PhD project Roel Schipper: Prefabricated double curved concrete panels

introduction
When ir. Roel Schipper and two other new lecturers applied for a position as lecturer in the Building Engineering group at TUD in 2007, one of the prerequisites for getting the job was that they would get a PhD degree. Every lecturer in Delft is supposed to have a ‘double career’: an educational one and a scientific one, the latter demonstrated by publications and preferably a PhD degree. Like many people in building industry and engineering practice Schipper did not have such a degree, since quickly after finishing his study at TUD in 1993 he started working at an engineering firm, spending his time merely on practical building design. After being accepted as lecturer, he therefore was offered the wonderful opportunity to spend a part of his time on a self chosen PhD research. He decided to start working on a special field of interest that drew his attention: double curved concrete panels. In this article the relevance and approach of this research are discussed.

prefabrication in concrete
Traditionally, prefabricated concrete façade elements stand for a significant market share in the total European building construction volume, both in high and low rise buildings. Concrete elements have the advantage of being a fully integrated part of the building structure, offering strength and stiffness, bearing floors and offering anchoring points for the outer skin (figure 2). Usually, these concrete elements are flat, that is, without curves.

free form concrete
Driven or facilitated by fast developments in CAD software in the last decades, ‘blob’ or ‘liquid’ architecture, further referred to here as ‘free form’, has come up as a development which opens the road to new and exiting shape experiments. Two recent examples of this kind of architecture are the Kunsthaus in Graz and the Yitzhak Rabin Center in Tel-Aviv (figure 3). While successes have already been achieved with low weight, non-structural façade elements such as aluminum and epoxy, concrete still does not seem to lend itself easily for freeform architecture. Single or double curved shapes in concrete require many unique flexible molds and thus lead to low repetition counts for the necessary formworks. The concrete reinforcement is often calculated using...
linear models such as beams and columns, furthermore the bending and assembling of reinforcement bars is considered difficult for curved shapes. An early demonstration of the possibilities in curved concrete is the project Der Neue Zollhof in Düsseldorf from Frank O’ Gehry (1998, figure 4). An even earlier example of freeform, although not in concrete but in natural stone, is the Casa Milà in Barcelona (1910, figure 1), designed by Gaudi. The fascinating possibilities of curvature speak for themselves.

Figure 3: Kunsthaus Graz (image Graz Tourism) and Yithak Rabin Center (image Moshe Safdie and Associates)

In the project in Düsseldorf double curved façades in prefabricated concrete have been applied. For each element an individual mould was machined on a CNC-mill, which was and still is a rather time consuming and expensive production method.

Figure 4: Double curved façade Der Neue Zollhof Dusseldorf, Frank Gehry Architects

More recent projects in concrete are the Spencer Dock Bridge in Dublin (architect Calatrava, 2009) and the EPFL Rolex Learning Center in Lausanne (architect SANAA, 2008). In both cases, the concrete was cast in situ on a base of preassembled timber of polyurethane formwork. An example of prefabrication of curved concrete is the Jubilee church in Rome (architect Richard Meier, 2004).
Spencer Dock Bridge Dublin
(Calatrava)

cast in situ concrete on a formwork of CNC-milled polystyrene with a polished coating of an epoxy resin (visible in picture)
(image Nedcam)

EPFL Rolex Learning Center
Lausanne (SANAA)

cast in situ concrete on a formwork of plywood: advanced computer techniques have been used for controlling geometry of the formwork
(image SANAA)

Jubilee Church Rome
(Richard Meier)

Prefabricated concrete panels cast with white self cleaning concrete mixture
(image Maarten Scheurwater)

Figure 5: several project in which double curved concrete was applied

All projects shown above clearly illustrate that curvature is a powerful way of expressing different kinds of shapes in architecture. International design contests nowadays often result in buildings with freeform elements in them. This results in a need for the building industry to facilitate the economic production of curved elements. Due to the high production costs, until now these complex shapes could only be achieved in high profile buildings, with a non-average budget. Schipper’s research aims to contribute to the process of finding more affordable production techniques.

earlier research

One of the Dutch pioneers in the field of describing and realising curvature in architecture in a more rational way is dr. Karel Vollers. In his book “Twist&Build” (010 publishers, 2001) he develops various systems and application opportunities for curvature in buildings. In his present research the “flexible mould” is the central concept: a technique that is used for the deformation of an initially flat material into a (double) curved element. The work of Vollers and PhD researcher Daan Rietbergen has so far proved to be a first step into realizing this goal: together with a glass manufacturer they already succeeded in applying this patented procedure for float glass. In the last year, the focus moved to the material concrete, involving Hurks
Beton as industrial partner. Two Master students Huyge and Schoofs from the Faculty of Architecture experimented in the CiTG Stevin II lab with several concrete mixtures and flexible moulds for the realization of curved panels.

Figure 6: flexible mould and curved concrete panel by Daan Rietbergen and students

In the lab several experiments were carried out, successfully resulting in a number of curved prototype façade panels in concrete. The MSc research however raised a number of interesting questions, a.o.:
- what is the right material for the mould?
- can the behavior of the mould material be predicted numerically?
- what is the right concrete mixture for a specific panel?

The Stevin II lab has outstanding facilities for creating all thinkable concrete mixtures in limited portions; technicians are available for conducting the experiments and supporting with knowledge and equipment.

research goal
The goal of the PhD project is to further elaborate this new production technology, aiming for an economically feasible procedure that uses concrete as material for free form façade elements. The study has already started with acquiring an overview of recent developments in the field of research and development and a first demonstration of realizing free form concrete elements. The MSc research that finished this summer has -in that respect- opened the road to further refinement of the “flexible mould” principle. If possible in cooperation with industrial partners, such as Hurks and Nedcam, solutions will be searched for the technological issues that rise. One could think of the choice of suitable mould materials, the CAD-CAM link between model and mould, design of concrete mixtures, but also the aspects of detailing and tolerances of prefabricated panels. Further industrial attention is welcomed, as well as input from MSc-students who want to collaborate in the project. Interested readers can contact Roel Schipper for further information.