TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Mechanical Science and Engineering Faculty of Civil Engineering

SHORT REPORT

Feasibility study on continuous and formwork-free construction process with 3D-printing of fresh concrete

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Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit

Bundesinstitut für Bau-, Stadt- und Raumforschung im Bundesamt für Bauwesen und Raumordnung

FORSCHUNGSINITIATIVE ZukunftBAU

3D-Concrete-Printing

Feasibility study on continuous and formwork-free construction process with 3D-printing of fresh concrete

Project duration: 29.09.2014 - 30.09.2016

Short report

– SWD-10.08.18.7-14.07 –

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The authors bear the responsibility for the content of this report.

Status quo

The common in-situ casting of concrete is highly labor- and time-intensive. Currently, researchers around the world are investigating methods to transfer established 3D printing technologies (plastic, metals) to construction processes and materials (concrete). This could limit the deficits of conventional concrete construction, reduce costs and increase labor productivity. In the research project at hand, the feasibility of a novel, formwork-free construction process was to be investigated interdisciplinary (mechanical engineering, building material technology and construction management).

Objectives of the research project

Firstly, the measures and conditions which enable an efficient and formwork-free construction with concrete were analyzed considering state of the art international researches. In contrast to the hitherto known approaches, this research project focused on practical implementation challenges: the innovative construction process to be carried out directly on site (in-situ), the machine technology to be based on established construction machines and cement-based materials similar to conventional concretes to be used.

Known additive manufacturing processes were analyzed and their potentials to be transferred to the construction processes were examined. Subsequently, required specification criteria for the in-situ construction process were defined and systematically investigated. The chair of construction machinery covered subjects about technical solutions for concrete conveying, design of printhead and mechanisms behind large scale robotics. The Institute of Construction Materials developed concretes suitable for 3D-printing and investigated their properties in fresh and hardened states. The Institute of Construction Management focused on the process optimization, studies on the required data structures and data formats as well as the economic viability, cost- and time-reduction potential of the innovative approach.

As a technological concept, it is provided that a printhead discharges layers of concrete, while it is precisely moved along the predetermined paths by a large-scale manipulator. After comparative investigations on various robotics concepts the truck mounted concrete pump machine became the focus of studies with respect to machinery. The truck mounted concrete pump contains the standard and necessary concrete transporter technology and its cantilever boom is suitable as a large scale manipulator. For the computer-controlled movement of the boom, control algorithms were developed and tested in collaboration with industry partners on a commercial pump. By reconciling the measured coordinates of the automatically controlled boom with the predetermined path of motion, the positioning accuracy of concrete boom could be validated. The major functions of the print head include the controlled discharge of fresh concrete and the molding of individual layers of concrete.

For the technical implementation, different solutions for individual tasks were developed and evaluated. These will serve as a basis for the further development of the entire system.

The building material investigations focused initially on the selection of raw materials and the determination of suitable compositions for printable concretes. A variety of concretes were developed which exhibit sufficient pumpability and extrudability on one hand and appropriate buildability and development of mechanical properties over time on the other hand. Moreover, suitable methods for characterization of extrudability and buildability of fresh concrete and mechanical properties of hardened printed concrete were developed. These methods were combined to a comprehensive approach for evaluating printability of concrete compositions. As the key unit of this approach "3D concrete printing testing device" was developed and build. It enabled not only testing properties of fresh concrete relevant for processing, but was also used for 3D printing of specimens for investigation of compressive and flexural strengths. Experimental studies confirmed the feasibility of the formwork-free 3D printing of fresh concrete. The developed fine-grained printable concretes are characterized by their good extrudability, sufficient buildability and high compressive strength.

In the construction management studies, user requirements and possible application scenarios were first analyzed. Replacement of masonry, especially when constructing residential buildings with up to 5 floors, was identified as target application in the first development step of the new technology. In the next step, analysis of the required data structures and data formats was carried out using the process chain of existing, small-structure 3D printing procedures as basis. Additionally, the cost efficiency was considered exemplarily for a single-family house model building. Thereby, the construction costs and time related impacts for production of the wall elements with targeted 3D concrete printing processes were studied and compared with conventional masonry construction. The results indicated a significant reduction in construction costs and execution time when the new construction technology would be applied.

Conclusion

The project demonstrated the feasibility of the suggested concrete technology. The most important deliveries include:

- List of specific requirements for machine technological aspects (printhead, robotics, concrete conveying),
- Suitable fine-grained concrete compositions and methodology for testing properties of printable concrete in fresh and hardened states,
- Efficiency analyses of construction costs and time,

- Technology demonstration through laboratory experiments on the scale of 1: 5.

The basis for the further development of the novel construction process is established on both technical and economical levels. The award of "bauma Innovation Prize 2016" for this research work and the growing interest of research community, industry and public underline the high importance of the project at hand. Therefore, the continuation of the research work up to the practical implementation of the technology is urgently recommended by the project participants.

Basic information

Short title:	Beton-3D-Druck
Project leader:	Prof. Dr.-Ing. Jürgen Weber TU Dresden, Chair of Construction Machines
Principal investigators:	Prof. em. Dr.-Ing. habil. Günter Kunze TU Dresden, Chair of Construction Machines
	Univ.-Prof. Dr.-Ing. Viktor Mechtcherine TU Dresden, Institute of Construction Materials
	Univ.-Prof. Dr.-Ing. Rainer Schach TU Dresden, Institute of Construction Management
Researchers:	Dipl.-Ing. Mathias Näther TU Dresden, Chair of Construction Machines
	M. Sc. Venkatesh Naidu Nerella TU Dresden, Institute of Construction Materials
	Dipl.-Ing. Martin Krause TU Dresden, Institute of Construction Management
Total costs:	662.909,64 €
Federal grant:	404.046,41 €
Project duration:	24 months

Figures

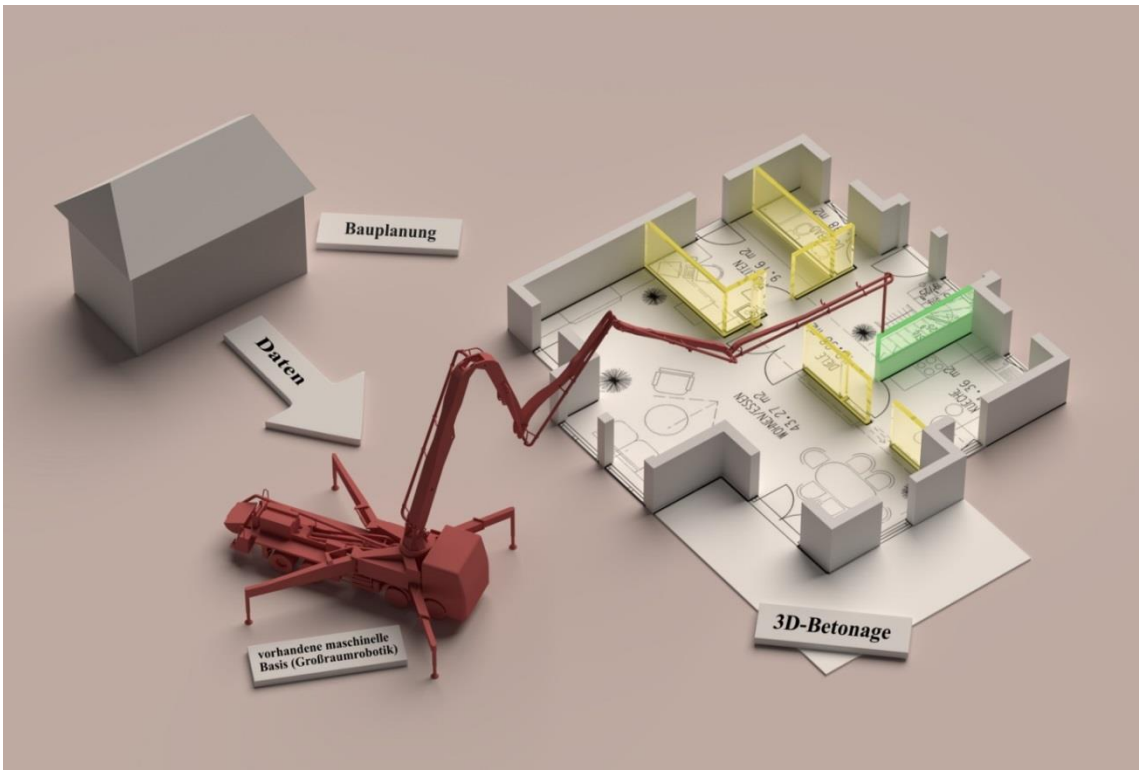

Figure 1: The essential elements of concrete printing technology

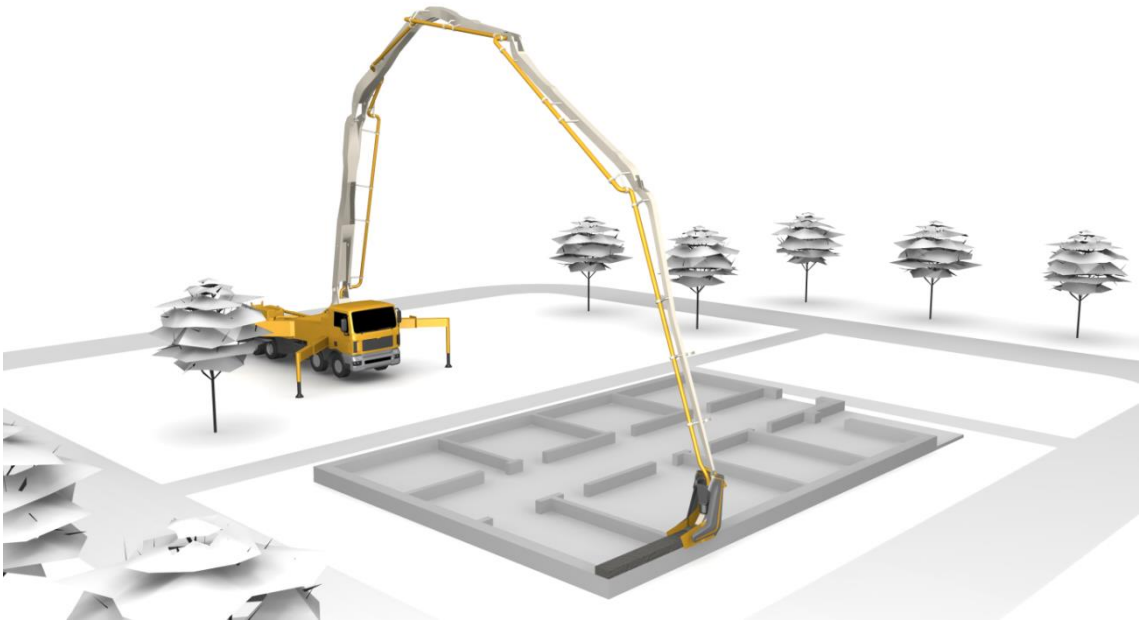

Figure 2: Concrete 3D printing directly on the construction site (animation)

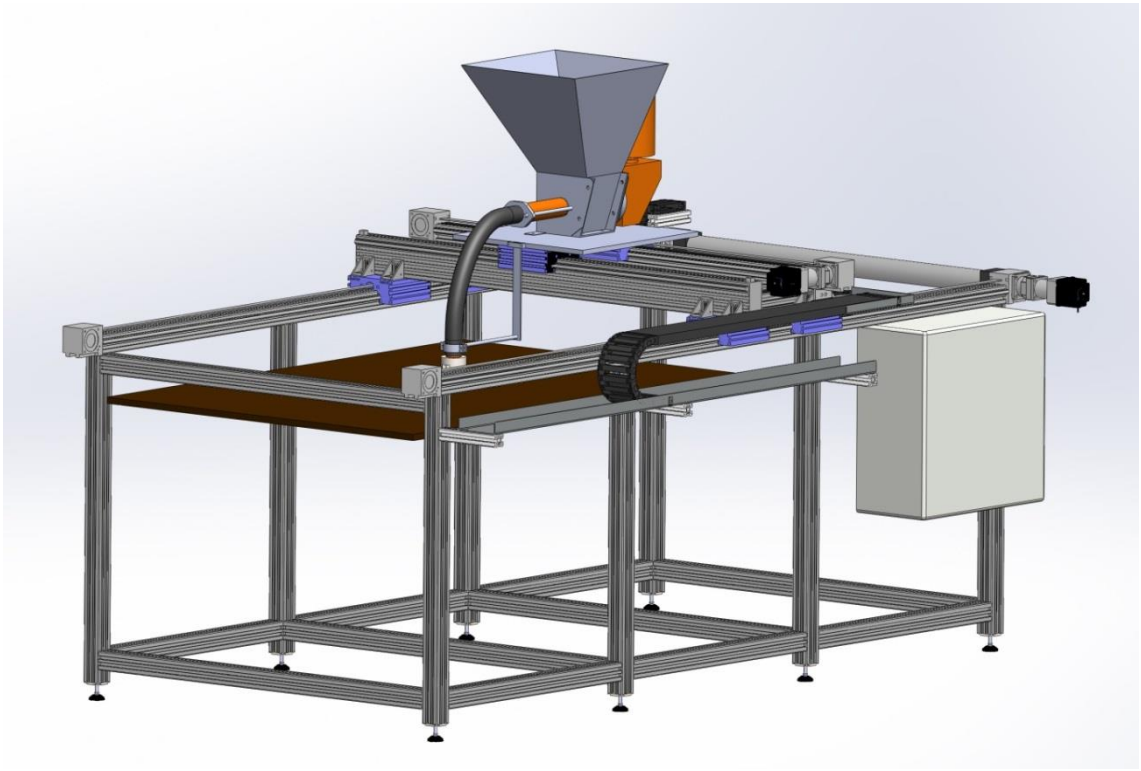

Figure 3: 3D concrete printing testing device (CAD representation)

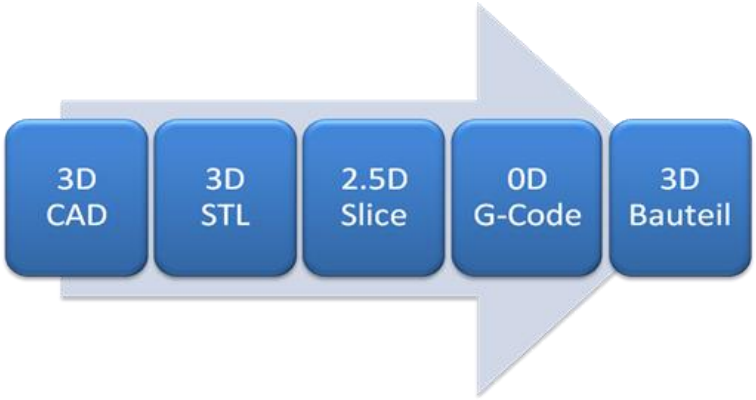

Figure 4: Process chain of data preparation

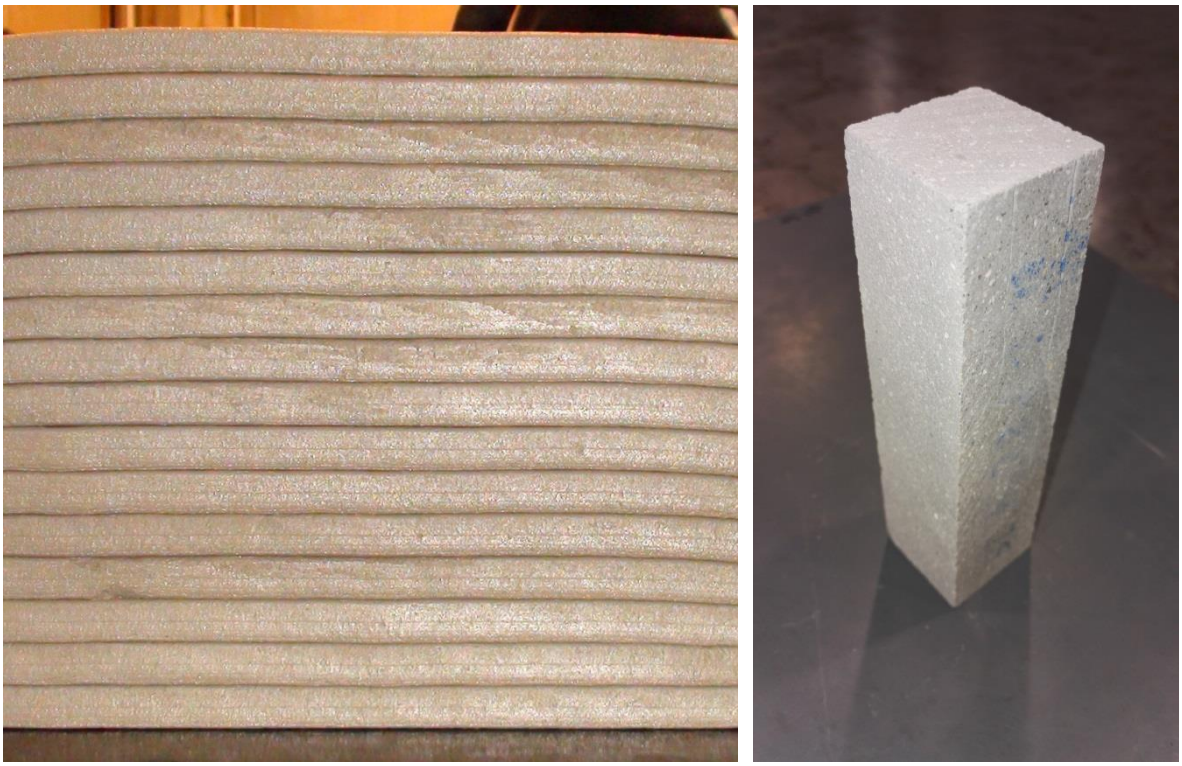

Figure 5: left: Printed concrete wall section, right: specimen for flexural tests