IASS 2018 BOSTON, JULY 16-20
CREATIVITY IN STRUCTURAL DESIGN

DANISH TECHNOLOGICAL INSTITUTE

3D Concrete Printing of post-tensioned elements

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3D Concrete Printing

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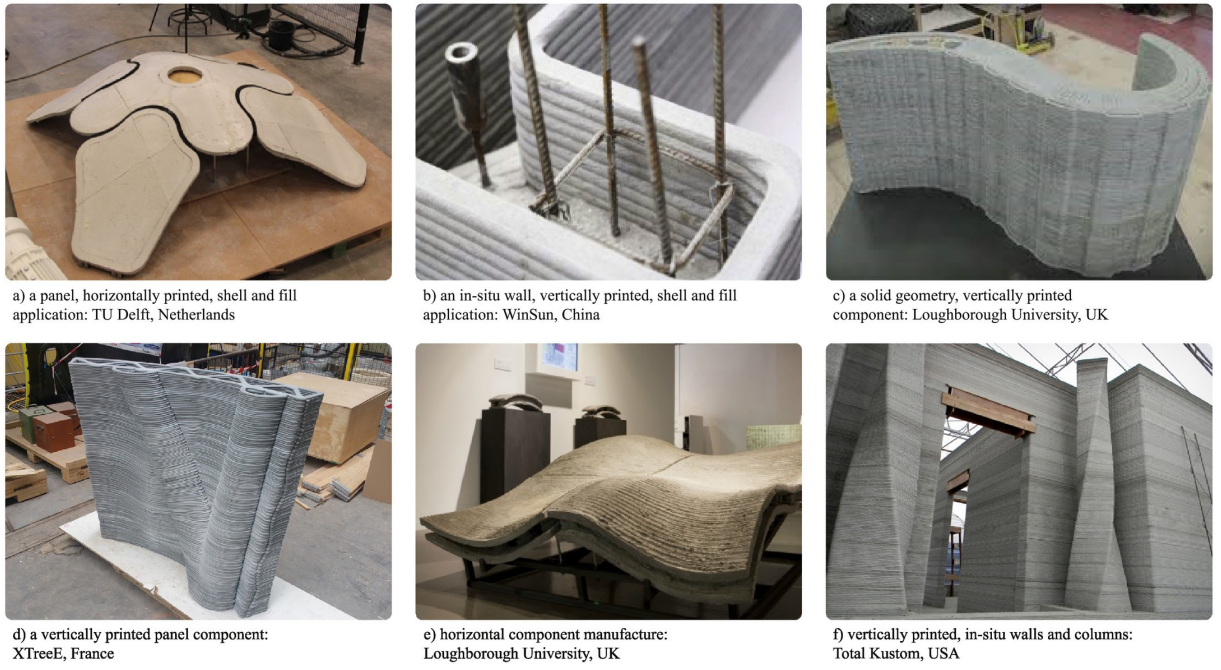
3D Concrete Printing (3DCP)

Process used to synthesize a 3D model in successive layers of material to create an object

Examples of 3DCP application:



a) a panel, horizontally printed, shell and fill application: TU Delft, Netherlands

b) an in-situ wall, vertically printed, shell and fill application: WinSun, China

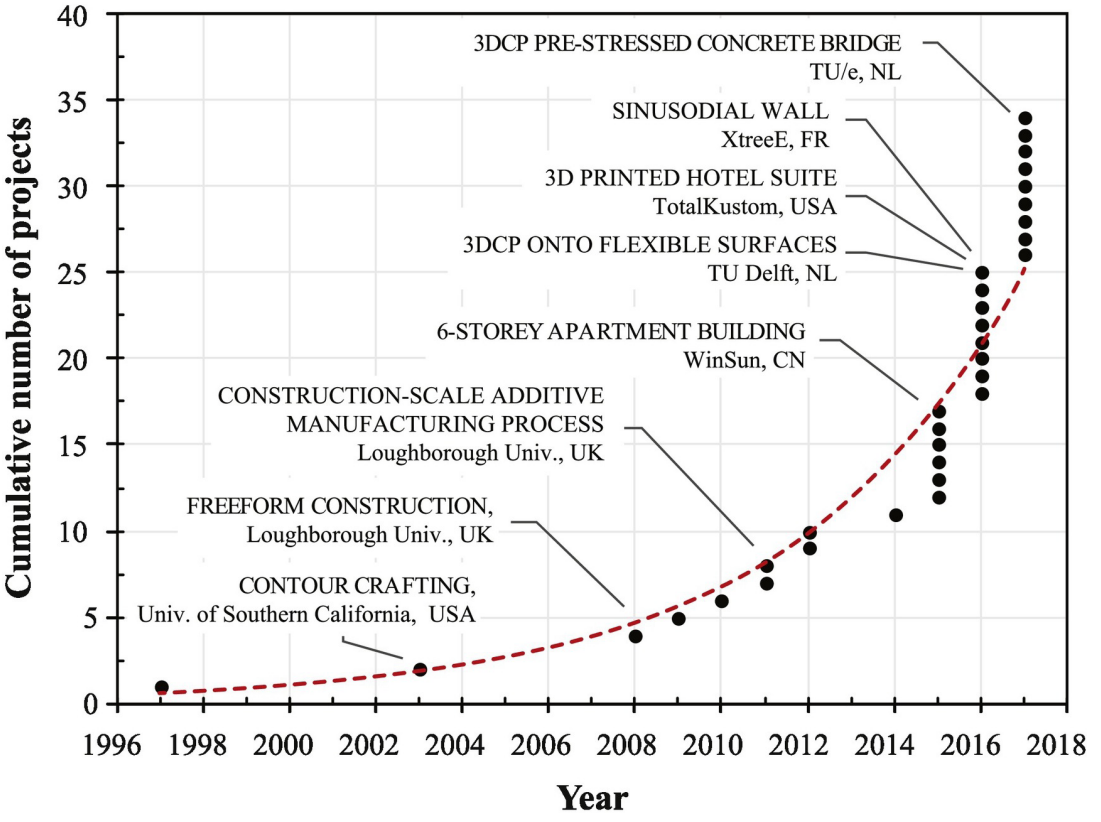
c) a solid geometry, vertically printed component: Loughborough University, UK

d) a vertically printed panel component: XTreeE, France

e) horizontal component manufacture: Loughborough University, UK

f) vertically printed, in-situ walls and columns: Total Kustom, USA

Source: https://doi.org/10.1016/j.cemconres.2018.05.006



3D Concrete Printing

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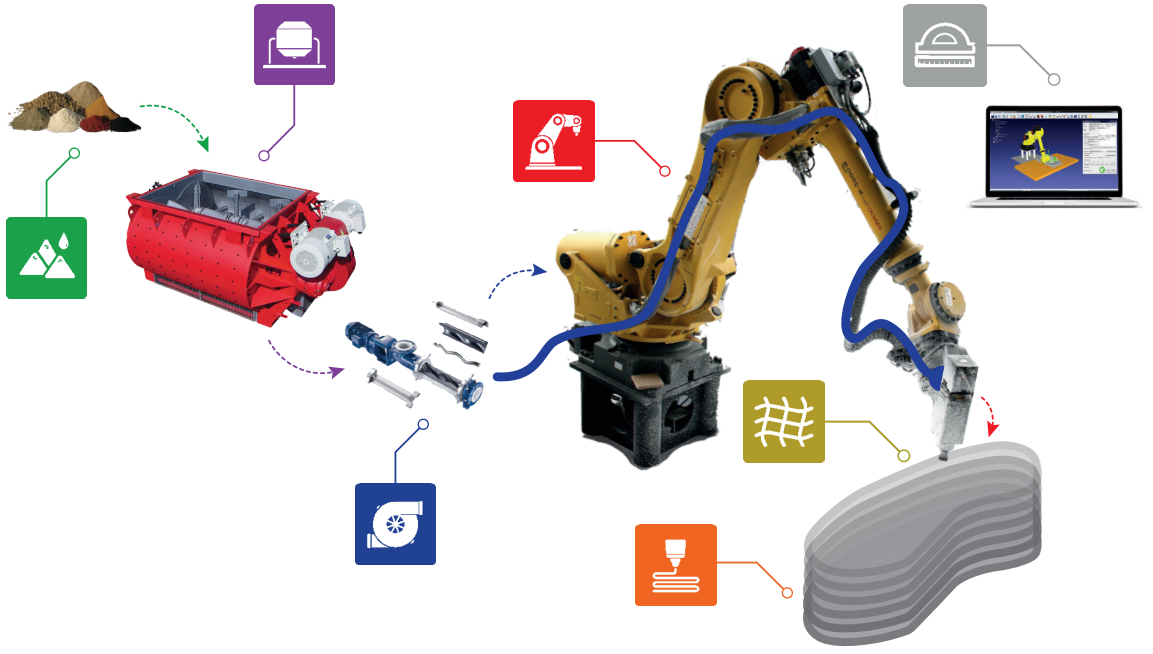
3D Concrete Printing (3DCP)
process used to synthesize a 3D model in successive layers of material to create an object

Robot-based 3DCP setup - modular construction:



DESIGN

MATERIALS

CONCRETE MIXER

CONCRETE PUMP

ROBOT CONTROL

CONCRETE EXTRUSION

REINFORCEMENT

3D Concrete Printing

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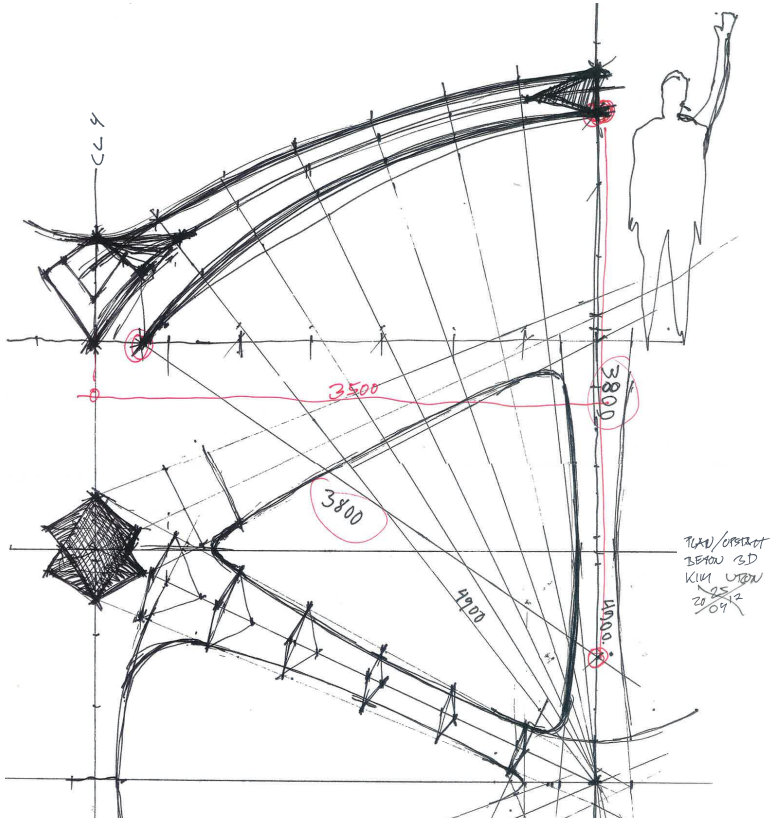
Objectives:

- to explore the 3DCP technology's potential in digital fabrication of concrete elements
- to validate a design concept that combines 3DCP and post-tensioned reinforcement

Experimental phase



Architectural design of a post-tensioned structure by Kim Utzon Architects (courtesy of Kim Uzon).

Production phase

Experimental phase

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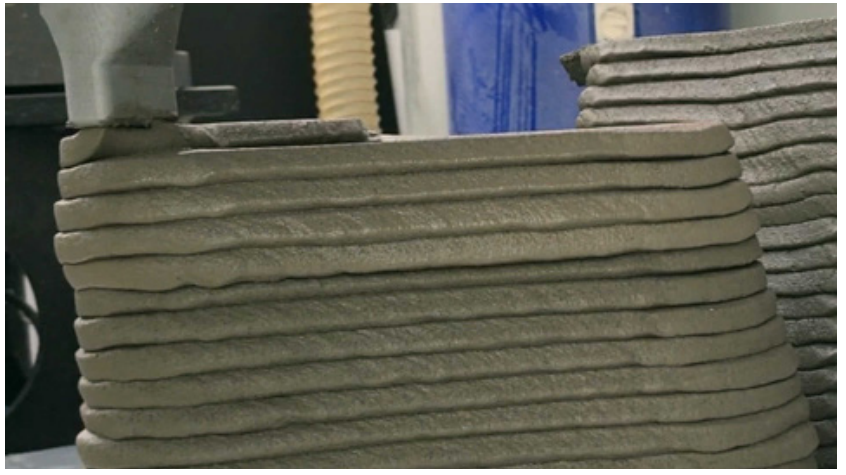
Fresh concrete "filament"

- Similar materials to that of concrete
- Max. particle size (1-4mm)
- Concrete admixtures



Material duality

Materials & mix design

- CEM I 52.5N
- Fly ash Class F
- Fine sand - $Ø_{max}$ = 1.0 mm
- Water/binder = 0.38
- Retarder = 0.2% wt.c
- Plasticizer = 0.1-0.5% wt.c

- easy to pump and maintain its workability (continuous pumping)
- sustain its hape with little deformation after extrusion
- controlled setting time and strength development

Experimental phase

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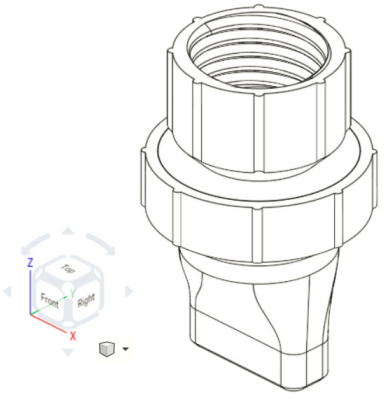
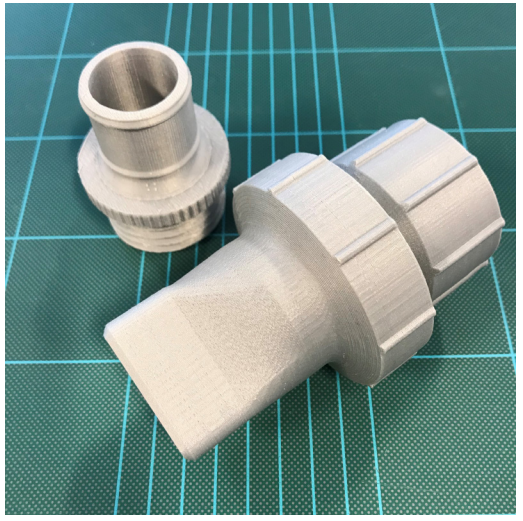
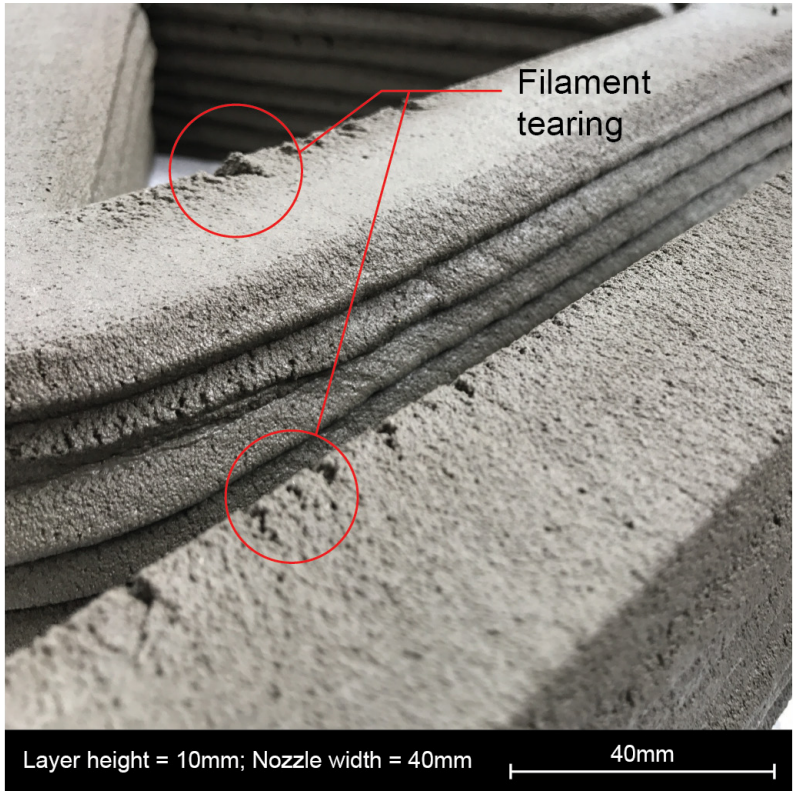
Nozzle geometry

Cross-section: 40x10mm





Visual inspection - empirical test to adjust the pumping flow rate



- In theory, a flow rate of 1.0 dm^3/min requires a nozzle speed equals 41.7 mm/s
- In practice, this speed was set at 30 mm/s to eliminate the tearing effect

Experimental phase

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Mix design

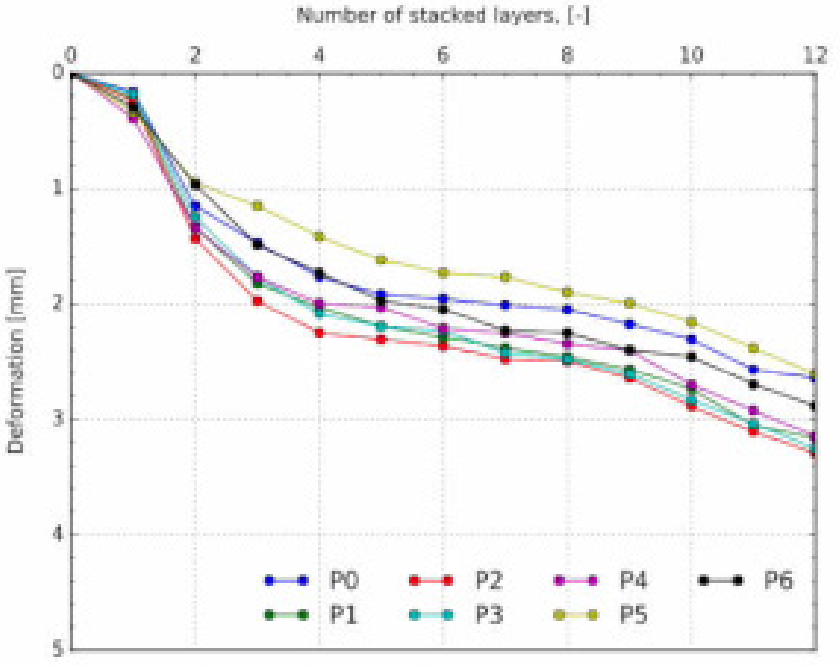
- CEM I 52.5N
- Fly ash Class F
- Sand ($Ø_{max}$=1.0 mm)
- water (w/b=0.38)
- Retarder (0.2% wtc.)
- Plasticizer (0.1% wtc.)

Print parameters

- Nozzle = 40x10mm
- Travel speed = 35mm/s
- Flow = 0.72dm^3/min

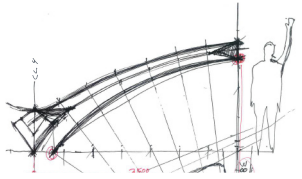
Material deformation

- Bottom layer deformation measured by means of image analysis



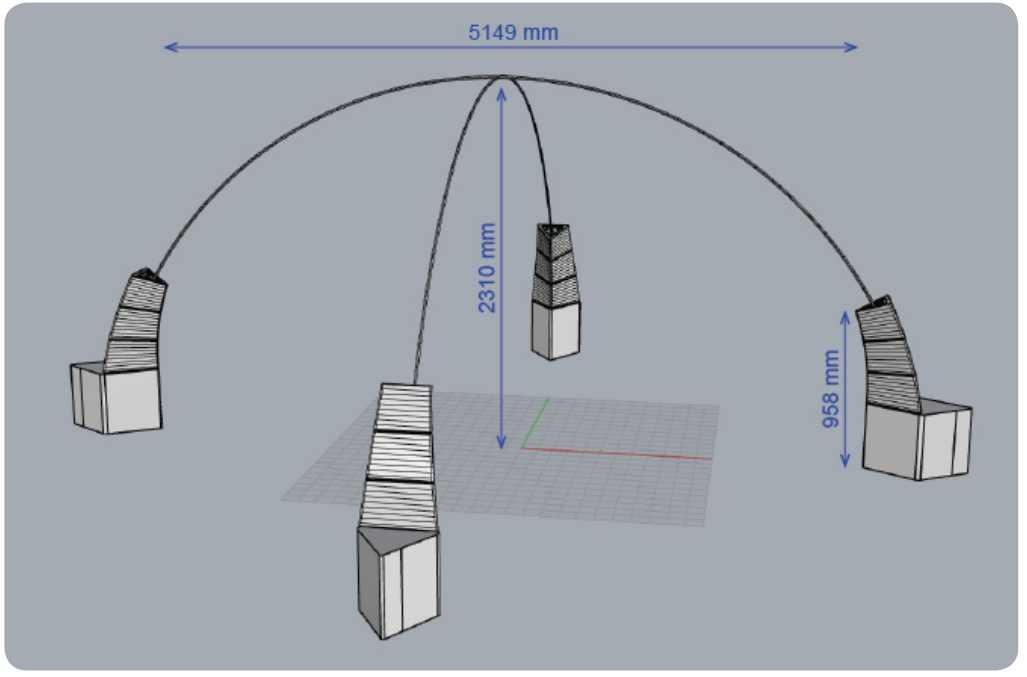
Production phase

From sketch to CAD-CAM

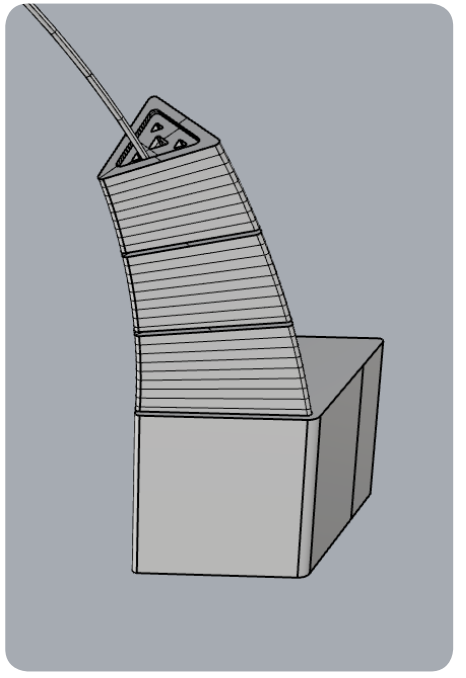


- The 3DCP process and materials imposed limitations in the architectural design
- The final structure comprises 4 columns - each of these is composed on 3 modules

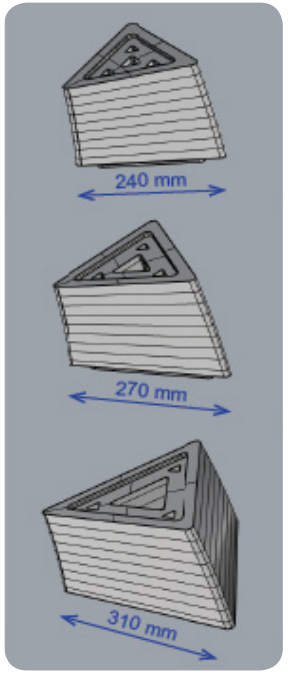
Modular design



4 column elements



3x4 modules



Production phase

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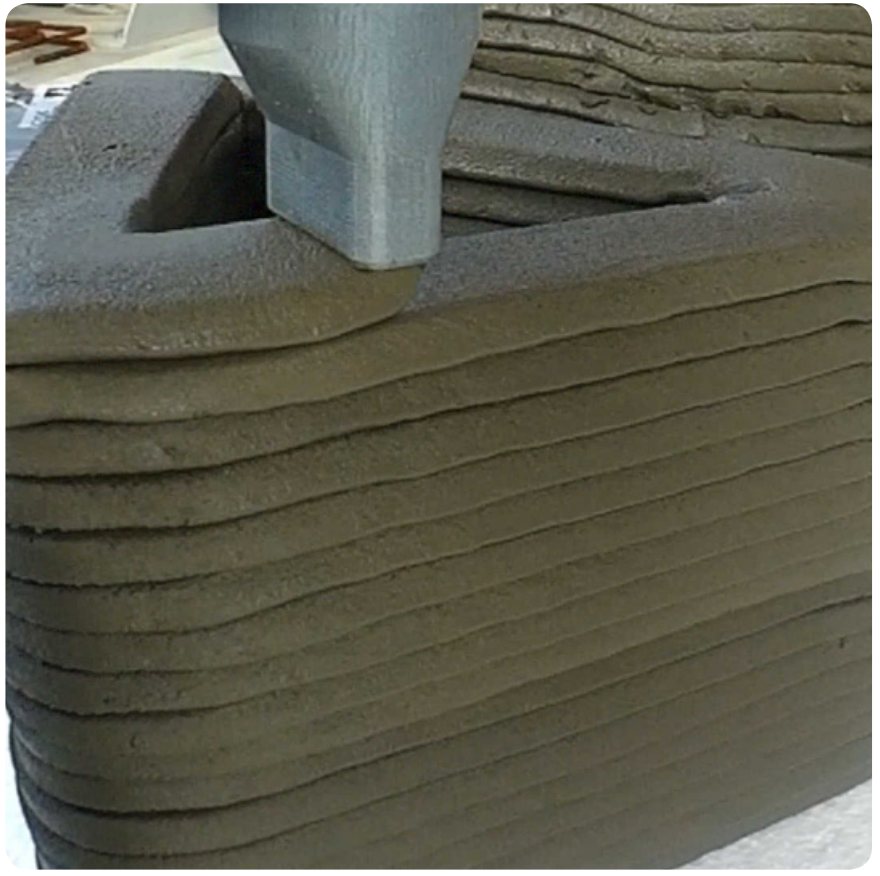
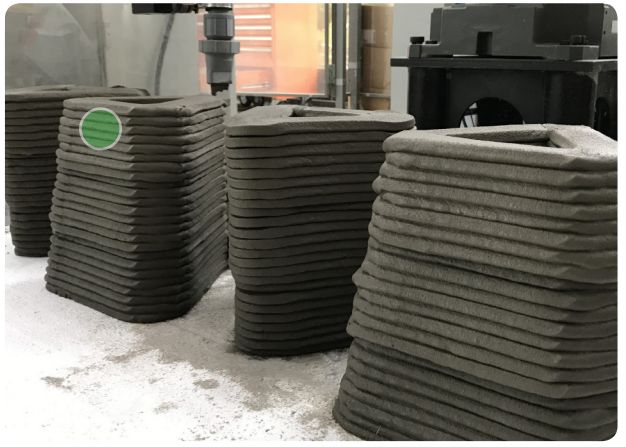
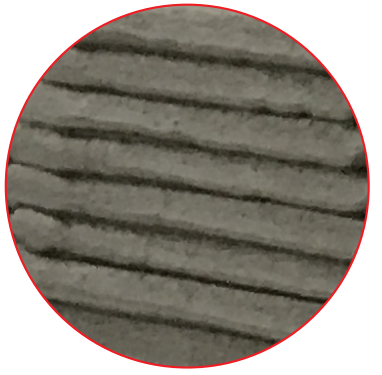
3D Concrete Printing

"Wet-on-wet" printing process

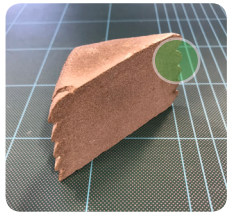


Visual inspection

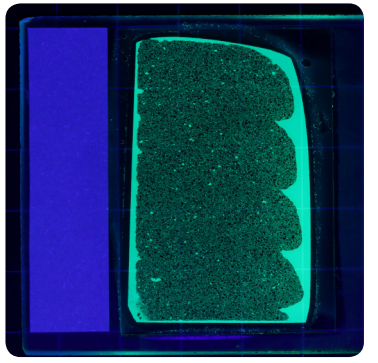




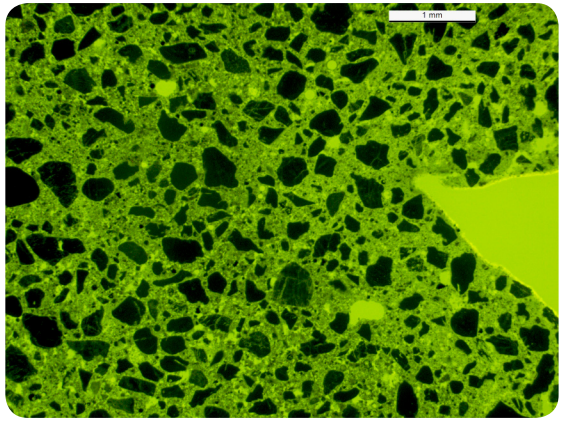
Layer interface - Microscopy



Thin section (UV Light)



Optical microscpe (16x)



Production phase

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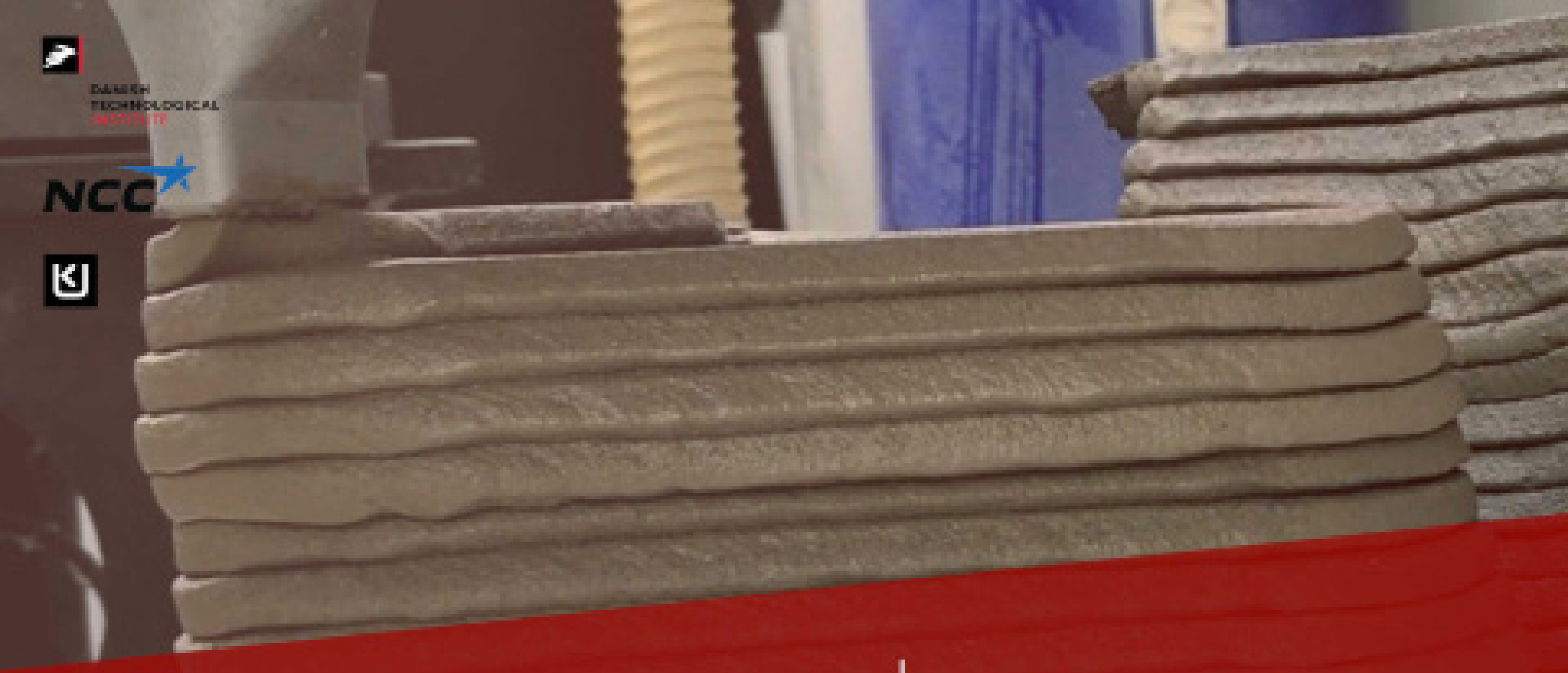
Assembly and post tensioning

Stacked and post-tensioned elements

Final structure located at the Dome of Visons, Pier 2 - Aarhus, DK



Dome of Visions

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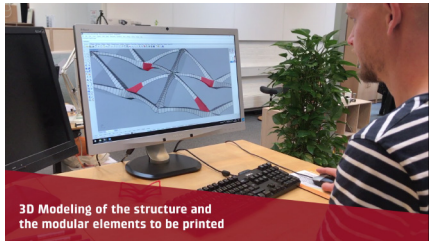
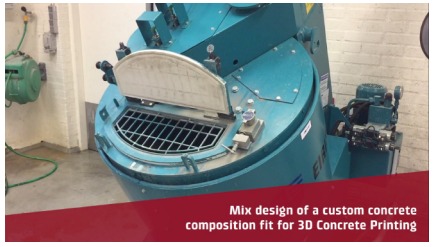
Final considerations


3D Modeling of the structure and the modular elements to be printed


Mix design of a custom concrete composition fit for 3D Concrete Printing


3D Concrete Printing at the Danish Technological Institute


Post-tensioned structural elements ready for transport

DESIGN → MATERIAL & PROCESS LANGUAGE

MATERIALS → VERY-EARLY AGE PROPERTIES

CONCRETE MIXER → ROBUSTNESS

CONCRETE PUMP → RELIABILITY

ROBOT CONTROL → SAFETY

CONCRETE EXTRUSION → ROBUSTNESS & PRECISION

REINFORCEMENT → POST-TENSIONING

3D CONCRETE PRINTING → **INTERDISCIPLINARITY**

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Thank you for your attention!

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