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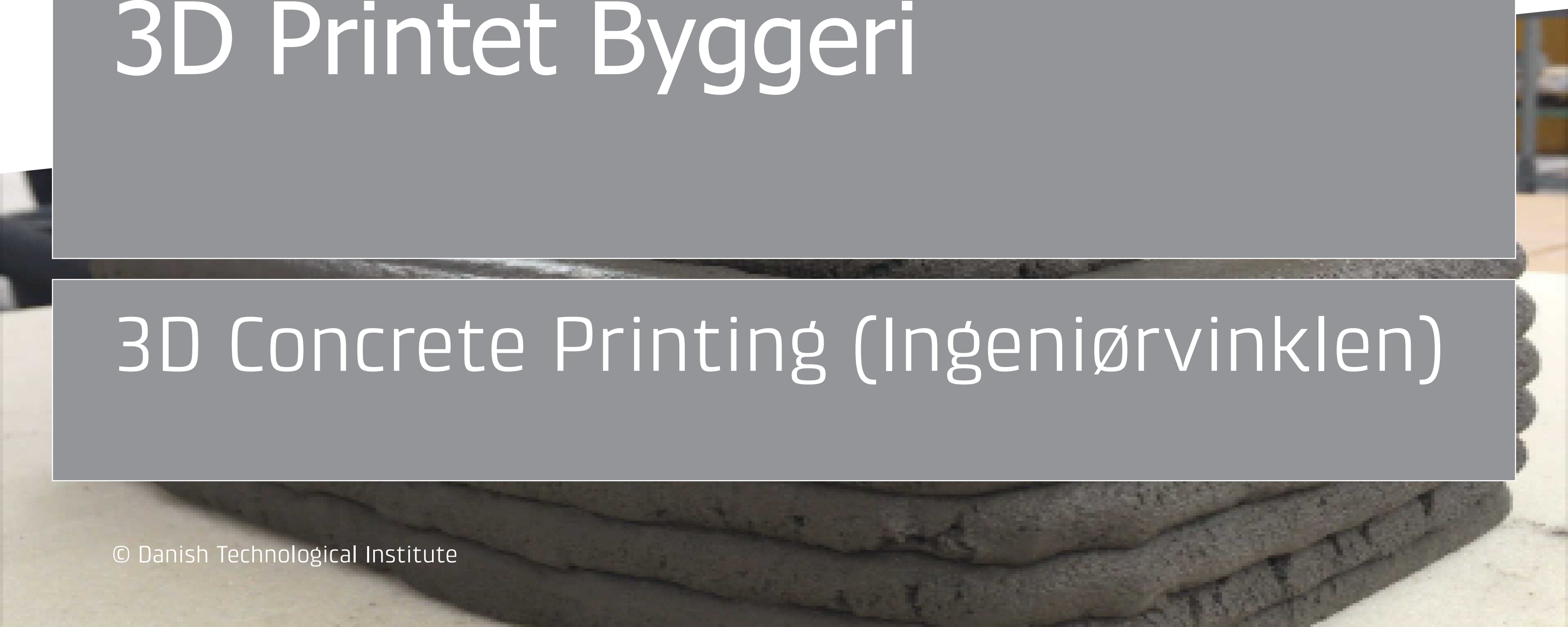
it's all about innovation

3D Printet Byggeri

3D Concrete Printing (Ingeniørvinklen)



3D Concrete Printing

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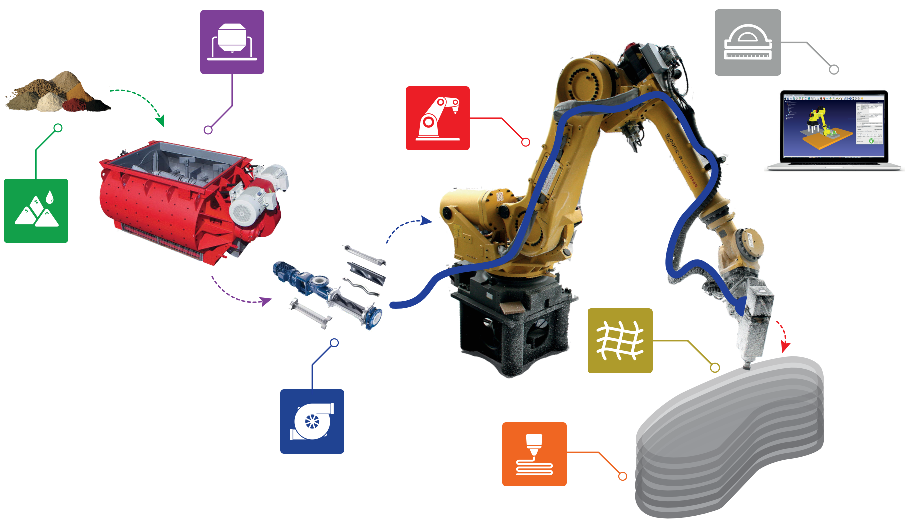
3D Concrete Printing refers to the process used to synthesize a 3D model in successive layers of material to create an object, e.g. a concrete wall

Robot-based 3D Printing Process:



MATERIALS

CONCRETE MIXER

CONCRETE PUMP

ROBOT CONTROL

CONCRETE EXTRUSION

REINFORCEMENT

DESIGN

MATERIALS

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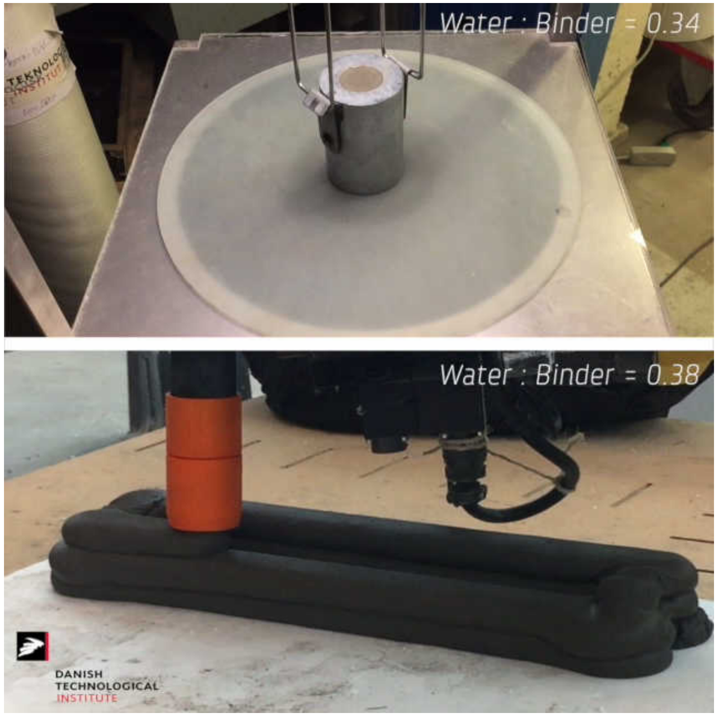
Fresh concrete is the filament:

- Similar materials to that of concrete
- Max. particle size (2 - 4mm)
- Must use concrete admixtures

Material challenges:

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



MATERIALS

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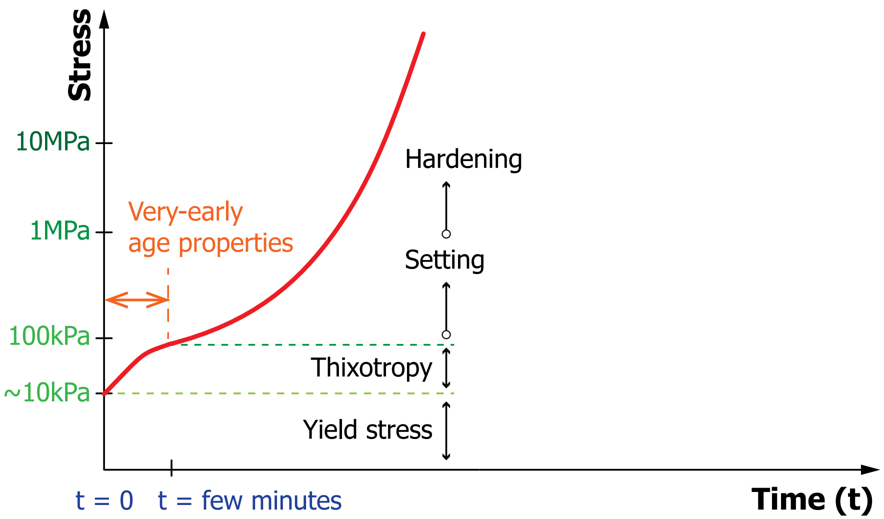
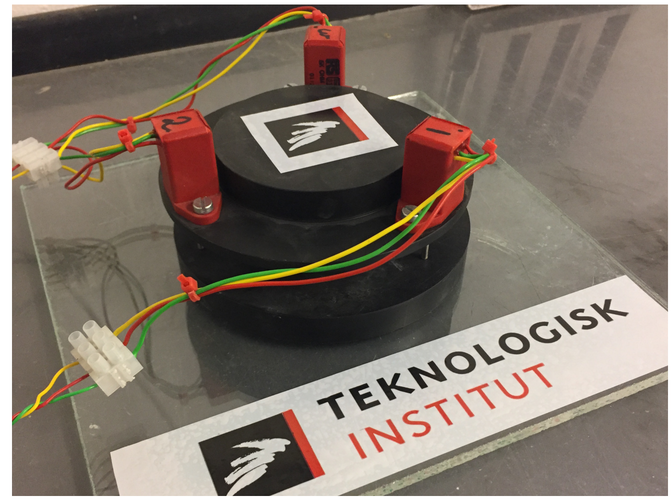
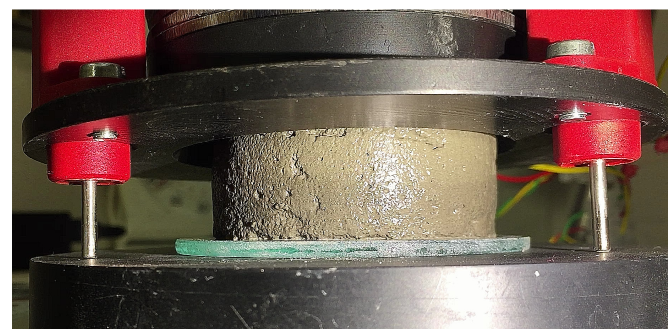
Concrete properties and mix design



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

DTI's Test device (under development)





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

CONCRETE MIXER

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Batch process:

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

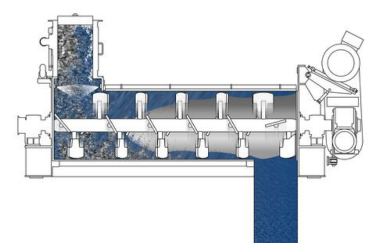
Mixing plant at DTI's Concrete Centre

Continuous mixing:

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

Source: MTec

Source: MTec

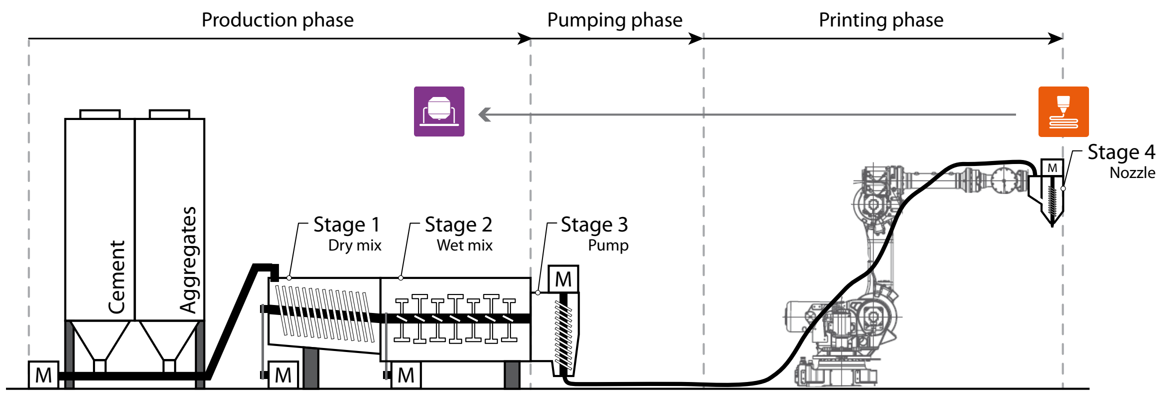


Source: BMH Systems

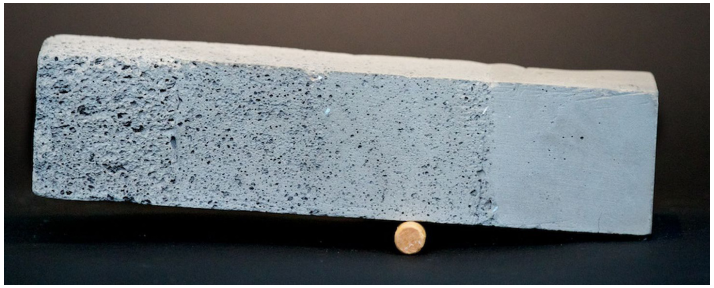
CONCRETE MIXER

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 Media Lab

CONCRETE PUMP

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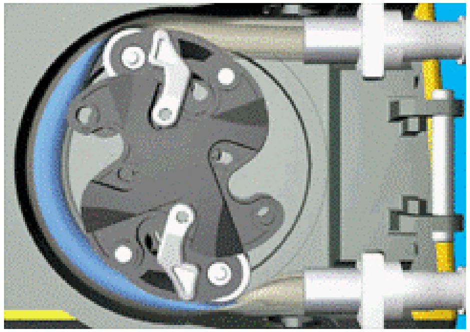
Peristaltic concrete pump:

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

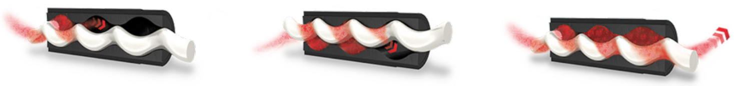


Progressive cavity pump:

- 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)

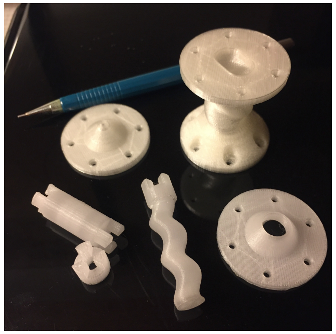


Source: PCM

CONCRETE PUMP

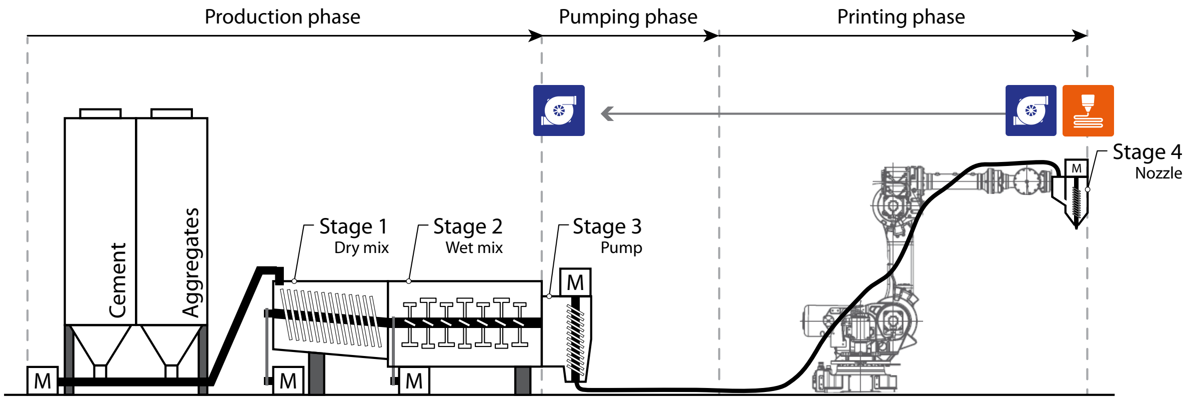
Progressive cavity pump

3D Printed prototype



DTI's progressive cavity pump

- Increase controlability and reliability of the printing process



ROBOT CONTROL

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"Manual" control:

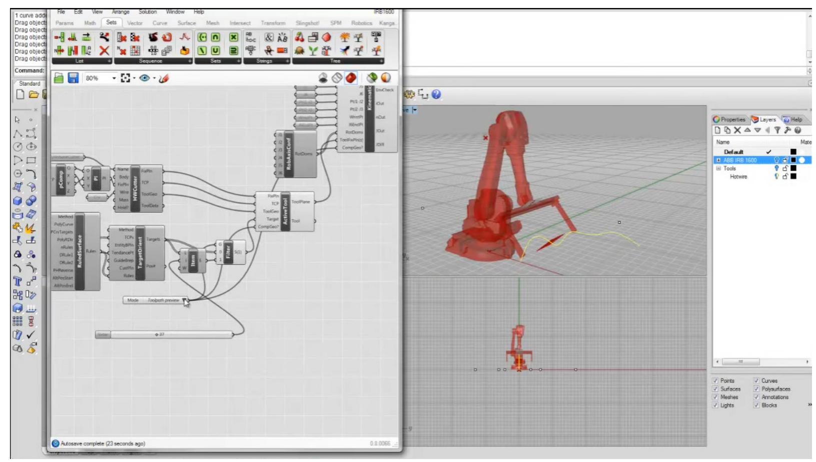
Simple scripts (tool path) written in .txt and sent to the robot via *Pendant Control*. This methods enables easy tests and will be useful for initial tests in the laboratory.

Manual control via Teach Pendandt

Automatic control:

Slicing software generating the robot control commands for a given geometry. This can be generated by slicing softwares.

- Rhino + GrassHopper + HAL Robotics
- RoboDK + Slic3r
- Python libraries (ABB and Fanuc)



Source: HAL Robotics

ROBOT CONTROL

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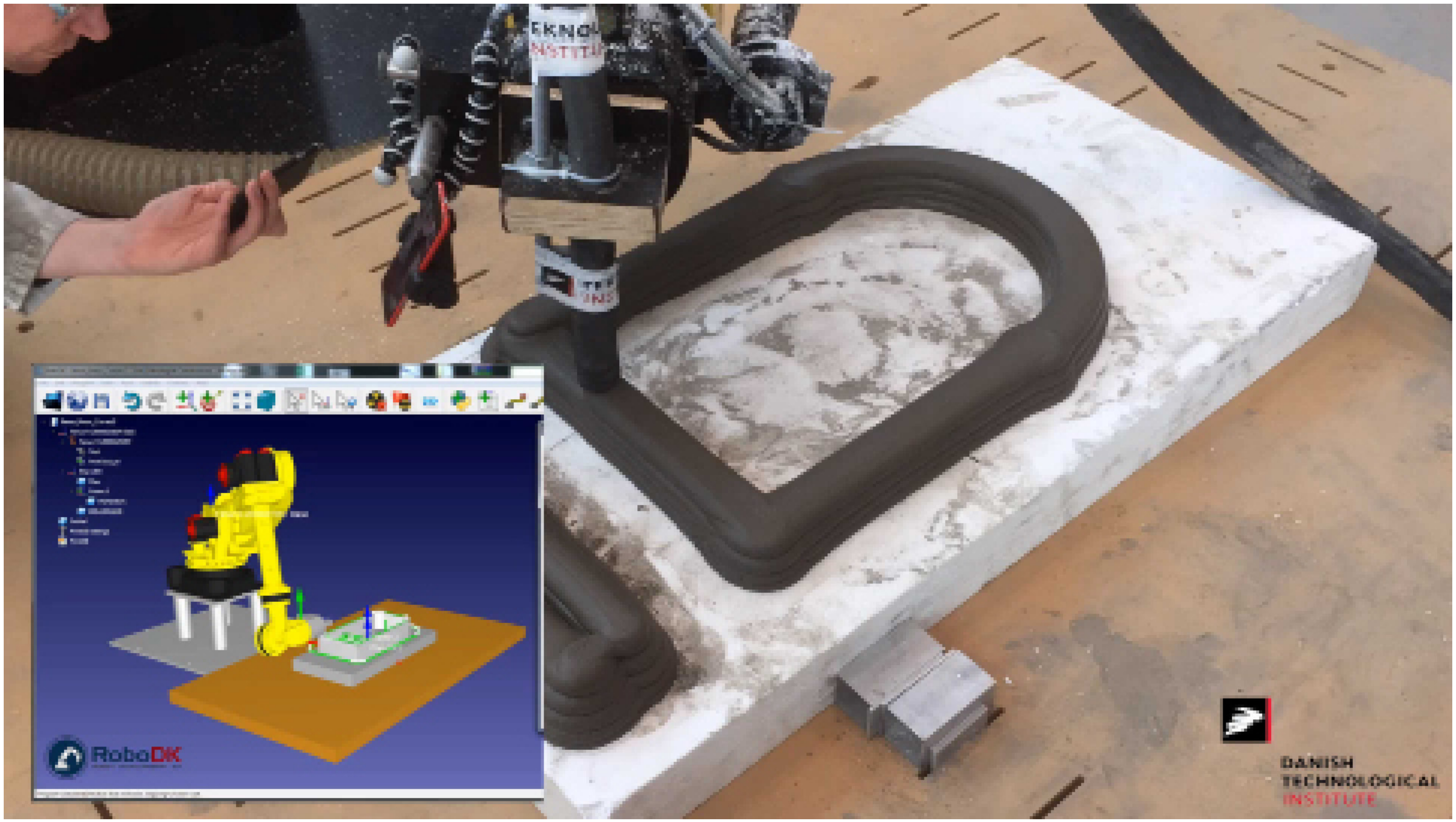
Robot controlling



CONCRETE EXTRUSION

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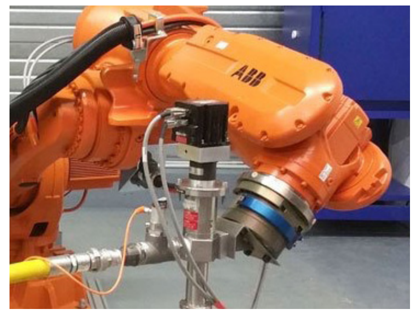
“Passive” robot nozzle:

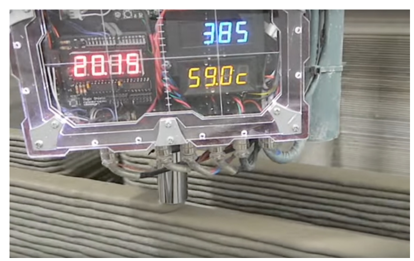
The extrusion is controlled by a pump and the robot nozzle works as a dispenser that defines the shape of the printed layers.

“Active” robot nozzle:

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



Source: XtreeE



Source: Total Kustom

Source: WASP

CONCRETE EXTRUSION

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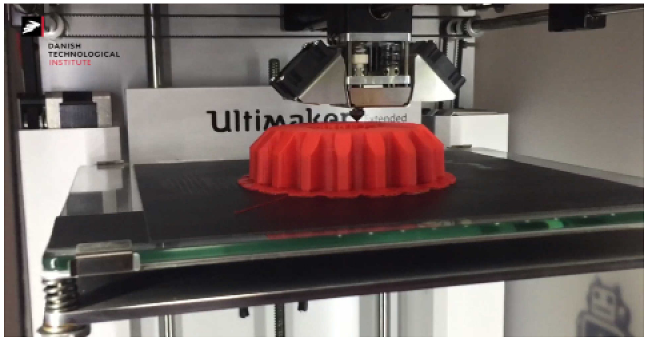
Nozzle concepts and experiments (in progress)



Concrete buildability = f(material properties at very-early age and components)

REINFORCEMENT

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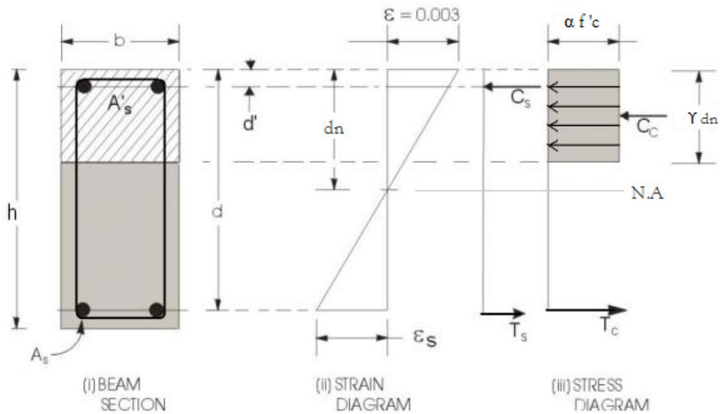
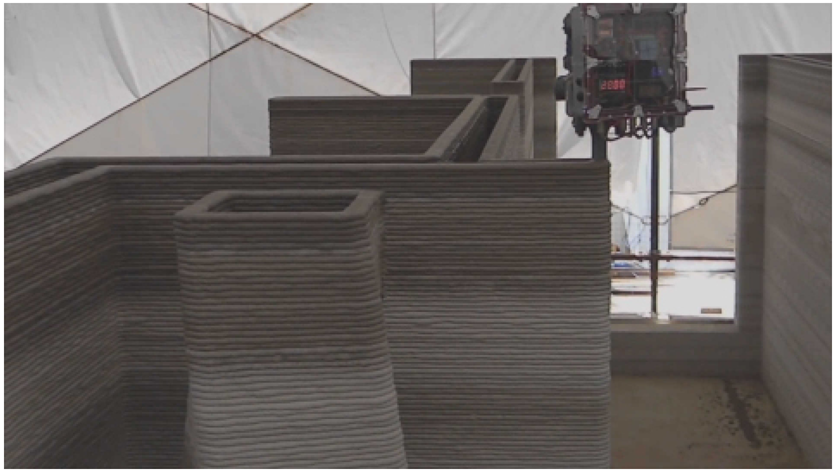
Steel reinforcement:

Basics of structural design (RC Beam)



Parameters:

- Concrete strength class (e.g. C25/30)
- Concrete exposure class (cover)
- Loads applied to the structure
- Type of reinforcement (steel)
- Limit state (Service-limit state)



Source: Total Kustom

Source: Apis Cor

REINFORCEMENT

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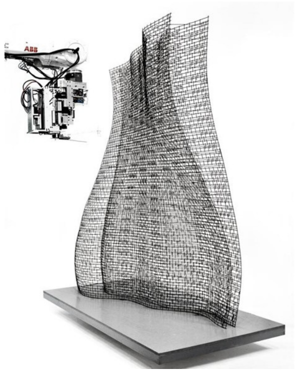
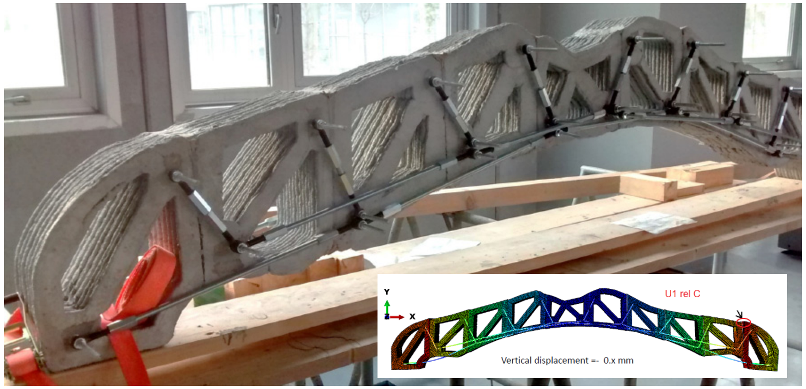
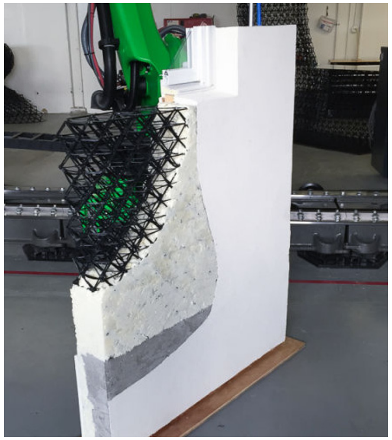


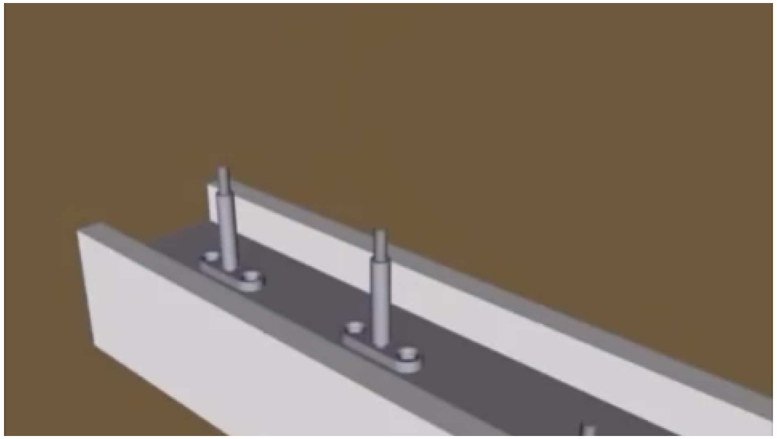
Source: ETH Zurich



Source: Univ. di Napoli Federico II



Source: Branch Technology



Source: Contour Crafting - Univ. of Southern California

Fibre-reinforcement

REINFORCEMENT

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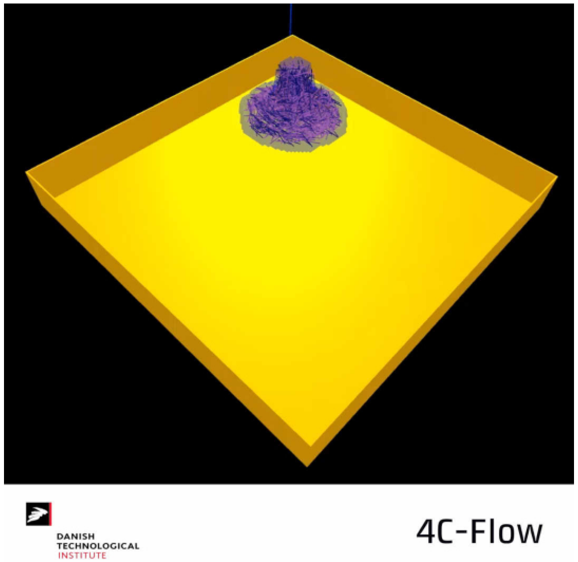
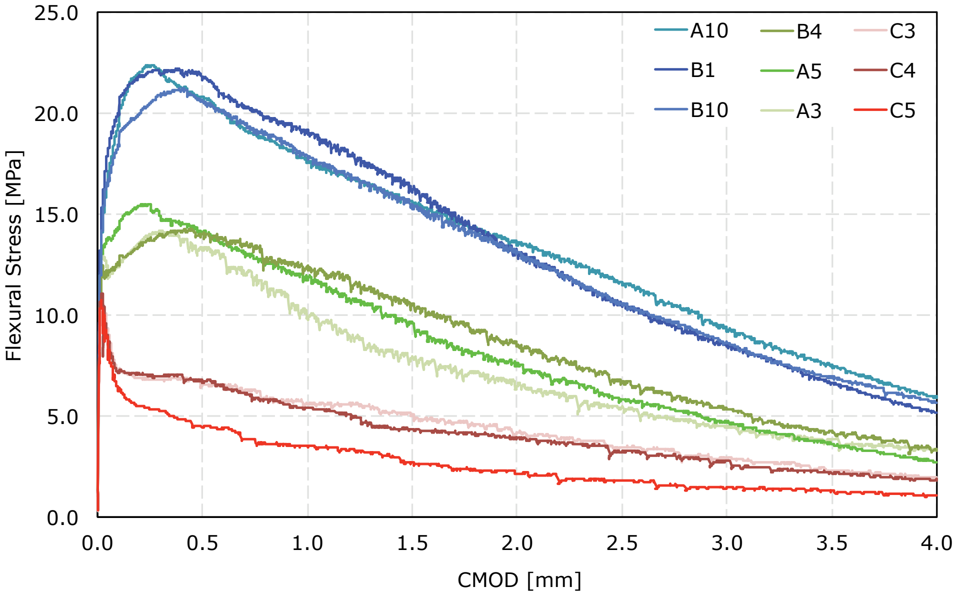
Fibre-reinforced concrete

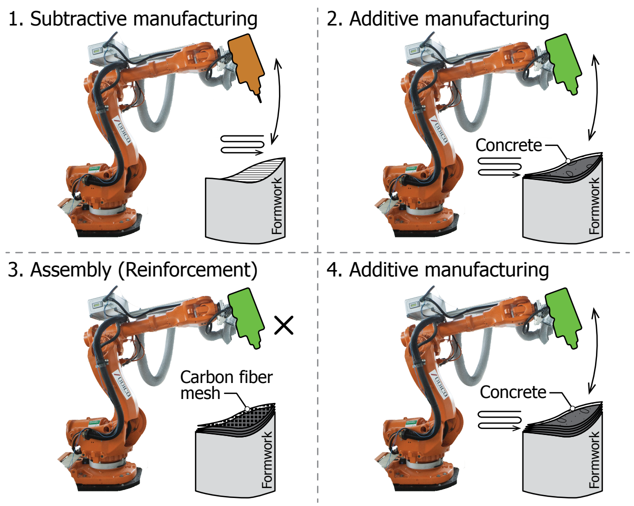


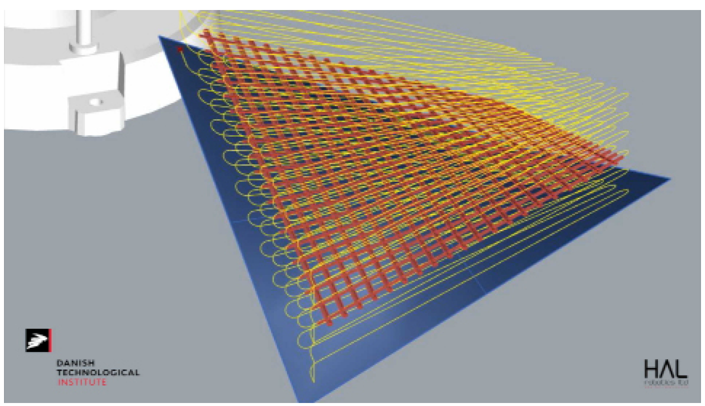


- Fibre-orientation can be controlled during 3D printing
- Different materials are available (steel, glass, carbon, etc)
- It can be of advantage in **thin-shell concrete sctructures** (incl. concrete formwork)
- It does not replace steel reinforcement in conventional load-bearing structures

REINFORCEMENT

Hybrid-manufacturing process:





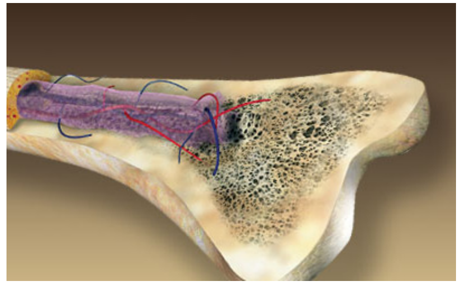
Carbon textile-reinforced concrete
30mm-thick double-curved panel

DESIGN

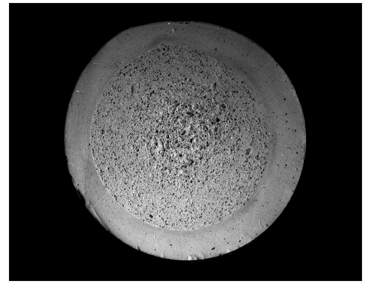
Rethinking architectural and structural design

Topology optimisation

Biomimetics (Nature-inspired design)



Source: Inst. for Creation Research



Source: MIT Media Lab

Artificial Inteligence (Generative design)

Source: ParaCloud Sun Shading

3DCP: Engineering challenges

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

3D CONCRETE PRINTING → **INTERDISCIPLINARITY**

3DCP: Knowledge Network

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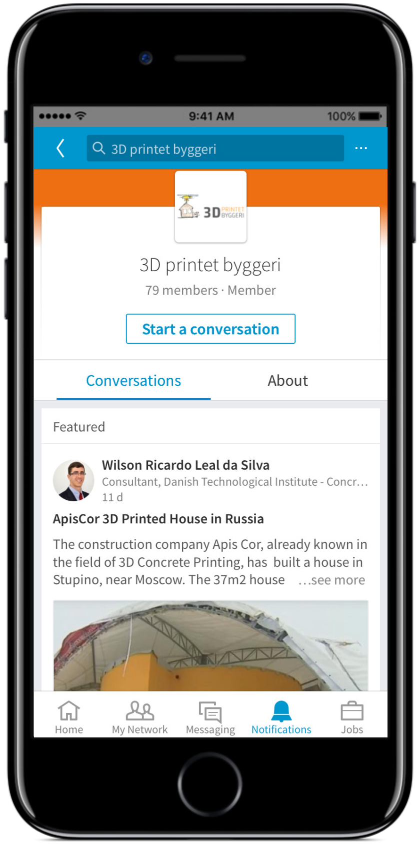
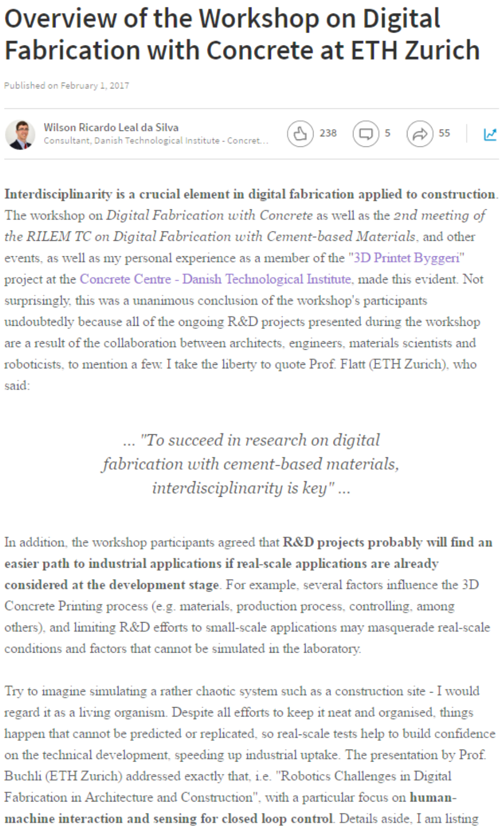
3D Printet Byggeri on LinkedIn





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

Published on February 1, 2017

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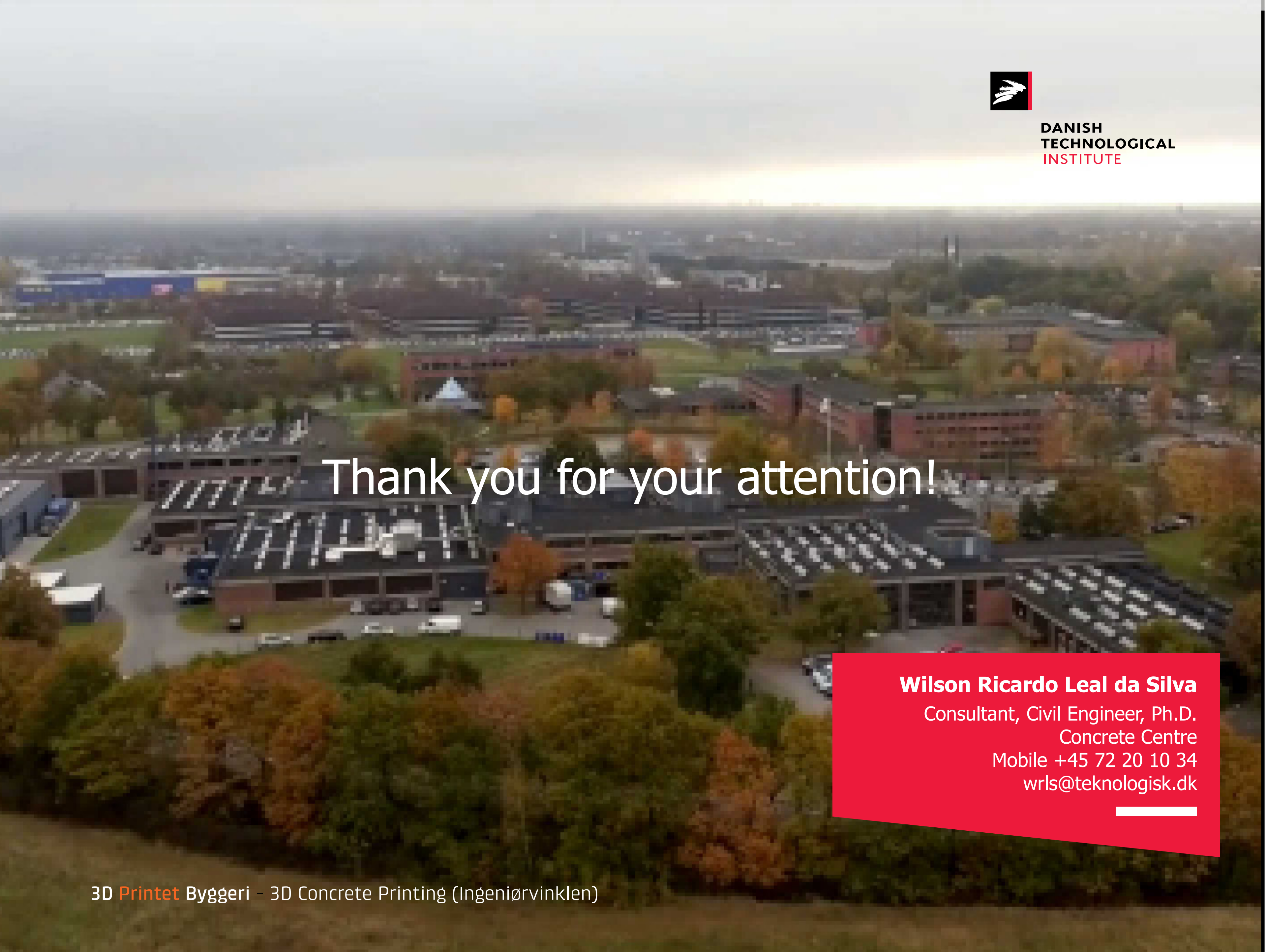
Consultant, Danish Technological Institute - Concret…
238 5 55

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



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Thank you for your attention!

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