Innovative construction with cast in place concrete using product models

Mats EMBORG
Ass Professor
Betongindustri AB
Stockholm, Sweden

Rogier JONGELING
PhD Student
Luleå Tech. University
Luleå, Sweden

Thomas OLOFSSON
Professor
Luleå Tech. University
Luleå, Sweden

Thorbjörn DORBELL
MSc
Betongindustri AB
Stockholm, Sweden

Summary

Some examples of innovative material and construction techniques applied for improving the productivity is presented e. g. new form system, reinforcement types, self compacting concrete. When combining with information technology based on product modeling, an important step towards an industrialized construction with cast in place concrete is made and the quality of the final product is improved.

Keywords: construction process, cast in place concrete, self compacting concrete, steel fibre reinforcement, left form system, information technology, product models

1. Construction Research at the Centre of eBygg and at Betongindustri

The development of reinforcement, concrete and forms during the last decades together with new construction methods have implied a markedly increased productivity, using cast in place concrete. Simultaneously, the quality of the final product has been enhanced. By combining these new findings with information technology using product modeling, the productivity and quality are even further improved.

At the eBygg [1], Centre for Information Technology in Construction of Luleå University of Technology (LTU), research projects are conducted in cooperation with the Swedish construction industry. The eBygg centre provides an academic environment where companies jointly conduct research on new building materials and production technologies. One such a company is the ready mix concrete supplier Betongindustri AB. By performing material and construction oriented research on concrete at own laboratories and at the research laboratory of LTU, Testlab, basic findings have been achieved that are further studied in full scale situations. This has served as an important input to the development of construction processes.

2. Development of Industrialized Construction

At present, promising activities are in progress to develop construction, using cast in place concrete. The concrete has been adapted to altering requirements regarding modern building methods and design solutions. For example, high performance concrete has been developed meeting needs for fast drying of slabs, high design strengths and fast strength development for a rapid construction of slender structures, and self compacting concrete for a healthy working environment and high productivity. New techniques of reinforcement are now combined with these concretes like the fibre reinforcement in e. g. combination with prestressing steel and new methods of pre-assembled reinforcement like the Bamtec© system. New types of forms are used e. g. various permanent form systems.

According to the general opinion in Scandinavia, for a broader industrialization of the building process with cast in place concrete, five main components are identified considering *material* and *construction* technique (*Fig 1*):

- *minimized reinforcement activities* utilizing different kinds fibre reinforced concrete and prefabricated reinforcement, reducing on-site operations and increasing the production rate [2],

- further *improvement of concrete qualities* that are customized for specific and optimal use. For example, *self-compacting concrete* can be tailor-made for the actual structure,
- *permanent formwork* minimizing site logistics. Form elements are prefabricated and erected on site. In [3] it is considered that the transition towards assembly on site of prefabricated building elements is a main component of industrialization,
- *weather independent* construction processes, e.g. by building a structure inside a climate protective tent; and
- modern technique of transporting the concrete on site. Available *systems of pumping* can be further adapted to each casting situation

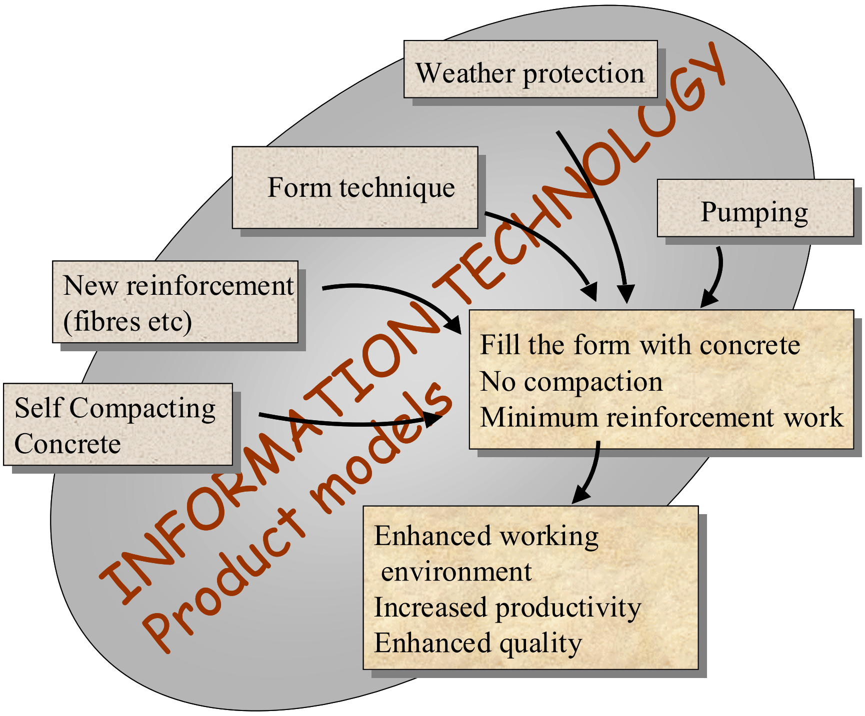

Fig. 1 Main development components of industrialized construction using cast in place concrete.

It is however not until these components of improvements are combined with *Information Technology,* see *Fig 1*, the important step towards an industrialized process is taken. Thus, shared product models improve multi-disciplinary decision-making for cast-in-place concrete structures.

3. Construction Methods and Materials

One component of evolving the building process is the new *Self Compacting Concrete* (SCC) originally developed in Japan about ten years ago. During the last six years, the SCC has successfully been used in several applications in Scandinavia and other places, both at civil engineering and housing projects, *Fig 2*. The SCC is now further optimized for these applications.

Three main properties are thus addressed: a) the *filling ability* i. e. the ability of the concrete to flow freely under its own weight and to completely fill formwork of any dimension and shape without leaving voids, b) *passing ability* i. e. the ability of concrete to flow freely in and around dense reinforcement without blocking and, c) *resistance to segregation* during placement, and while flowing, the concrete should retain its homogeneity.

Important research projects on material and constructional aspects of SCC have recently been carried out and are in progress, e. g. the 4 year Brite-Euram international project SCC [4], the 3 year Growth international project Testing-SCC [5] and other research projects e. g. reported in proceedings of international conferences [6] [7].

Fig. 2 Example of the use of Self Compacting Concrete at the casting of a bridge foundation and a slab of a house. No compaction is needed, improving the working environment and productivity.

The concrete is now combined with steel fibre reinforcement - where it is possible - and with new pumping techniques. A wide range of applications are possible, from the traditional slab on ground structures to ground walls and walls of houses for which the latter cases a considerable load bearing capacity is aimed at.

Another such a new technique is the new innovative *VS© form system* constituting of light cement/wood boards connected to each other by simple fasteners, see *Fig 3*. Pre-reinforced wall and slab sections are mounted on site and are concreted with specially developed flowable concrete. The VS© system has been applied at several full-scale projects in e. g. Austria and Germany and is now furthered refined with the new SCC and new types of reinforcement.

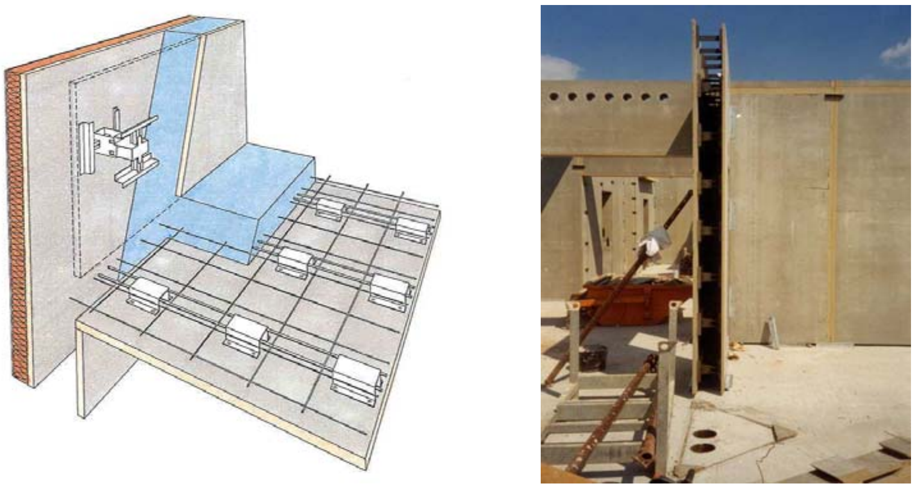

Fig. 3 The VS© lightweight form system for effective construction with self compacting concrete.

4. 4D Product Modeling

Information technology in the form of product modeling is starting to be adapted by the cast in place concrete sector. Product models are data models containing product and process information, such as geometry, planning and work-documents. Shared product modeling systems are considered to be of critical importance to improve the multi-disciplinary decision making, see *Fig 4*, regarding cast-in-place concrete structures. Several examples can be given of the potential use and show the necessity of product modeling for the industry [8] [9]:

- During the *early design* stage of a project, the concrete suppliers can cooperate with a project developer on possible construction solutions. Decisions based on early analyses of a design have a big impact on the final project outcome and costs [10];

- in the *detailed design* phase the supplier may recommend the structural engineer to use specific material;
- 4D simulations can be used during the *production planning* phase of a project to e.g. simulate different material properties and various production process alternatives, such as specific form work solutions;
- the 4D model serve as a basis during the production process to control the *delivery process and to coordinate the logistics on site* as well as to control the drying and hardening process of concrete; and
- *innovations* aimed at industrialization can be modeled and simulated in all building phases by using a virtual construction approach.

In a feasibility study, in which Betongindustri participated, it is explored where product models can be applied and how they can be adapted, *Fig 4*. An internet-based 3D modeling system is thus applied by which a residential structure in Stockholm is modeled with the Enterprixe© software system [11] that now is adapted to cast in place systems, see *Fig 5*. Several examples are created that are typical for the design, planning and production processes of cast in place concrete. By modeling the progress of the construction, also the fourth dimension – time – is introduced. For example, the drying process of concrete slabs can be computed, visualized, planned for and thus controlled, avoiding moisture problem at too early cover with e. g. linoleum carpets.

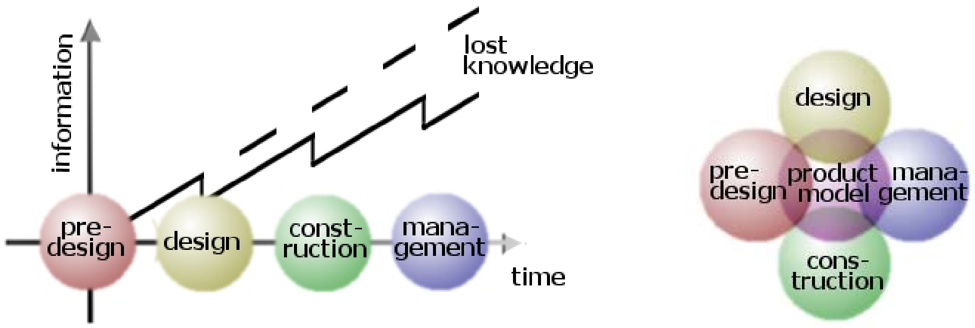

Fig. 4 In a traditional building process, knowledge is lost due to insufficient transition of data between actors in different phases (left). With an integrated building process, using Product Models (right), the co-ordination is increased, reducing the possible loss of knowledge, from eBygg [1]

5. Simulating Innovations

The process of introducing new innovations is difficult due to the complexity of the building process and current practice. The time-pressure is demanding, leaving little room for innovative solutions. Introducing innovations is constrained by the fact that they are difficult to describe and to explain. The evaluative and predictive components of information sharing are even more challenging [12]. One way of introducing new innovations is full scale pilot projects, but these projects are costly and resource intensive. Furthermore, there is a risk in full scale pilots that the efficiency and effectiveness of an innovation are not clearly shown, caused by a lack of experience and parameters (e.g. weather conditions) that are beyond control of the project organization.

The possibility to build a structure virtually and to simulate innovative solutions in 4D is considered to be very useful, as it involves low costs and no construction risks. In the residential building case, two identical structures are modeled of which one is industrialized and one is used as a 0-reference representing today's construction practice. The parallel models provide a good basis to explain and to evaluate alternative construction methods. A detailed planning of formwork and casting sequences is made in Enterprixe© in combination with MS Project© that is two-way linked to the system. *Figure 5a-d* presents four successive screen captures of a 4D simulation of an industrialized virtual building.

A number of scenarios are modeled and per scenario various combinations are made of different design, planning and production solutions. Concrete parameters, such as the Concrete Class and the

Water to Cement ratio, are configured per scenario to illustrate their impact on design, planning and production. Weather influences are taken into account in the scenarios for e.g. concrete hydration, strength growth and drying process. Regarding the drying process of concrete slabs different scenarios are created for various climate conditions (temperature and humidity).

The use of 4D for cast-in-place concrete is currently limited to simulations of predefined scenarios, mainly used for e. g. marketing purposes. The 4D functionality can be further developed applying as a dynamic instrument to predict consequences of alternative design, planning and production decisions. The development and use of standardized product libraries containing standard activities and time stamps is relevant in this respect. Currently, the calculations and planning are mainly performed manually, but it is expected that this process will be partly computerized. The consequences for the cast in place concrete industry are both positive and negative. By using standard product information from a database one can enhance standardization of products and processes, and automatically can generate a fourth dimension for 3D models.

However, cast in place concrete is not a single standard product and has no standard process. The products and processes are to a certain extent standard, but require in many projects customization made by a long term experienced concrete engineer using specific expert programs to calculate for example required material properties. With standard recipes for cast in place concrete one risks to adapt sub-optimal product and process solutions. One can even wonder if it is desired to totally automate the process of calculations and planning? From a quality perspective one cannot be too anxious, but when the competitiveness is considered to the steel and prefabricated concrete industries it becomes clear that certain automation is necessary in order to remain competitive in the future.

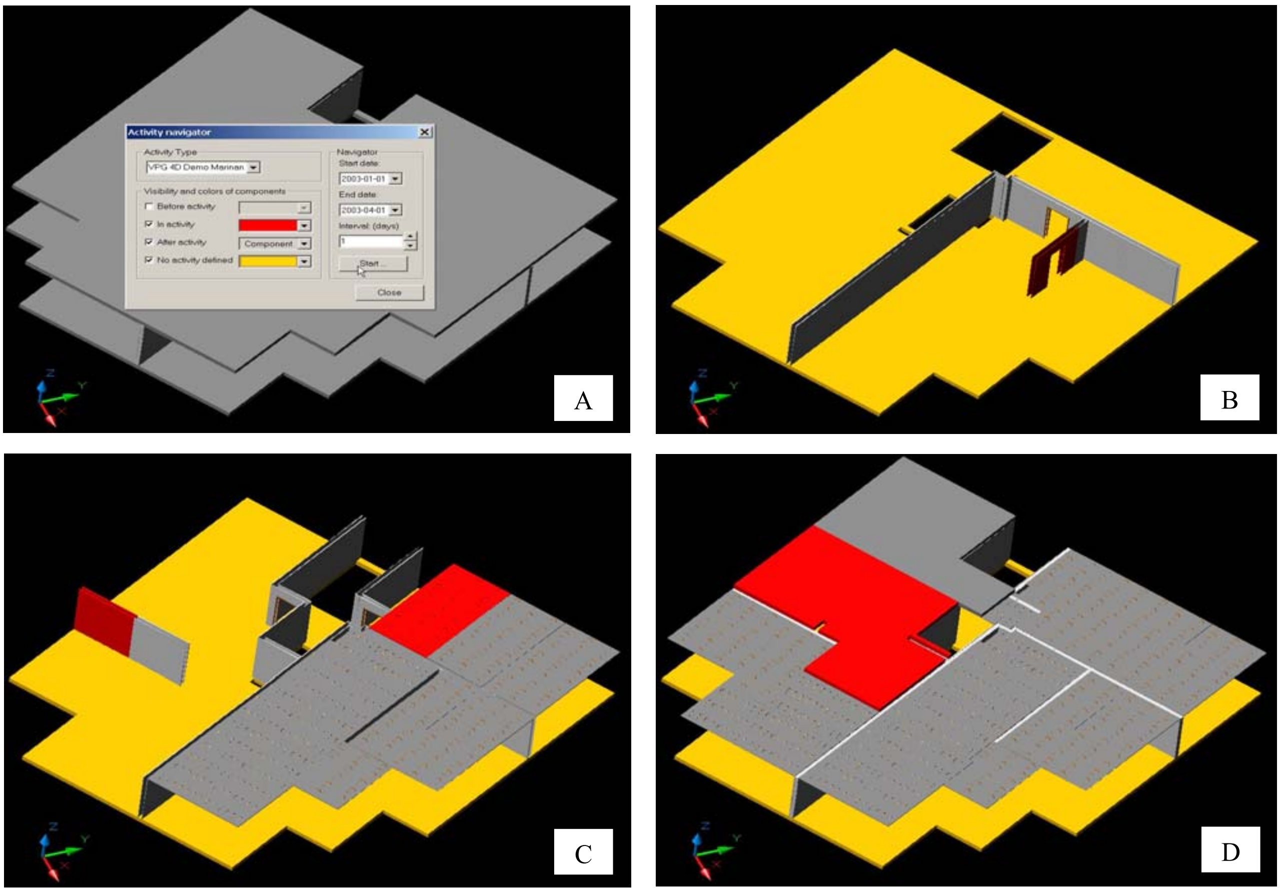

Fig. 5: Example of 4D simulation of left formwork with the Product Model System Enterprixe© [10]. Color settings are made (A) and the time interval is set. Yellow elements represent elements with no activities defined (B) while elements in activity (built) are red and after activity grey (finalized). Using 4D simulation one can identify the possibility for concurrent activities (C). Casting sequences can be optimized to suit production and site logistics (D), from Jongeling et al [8] [9].

6. Conclusions and Discussion

It can be concluded, that a large step into a more industrialized building process is only taken if all innovative material techniques and production methods are combined simultaneously according to *Fig 1*. Furthermore, by also applying information technology to the cast in place concrete construction an even longer step is taken to the industrialization. Virtual construction can facilitate the introduction and application of new innovations aimed at industrialization. 4D simulations show a broad variety of design, planning and production alternatives of cast in place concrete. The objective is to utilize the full potential of 4D as instrument to control construction and to dynamically predict consequences of alternative design, planning and production decisions that are made during a project. However, the technical and organizational implications of such a practice for the cast in place concrete industry require further research. Especially the balance between automation and customization, and between quality and competitiveness are topics that need further study.

An interesting and challenging continuation of the research is expected in next years, supporting the development of an industrial construction process!

7. References

[1] eBygg: Centre for Information Technology in Construction of Luleå University of Technology (LTU) http://e-bygg.ce.luth.se.

[2] EMBORG M., "Industrial Construction of Frames using High Performance Concrete", *Bygg och Teknik,* no 7, 2003, pp 7- 9 (in Swedish).

[3] BYFORS J., "SCC is an important step towards industrialization of the building industry", *Proceedings of the First International RILEM symposium on Self Compacting Concrete* (eds: Skarendahl and Peterson), Stockholm, Sweden, 1999, 15-24 pp.

[4] WALLEVIK O., NIELSSON I. (editors), "*Self Compacting Concrete*", Proceedings of the 3rd International RILEM symposium, 17-20 Aug, 2002, Reykjavik,1028 pp.

[5] SCC. "*Rational Production and Improved Working Environment through using Self Compacting Concrete*", Brite Euram Project (coordinator NCC), http://scc.ce.luth.se.

[6] SKARENDAHL Å., PETERSON Ö. (editors), "*The First International Rilem Symposium on Self Compacting Concrete*", Sept 13 – 14, 1999, Stockholm, Rilem Proceeding no 7, 1999.

[7] Testing SCC, "*Test methods for self compacting concrete*", Growth project GRD2-2000-30024, (coordinator: Univ. of Paisley, GB) homepage: http://www.acmcentre.com/testing-scc

[8] JONGELING R., "*Product Models for Cast in Place Concrete*", Division of Structural Engineering, Luleå Technical University, Technical Report 2003:01, 104 pp.

[9] JONGELING R., OLOFSSON T. and EMBORG E., "Product Modelling for Industrialized Cast in Place Concrete Structures", *To be published on the International Conference on Construction Information & Technology 2004*, Langkawi, Malaysia.

[10] LAITINEN J., "*Model based construction process management*", Royal Institute of Technology (KTH), Construction Management and Economics, Stockholm, Sweden, 1998.

[11] ENTERPRIXE, *Enterprixe White Paper*, Internet: www.Enterprixe.com.

[12] LISTON K., FISCHER M. and WINOGRAD T., "Focused sharing of information for multi-disciplinary decision making by project teams", ITcon *Electronic Journal of Information Technology in Construction*, Vol. 6, 2001, 69-81 pp.