before fracture appeared in the beam). The heavily loaded beam had a relatively large vertical deformation at 6 cm, but no visible cracks neither in the stress nor in the strain side of the beam. In conventional reinforced concrete cracks will always appear in the tension side of the beam.

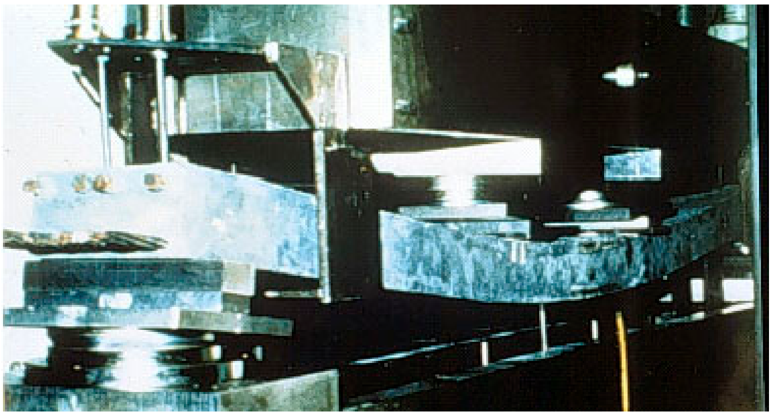


Figure 5. CRC-beam exposed to bending. The strength was 327 MPa, but the test could not be continued to fracture because of the test machine's limited capability, hence the strength is before fracture appears in the beam. The beam was deformed 6 cm in vertical position, without having visible cracks neither in the tension- nor in the compression side of the beam. When the beam was unloaded the beam only had a minor remaining deformation on 1 cm. (1). (10).

When the beam was unloaded it almost regained its original form. It had only a minor remaining deformation of 1 cm. (1). This is a unique behavior in deformation compared with the deformation results of conventional reinforced concrete.
For design of buildings, which have to be able to resist attacks like terror, earthquake and fatigue, CRC is unique compared with both conventional reinforced concrete and construction-steel, because CRC can resist very heavy impact loads. This is shown in figure 6. (1).

Figure 6. Different kinds of explosive tests and tests where materials are exposed to grenades fired from a canon. The CRC-panels were deformed but not destroyed like both the panels of a strong conventional reinforced concrete and the panels of construction-steel were when exposed to explosives. In the last picture the second panel of CRC catches a grenade of 45 kilo. There were 5 panels of CRC; the three last panels were intact. In comparison it should be mentioned that the grenade continued right through the five panels of strong conventional reinforced concrete and destroyed them completely. (1). (10).

In practice the reinforcements in CRC don't corrode because of the dense structure.
The way CRC responds to fire is closely connected with design and drying. In some areas CRC has a better response to fire than conventional reinforced concrete, but other constructions of CRC need to be protected with fireproof methods as those known from fireproofing construction-steel. (1). (2). (8).

Manufacturing of CRC-constructions

CRC-constructions can be manufactured at a factory, prefabricated, or at the site in-situ, as known for conventional concrete but by processes as depositing, extruding, spraying and die-casting.

CRC-joints and hybrid constructions

CRC-constructions can be constructed of prefabricated elements joined at the site by new very strong, slender and ductile joints based on the CRC-technology. One example is the joint "CRC-jointcast" which has a smaller width and straight reinforcements contrary to conventional joints where the width is larger and the reinforcements curved. CRC can be used for joining prefabricated elements of CRC, of reinforced concrete but also of construction-steel, (when joining hollow piles of steel).

Figure 7. The joints can be slender and neat with CRC. CRC-jointcast is an example of a joint based on CRC-technology. The width of this joint is smaller than conventional and the reinforcement is straight contrary to the conventional where it is curved, which makes it more simple to manufacture.

The present applications of CRC

CRC has been used in a wide range of areas. The following are examples.

House-building sector

In the house-building sector CRC has primarily been used for stairs, balconies and for joining prefabricated elements by CRC-jointcast. The Danish firm Hi-Con ApS, has specialized in manufacturing slender prefabricated CRC-elements such as stairs and balconies, with thickness of material as low as 35 mm increasing to 100 mm in the string for steps in some stairs and 50-60 mm for some balconies.

Figure 8. Stairs and balconies of CRC. (pictures Bendt Aarup).

Building sector

In the building sector 40.000 CRC-slabs load-carrying drain covers have been used in the Great Belt-tunnel in Denmark under the railway. The slabs were designed to carry varying loads from trains and to comply with a requirement of 100 years lifetime exposed to seawater. (10).

CRC has also been used for strengthening bridges of steel, where it with plates of steel creates strong, ductile and loadcarrying steel-CRC hybrid-constructions. The Danish Firm Densit A/S has in cooperation with the Danish firm COWI Consult A/S constructed such a bridge in the East, while the Danish firm Contec Aps in cooperation with the University of Delft and the government of Holland, applied the principles for strengthening bridges in Holland. Contec Aps are pioneers in relation to engineering and practical use of CRC. They are presently, together with the University of Delft and the government of Holland, developing new strong and ductile hybrid-constructions of CRC and steel for strengthening bridges, and also for replacing the present embankments of steel in Holland. (3).

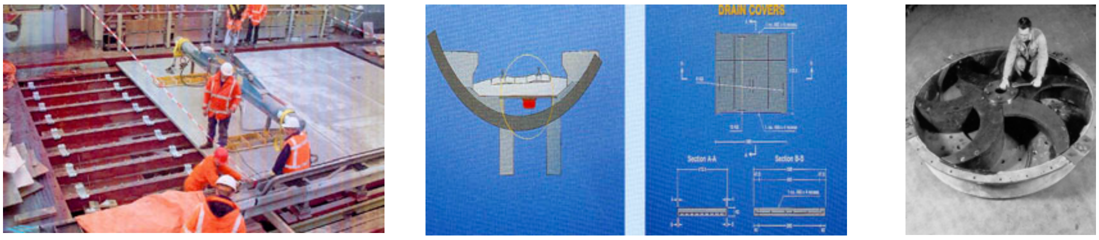


Figure 9. Klaagbruggen in Holland is strengthened with prefabricated CRC-plates. (3). 40.000 CRC-slabs have been used in the Great Belt Tunnel in Denmark. They were designed to withstand varying loads from trains and 100 years lifetime exposed to seawater. CRC has also been used for shovels in cement mills, where they lasted 5-10 years, whereas the earlier type made of cast steel only lasted 1/2 year. (1).

Plants and the machine sector

CRC is mostly used in the plants and the machine sector. CRC has been used for strengthening a floating dock of steel, with a principle reminding of that used for strengthening bridges of steel. It has been used for 3-4 meter large shovels in cement mills. They lasted 5-10 years, whereas the earlier types made of cast steel only lasted 1/2 year. (1). CRC has also, with a very thin layer of nickel, been used for meter-large pressure tools for forming elements like bodywork plates in steel for cars.

The Off-shore industry

CRC has been used for strengthening load-carrying main constructions of platforms and for strengthening piles of steel in the seabed.

The safety industry

It has also been used for safety-boxes all over the world and for larger protective installations and structures in banks, and so on.

If you think of a brick, and you are consulting the orders, you consider the nature of brick ”what do you want brick”? Brick says ”I like an arch” if you say to brick ”Arches are expensive and I can use concrete lintel over an opening. What do you think of that brick?
Brick says ”I like an Arch” : It is important that you bandy it about as though to say ”Well we have a lot of material, we can do it in one way, we can do it in another way”. It’s not true. You must honour and glorify the brick instead of short-changing it and giving it an inferior job to do in which it looses its character, as for example, when you use it as an infill material, which I have done and you have done. Using brick so makes it feel as if it is a servant, and brick is beautiful material. Khan, Louis I., 1973.(11).

Introduction to the design forum of CRC for giant constructions

The new Concrete technology has architectural potentials for smaller constructions but also for the extraordinarily large ones. But the architectural form has still not surfaced and is more or less unknown. Therefore the writer of this article carried out a development project at the Aarhus School of Architecture in 2002-2004, (based on analyses made in a ph.d. project, (2)), aiming at encircling and visualizing visions for the architectural potentials for giant constructions using the new concrete.
The design forum and the visions for the architectural form for giant constructions made of CRC presented in this article are taken from this development project. Sketches and models, which are 30-100 cm, illustrate the visions, but they also represent visions for giant constructions made of CRC with spans of 500-1000 meter. The architectural forms of the models presented are based on the design in an attempt to articulate CRC´s unique properties and architectural formal idiosyncrasy, but indeed also with an artistic intention. The models are not a presentation of completed architectural projects of everlasting merit, but illustrations of the visual awareness inspired by the feeling for the peculiar character and the spatial potentials of the new concrete

The criteria for the used design forum and the design forum are presented In the following text - and the visions for the architectural form for giant constructions of CRC are illustrated.

Criteria for establishing the design forum for the new concrete

The design forum presented is based on three criteria:

1. The Functional demands for the construction-safety, durability and comfort[7]
2. The Scale of the constructions - the very large constructions
3. The material - the new concrete, Compact Reinforced Composite, CRC.

1. Functional demands for the constructions

The constructions looked at are parts of a fictive building. A fictive building is looked upon only as a construction, and not in the same context as a real building. The construction in the fictive building will then only have to fulfill the demands for safety, durability and comfort, while more specific demands related to the use of the building, such as distribution of the rooms, electrical light, accessibility for handicapped and so on, are excluded from the considerations. The primary function of the constructions in the fictive buildings is to lead the forces from where they occur to the earth.

2. Scale of the constructions

The scale influences the construction-form. It was an aspect, which Galileo Galilei mentioned already in 1638 in his "Two New Sciences". (12).

Clearly then if one wishes to maintain in a giant the same proportions of limb as that found in an ordinary man, he must either find a harder and stronger material for making bones, or he must admit a diminution of strength comparison with men of medium stature; for if his height be increased inordinately, he will fall and be crushed under his own weight. Galileo Galilei, 1638.(12.

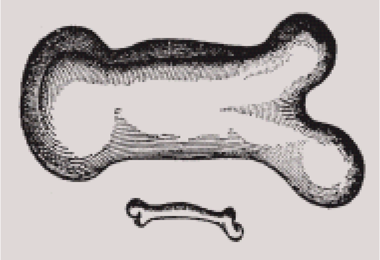


Figure 10. The bone of the giant can not just be upscaled from the human bone, because it can't carry its own weight. Instead some dimensions of the bone have to be increased more than described by the upscaling, but it changes the form of the bone completely. (12).

By upscaling a construction, (by increasing the dimensions proportionately), the self-weight increases proportionately with the volume of the construction by a factor of third power, n^3, while its carrying capacity only increases proportionately with the cross section by a factor of second power, n^2. Some constructions will, as the bone of the giant in the example of Galileo Galilei, therefore collapse under its own weight. To avoid a collapse by upscaling it can bee necessary to replace a weaker material with a stronger one or to increase some dimensions more than given by the upscaling - but then the construction completely changes its form - as shown in figure 10.

The constructions described in this article are the giant constructions with spans of 500-1000 meter - the giant scale - but with a slender form.

The material

The material is the new concrete, Compact Reinforced Composite, CRC, described above.

From these three criteria - the functions of the constructions in the fictive building, the giant scale and the new concrete, CRC, and the desire for articulating the unique properties and the special architectural peculiarity of the new concrete - a design forum has been established. It is presented in the following text.

The design forum of the new concrete for giant constructions

Giant constructions made of the new concrete ought to be formed as to effectively utilize the:

1. Relatively high strengths, stiffness and relatively low weights

2. Unique fracture mechanical properties
3. Processes with which constructions of CRC are produced
4. Good wearing qualities and resistance to outdoor environment

1. Relatively high strengths, stiffness and relatively low weights

To utilize the strengths, stiffness and the weights, the giant constructions of CRC can be formed with a large spatial space, but hollow and with minimal use of material. For example as:

A. Hollow containers which are made of slender sheets, shells or profiles
B. Discrete, slender elements which are joined in such a way that they statically work together as one large spatial system.

Analyses have pointed out that the space needed for utilizing all the strengths and stiffness at the same time in giant constructions of CRC is much smaller than the space needed for constructions of conventional reinforced concrete and comparable with the space of the constructions made of construction-steel. (2).

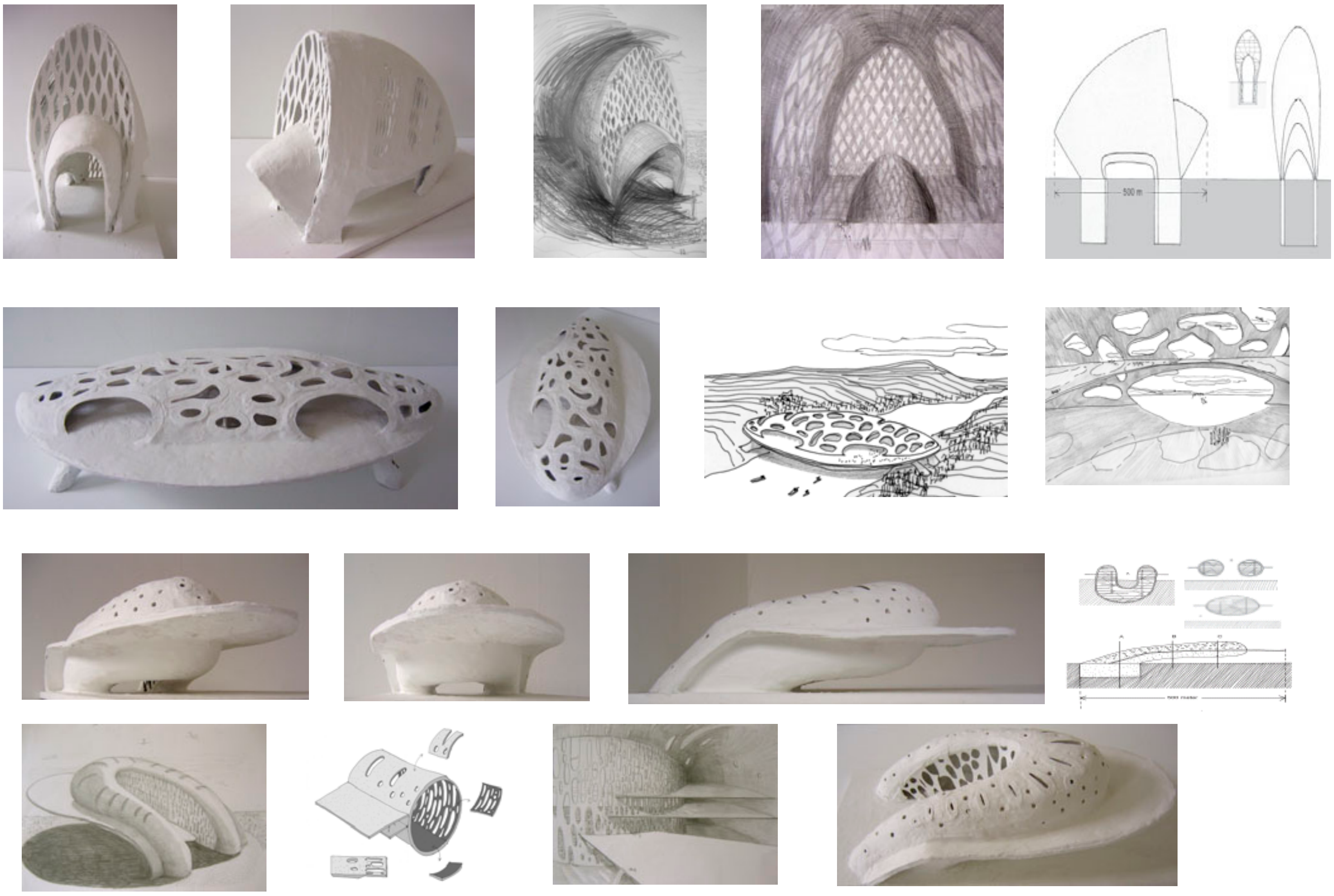


Figure 11. Models showing form potentials for giant constructions of CRC formed after the container principle mentioned above. (13).

By utilizing the good fracture-mechanical properties of CRC, as mentioned in the following - and with the processes with which CRC-constructions are manufactured - large freedom for forming giant constructions can be achieved.

2. Unique fracture-mechanical properties

Utilizing the unique-fracture mechanical properties of the new concrete, the giant constructions can reach large degrees of form freedom, because it is possible to:

1. Join different types of elements, profiles, sheets and so on, with smooth joints
2. Join elements of different shapes
3. Carry out perforations in many ways, allowing a relatively large percentage of perforations

4. Vary the thickness of the elements and the joints between differently shaped elements.

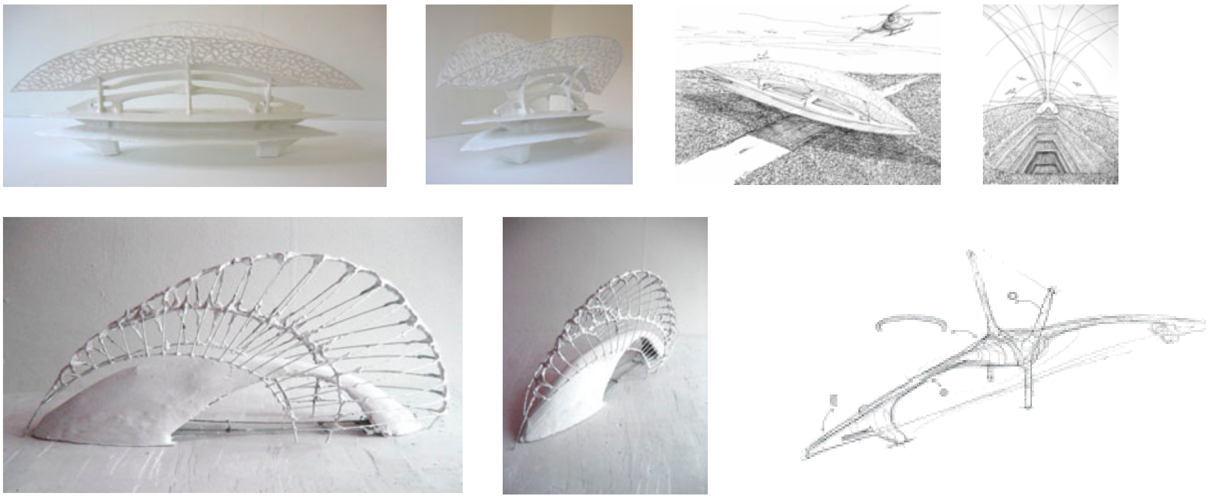
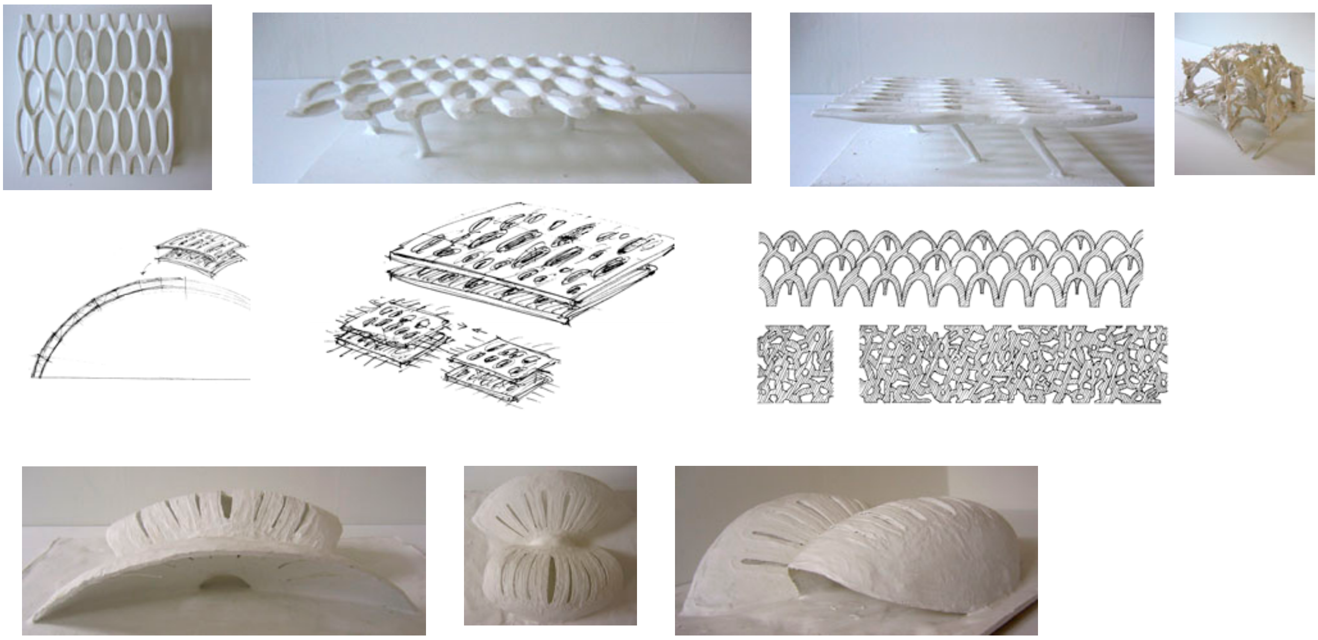


Figure 12. Models of giant constructions made of CRC, which are formed of different elements of varying thickness, perforations and smooth joining of the different shapes. (13).

3. Taking advantage of the processes with which the constructions of CRC are produced

To fully exploit the processes when the new concrete is used in giant constructions, and at the same time take advantage of the joining techniques based on this, the following should be taken into account:

1.Because the new concrete most often is poured or cast in moulds or forms, it opens up for a variety of expressions, spanning from the plastic, sculptural form to the more stringent, geometrical form.
2. Articulation of volume, surface and profile is possible in one and the same giant construction – normally only achieved using a combination of materials
3. Offers a choice of visible or invisible joints and opens up for a variety of expressions. A giant construction can have the appearance of poured concrete or the looks of prefabricated elements – regardless of the actual building process



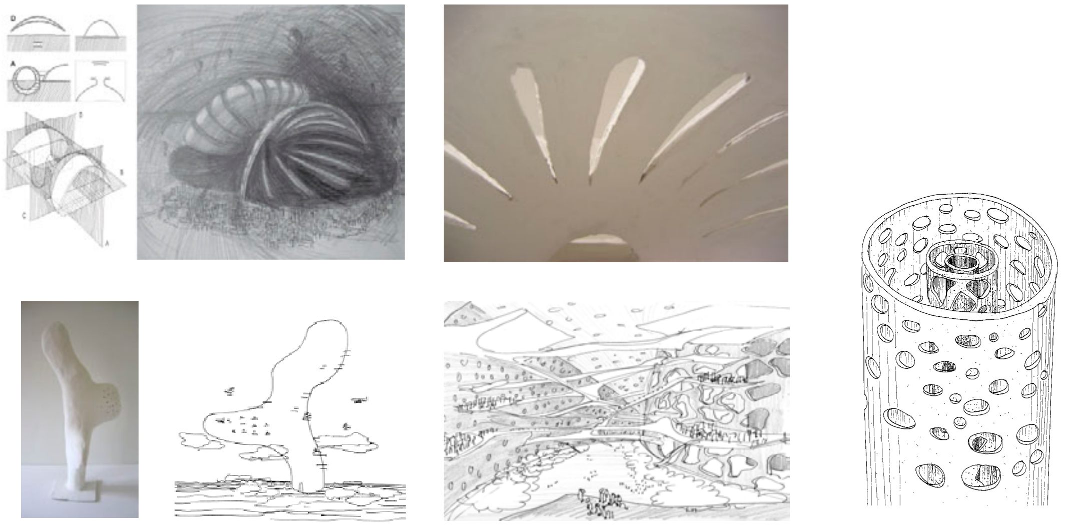


Figure 13. The giant constructions in CRC can be made of prefabricated elements which can be joined with visible but also invisible very strong, ductile and slender joints. Models of a prefabricated element in CRC for a giant construction in CRC and models of giant constructions in CRC. (13).

4. Good wearability and resistance to outdoor environment

To utilize the good wearing qualities and resistance to the outdoor environment, giant constructions of CRC can be used in:

1. Foundation, top dressings and buildings, with a smooth cross-over between the different parts if desired
2. Giant constructions placed on the surface, but also in the seawater.

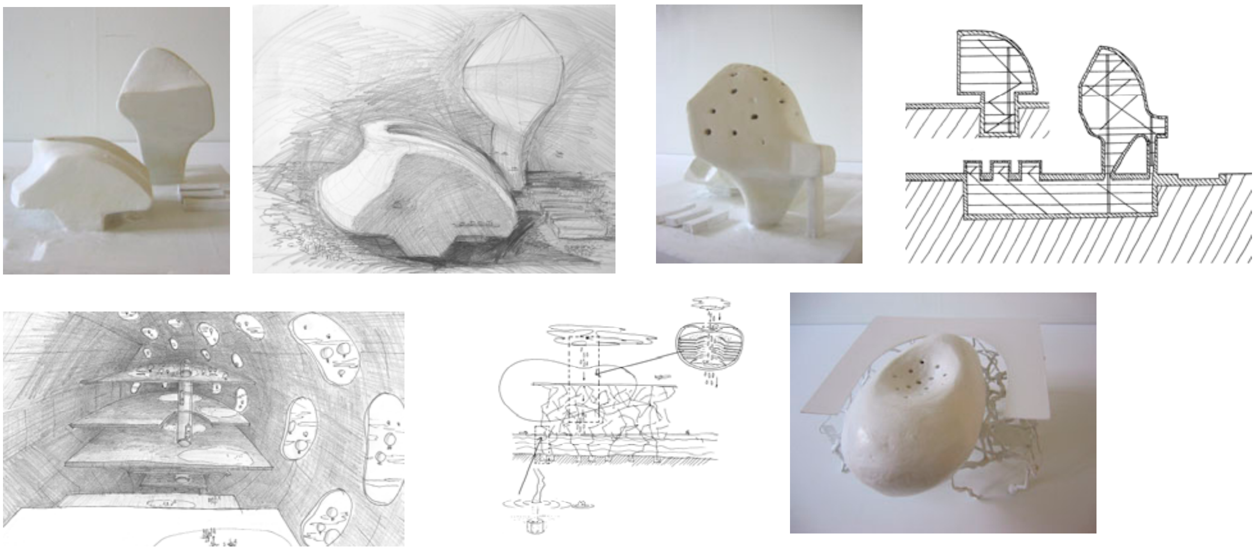


Figure 14. Model showing giant hollow constructions in CRC with a smooth cross-over to the foundation and the top dressing and another model which is placed in the water. (13).

The models shown in this article are far from adequate for the author's visions for the architectural possibilities for giant constructions of CRC. But it is the author's hope that this article will inspire others to catch the balls thrown into the air and play with them creatively and use them in the future.

Notes:

1. Aalborg Portland A/S is producing cement.
2. A composite material is according to Leslie Holliday, (1966), a solid made by physically combining two or more existing sub-materials. In this way a multi-facetted system arise, where the different physical properties of the sub-materials can be utilized. (7).
3. In conventional reinforced concrete there will always be visible cracks in tension.
4. For example as shovels in cement mills, for strengthening bridges of steel, as drains in the Great Belt Tunnel, and so on.
5. As balconies, stairs and joint-techniques, CRC-jointcast.
6. The ductile fracture is preferred in buildings because the deformation is observable before it breaks, revealing an early warning of the collapse of the construction. Contrary to the brittle fracture, which is an unacceptable fracture-form in buildings, because it gives no early warning before the total collapse of the construction.
7. Comfort is here related to deformation -bending down and outwards and to oscillations when loading the constructions.
8. A further description of the development project can be seen at the homepage of Aarhus School of Architecture at the following address: www.a-aarhus.dk/AAA/forskning/e-publishing/BETONS%20FORM.pdf

List of literature

1. Bache, Hans Henrik, 1992, Ny beton- ny teknologi, Betonteknik, 8/04/1992, Aalborg, Aalborg Portland A/S
2. Bache, Anja Margrethe, 2002, CRC, undersøgelse af en ny betonteknologis arkitektoniske potentialer vurderet udfra holdbarhed, komfort og form, Aarhus, Arkitektskolen i Aarhus
3. Buitelaar, Peter, Contec ApS & Bramm, C.R. Delfts university & Kaptailn, N., Ministry of transport, Public Works and Water management, Structural Development Department, Netherlands, 2002, Reinforced high performance concrete overlay system for steel bridges, 5.th International Symposium on high Strength/High Performance Concrete
4. Gordon, J.E., 1984, The New Science of Strong Materials, 3.edition, Prince, Prince University Press
5. Bache, Hans Henrik, 1979, Densitpatent, International Patent Application no. PCT/DK/79/00047, ”Shaped Particle and Composite Material and Method for Producing the same” 93p.p.
6. Bache, Hans Henrik, 1987, International Patent Application no. PCT/DK/87/00072, Compact Reinforced Composite
7. Holliday, Leslie, 1966, Composite Materials, Amsterdam, Elsevier Publishing Company.
8. Jensen, Bjarne Chr. & Aarup, Bendt, 1996, Fire Resistance of fibre reinforced Silica Fume based Concrete, 4.th International Symposium on Utilization of High-strength/High-performance concrete, Paris
9. Jensen, Lars Rom, Januar 2001, Kraftoverførende samling af betonelementer, Byggeindustrien Byggeforum, nr. 1, København
10. Bache, Hans Henrik, 1995, Concrete and concrete technology in a broad perspective, the second CANMAT/ACI International Symposium on Advances in Concrete Technology, Las Vegas, Nevada, USA, June 11-14, Aalborg Portland A/S, CBL Reprint no. 27
11. Khan, Louis, 1973, Materials, Forelæsning ved Pratt Institute, School of Architecture, N.Y.
12. Galileo Galilei, 1954, Dialogues Concerning Two New Sciences, Dover Publications Inc., New York
13. Bache, Anja, 2004, Ny betons form for kæmpekonstruktioner, Aarhus, Arkitektskolen i Aarhus, www.a-aarhus.dk/AAA/forskning/e-publishing/BETONS%20FORM.pdf

More profound literature about CRC

1. Bache, Hans Henrik, 1995, Concrete and concrete technology in a broad perspective, the second CANMAT/ACI International Symposium on Advances in Concrete Technology, Las Vegas, Nevada, USA, June 11-14, Aalborg Portland A/S, CBL Reprint no. 27
2. Bache, Hans Henrik, 1992, Ny beton- ny teknologi, Betonteknik, 8/04/1992, Aalborg, Aalborg Portland A/S
3. Bache, Hans Henrik, 23.01.1981, Udviklingen fra beton til Densit, CBL Intern rapport No.26, Aalborg, Aalborg Portland A/S.

4. Bache, Hans Henrik, 1987, Introduction to Compact Reinforced Composite, Oslo, Nordic Concrete Research Publication No.6, Paper p.19-33, Nordic Concrete Referation

5. Bache, Hans Henrik, 1987, Højstyrkebetons udvikling gennem 25 år, CBL særtryk nr.17, Aalborg, Aalborg Portland A/S

6. Bache, Hans Henrik, 1988, The New Strong Cements: Their use in Structures, CBL Reprint No.16, Aalborg, Aalborg Portland A/S

7. Bache, Hans Henrik, 1990, Brudmekanik, Beton-teknik 3/12, Aalborg, Aalborg Portland A/S

8. Bache, Hens Henrik, June 24-26 1991, Principles of Similitudein Design of Reinforced Brittle Matrix Composites, International Workshop ”High Performance Fiber Reinforced Cement Composites”, Mainz Germany, CBL Reprint No.23, Aalborg, Aalborg Portland A/S

9. Duedahl, Thomas & Nielsen, Martin Svenning, 1993, Beregningsmodel til bestemmelse af spændings- og deformationstilstanden for bøjningspåvirkede CRC-bjælker, Aalborg, Aalborg Universitet

10. Hesche, Gert, 1988, Exsperimental research on Compact Reinforced Composite, CRC, Beams, Aalborg, Aalborg Universitet

11. Bache, Hans Henrik, 10-12 June 1981, Densified Cement/Ultra-fine Particle based materials, The second International Conference on Superplasticizers in Concrete, CBL rapport nr.40, Ottawa, Aalborg Portland A/S

12. Bache, Anja, 2004, Ny betons form for kæmpekonstruktioner, Aarhus, Arkitektskolen i Aarhus, www.a-aarhus.dk/AAA/forskning/e-publishing/BETONS%20FORM.pdf

13. Bache, Anja Margrethe, 2002, CRC, undersøgelse af en ny betonteknologis arkitektoniske potentialer vurderet udfra holdbarhed, komfort og form, Aarhus, Arkitektskolen i Aarhus

14. Bache, Anja Margrethe, 1994, CRC-metal et brudmekanisk designkoncept, Lyngby, Danmarks Tekniske Universitet

Some firms working with the CRC-technology

1. **Contec ApS**
   Sells materials for CRC and are pioneers in relation to engineering and practical use of the CRC.
   bs@contec-aps.dk, Axel Kiers Vej 30, DK-8270 Højbjerg, (0045) 86721723. Their homepage are under construction.

2. **Hi-con ApS**
   Produce slender balconies, stairs and joints of CRC
   Hi_Con ApS., www.hi-con.dk, Gørtelvej 8, DK-9320 Hjallerup, (0045) 98283710

3. **Densit A/S**
   Densit A/S concentrates on the use of CRC in safety-industry, top dressings, safety-boxes and offshore constructions
   Densit A/S, www.densit.dk, P.O. Box 220, DK-9100 Aalborg, (0045) 98167011

4. **CRC-technology ApS**
   Sells CRC-materials and have a very informative homepage.
   CRC-technology Aps www.crc-tech.dk, Østermarken 119, 9320 Hjallerup, Denamrk, (0045) 96473010