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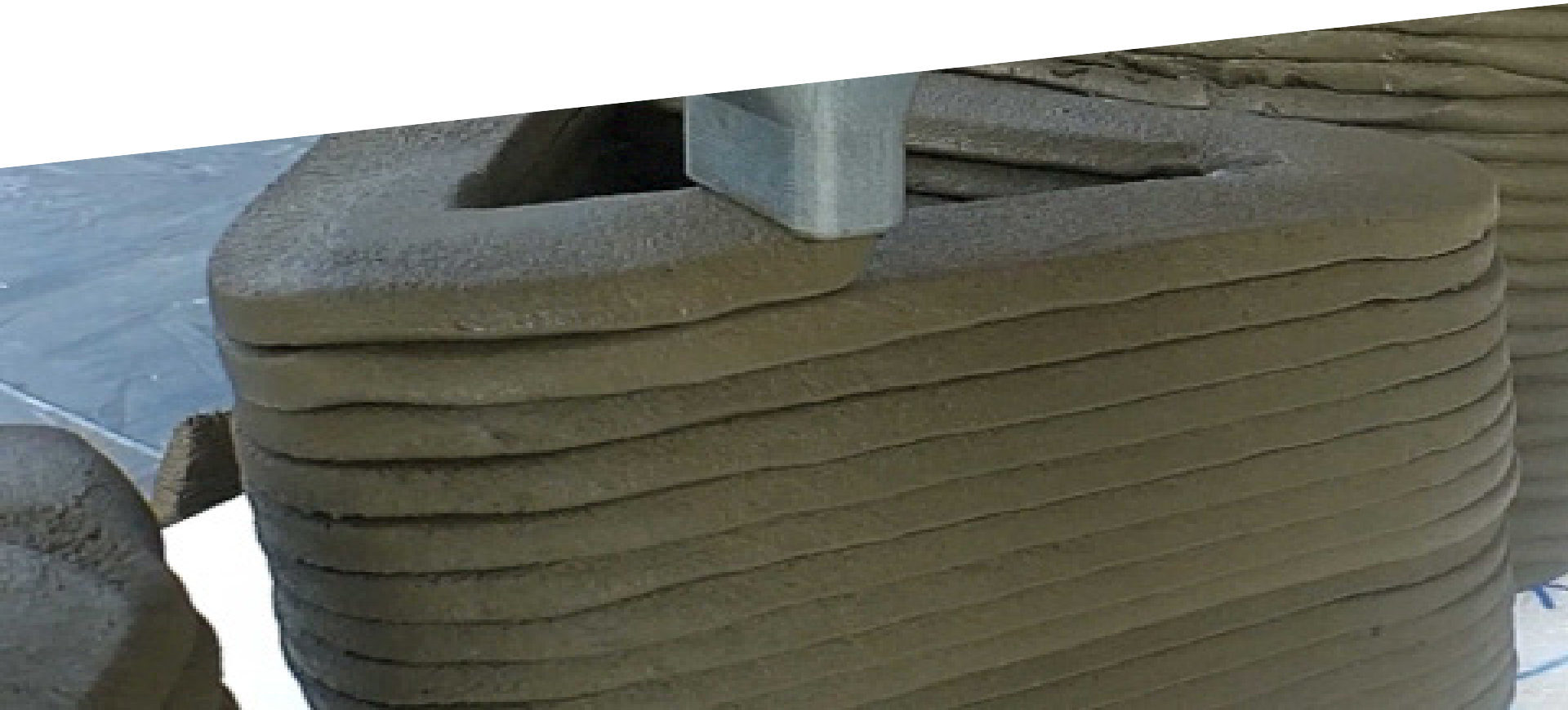
3D Concrete Printing - from material design to extrusion

Annual Civil Engineering Workshop at Ecole Centrale de Lille
July, 2017



3D Concrete Printing

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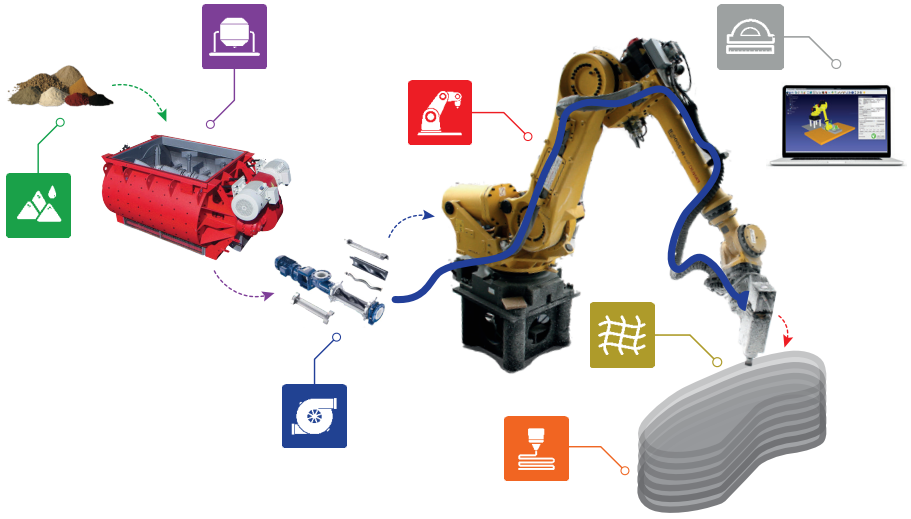
3D Concrete Printing refers to the process used to synthesize a 3D model in successive layers of material to create an object, e.g. a concrete wall

Robot-based 3D Printing Process:



MATERIALS

CONCRETE MIXER

CONCRETE PUMP

ROBOT CONTROL

CONCRETE EXTRUSION

REINFORCEMENT

DESIGN

MATERIALS

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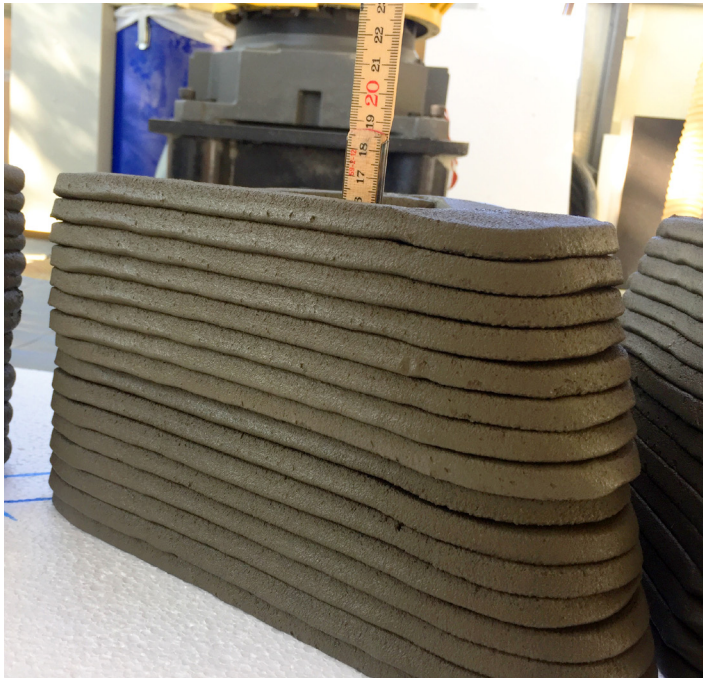
Fresh concrete is the filament:

- Similar materials to that of concrete
- Max. particle size (up to 2.0 mm)
- Concrete admixtures



Material challenges:

- Pumpability vs. Buildability
- Concrete rheology (fresh state)

MATERIALS

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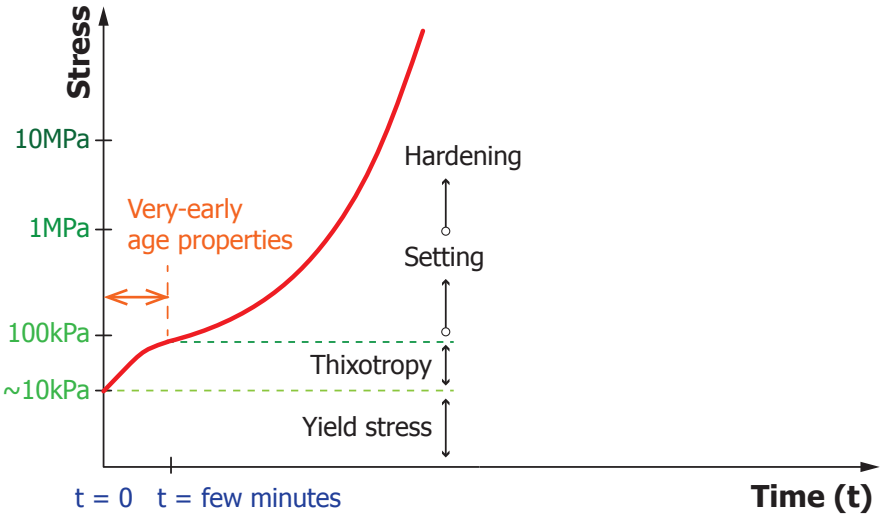
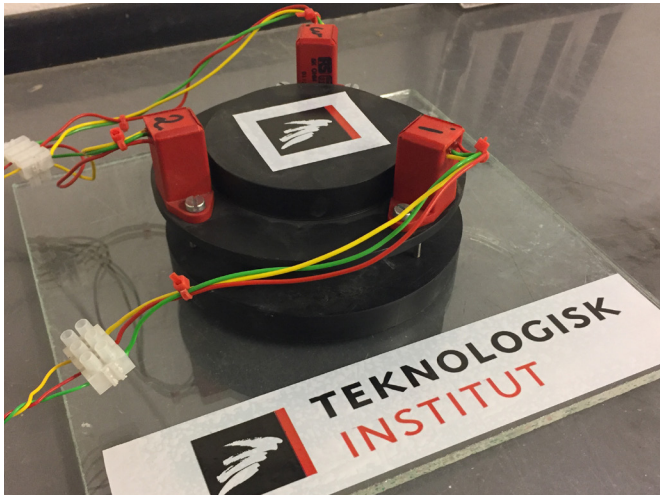
Concrete properties and mix design



- Cement hydration
- Concrete admixtures
- Strength development
- Drying shrinkage ...

Test device - layer deformation measurements



Nothing we do not know... But now we need all of it at once and with high precision

MATERIALS

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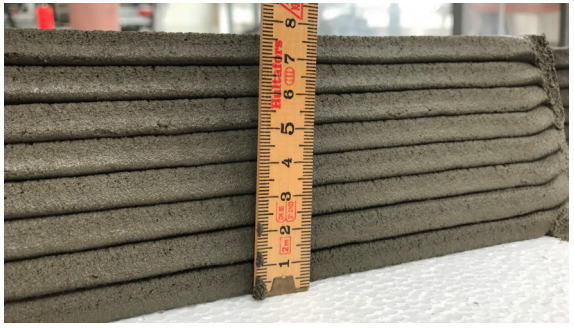
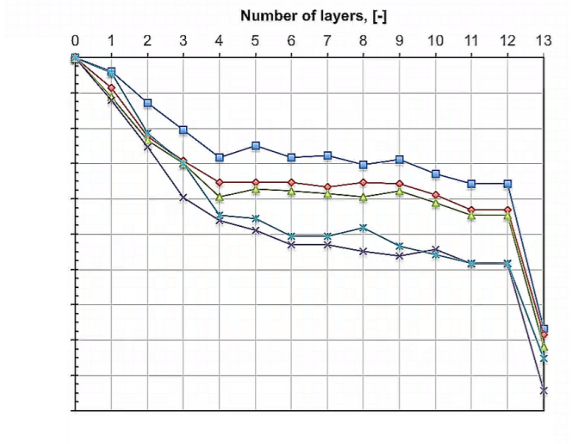
Buildability of fresh concrete (without the use of accelerators)





CONCRETE MIXER

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Batch process:

- **Concrete composition is constant**
- *Fresh-state properties* can be adjusted by adding admixtures while printing

Mixing plant at DTI's Concrete Centre

Continuous mixing:

- **Concrete composition is adjustable**
- *Fresh and hardened-state properties* can be adjusted while printing

Source: MTec

CONCRETE MIXER

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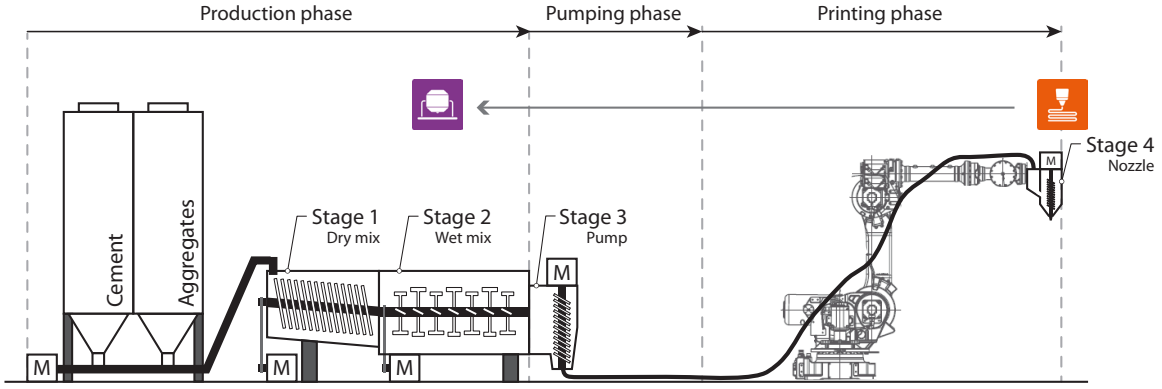
Feedback system in a continuous mixing production process:

- Increase robustness of the production process
- Enable the production of functionally-graded concrete elements



Funtionally-graded concrete sample

Source: MIT

CONCRETE PUMP

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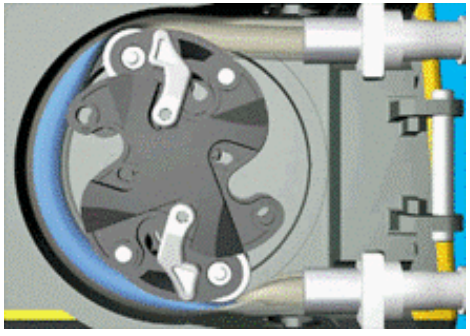
Peristaltic concrete pump:

- Pulsating extrusion (poor controllability)
- Large equipment for initial tests

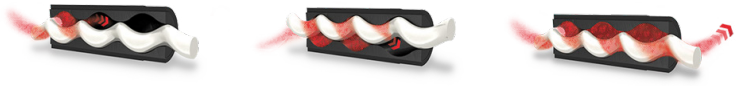


Progressive cavity pump:

- Controlled extrusion (rotor-stator)
- Enables high-resolution printing
- Low oozing (preditable material flow)
- Suitable for high-viscosity materials

Source: PCM

Endless-piston principle (True positive displacement)



Source: PCM

CONCRETE PUMP

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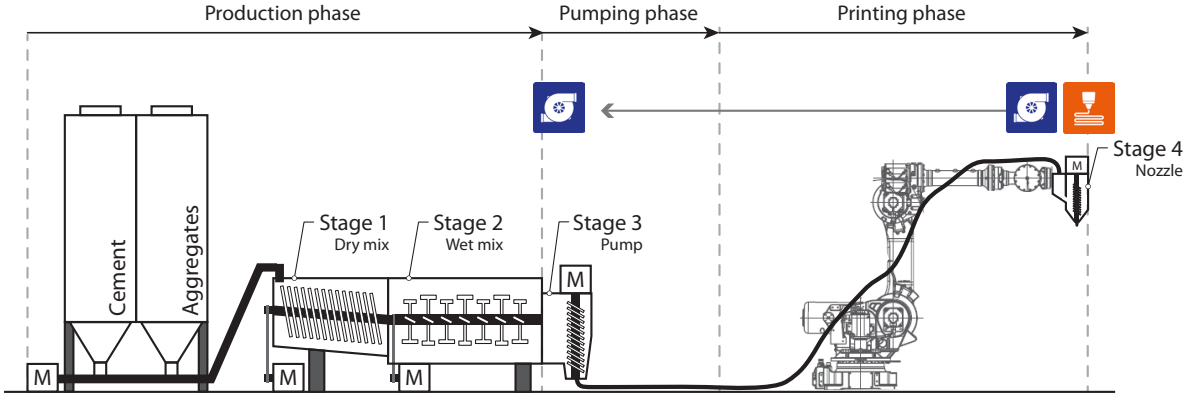
Progressive cavity pump

3D Printed prototype

DTI's progressive cavity pump

- Increase controlability and reliability of the printing process



CONCRETE EXTRUSION

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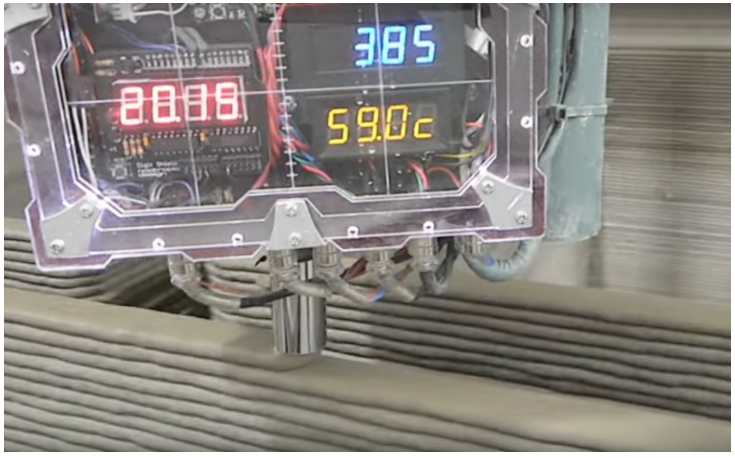
"Passive" robot nozzle:

The extrusion is controlled by a pump and the robot nozzle works as a dispenser that defines the shape of the printed layers.

"Active" robot nozzle:

The extrusion is controlled at the nozzle by a pump, enabling great precision and addition of admixtures during extrusion.



Source: Total Kustom

CONCRETE EXTRUSION

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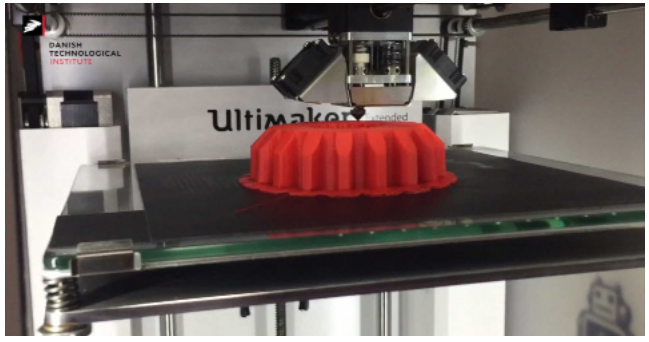
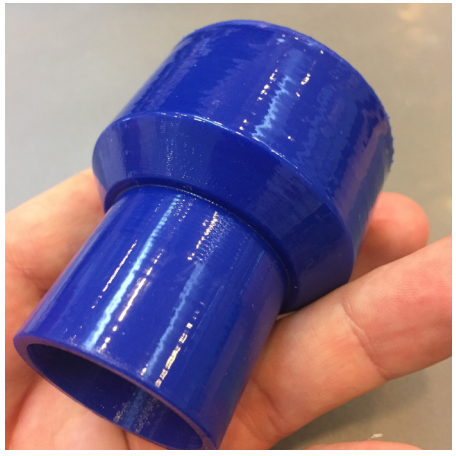
Nozzle experiments (3D Printed Nozzles)





Concrete buildability = f(properties at very-early age, e.g. yield stress)

3D Concrete Printing

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MATERIALS	VERY-EARLY AGE PROPERTIES
CONCRETE MIXER	ROBUSTNESS
	FEEDBACK SYSTEM
CONCRETE PUMP	RELIABILITY
ROBOT CONTROL	AWARENESS (SAFETY)
CONCRETE EXTRUSION	ROBUSTNESS & PRECISION
REINFORCEMENT	TRANSVERSAL REINFORCEMENT
	TECHNICAL STANDARDS
DESIGN	RETHINK DESIGN METHODS

3D CONCRETE PRINTING → **INTERDISCIPLINARITY**

3D Concrete Printing

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3DCP: Knowledge Network

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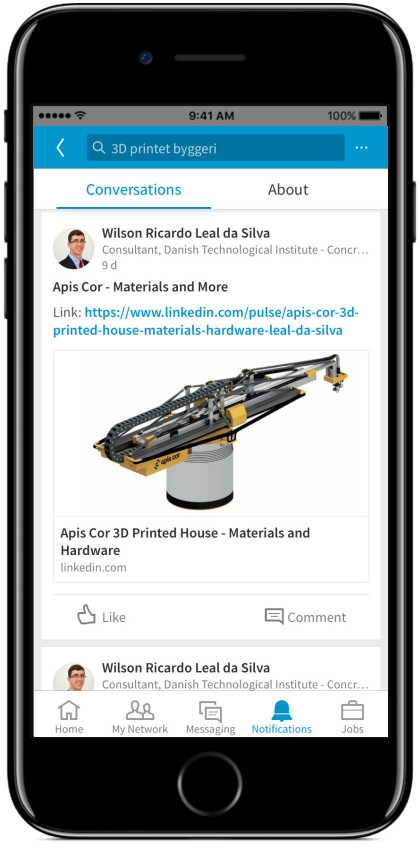
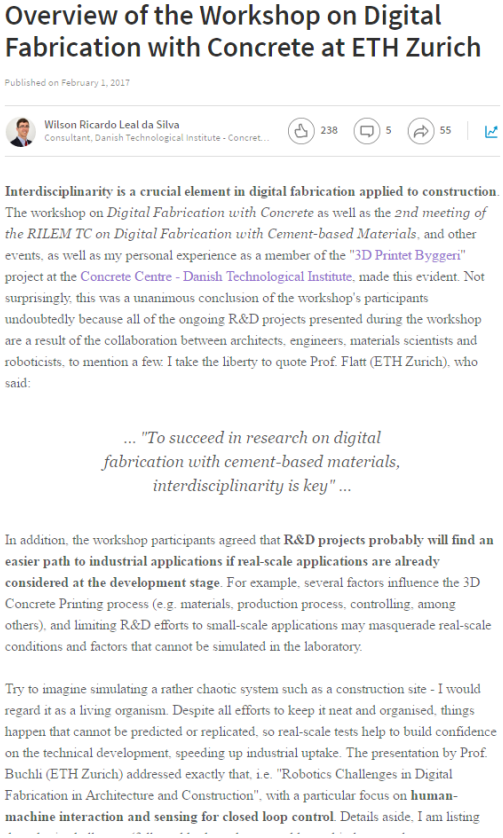
3D Printet Byggeri on LinkedIn





Overview of the Workshop on Digital Fabrication with Concrete at ETH Zurich

Published on February 1, 2017

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238 5 55

Interdisciplinarity is a crucial element in digital fabrication applied to construction. The workshop on *Digital Fabrication with Concrete* as well as the *2nd meeting of the RILEM TC on Digital Fabrication with Cement-based Materials*, and other events, as well as my personal experience as a member of the "3D Printet Byggeri" project at the Concrete Centre - Danish Technological Institute, made this evident. Not surprisingly, this was a unanimous conclusion of the workshop's participants undoubtedly because all of the ongoing R&D projects presented during the workshop are a result of the collaboration between architects, engineers, materials scientists and roboticists, to mention a few. I take the liberty to quote Prof. Flatt (ETH Zurich), who said:

... "To succeed in research on digital fabrication with cement-based materials, interdisciplinarity is key" ...

In addition, the workshop participants agreed that **R&D projects probably will find an easier path to industrial applications if real-scale applications are already considered at the development stage**. For example, several factors influence the 3D Concrete Printing process (e.g. materials, production process, controlling, among others), and limiting R&D efforts to small-scale applications may masquerade real-scale conditions and factors that cannot be simulated in the laboratory.

Try to imagine simulating a rather chaotic system such as a construction site - I would regard it as a living organism. Despite all efforts to keep it neat and organised, things happen that cannot be predicted or replicated, so real-scale tests help to build confidence on the technical development, speeding up industrial uptake. The presentation by Prof. Buchli (ETH Zurich) addressed exactly that, i.e. "Robotics Challenges in Digital Fabrication in Architecture and Construction", with a particular focus on **human-machine interaction and sensing for closed loop control**. Details aside, I am listing

Thank you for your attention!

Reference to this presentation:
Leal da Silva, W.R. (2017). 3D Concrete Printing - from material design to extrusion. [Presentation Slides] Retrieved from Danish Technological Institute website: https://www.dti.dk/projects/3d-printed-buildings/36993

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