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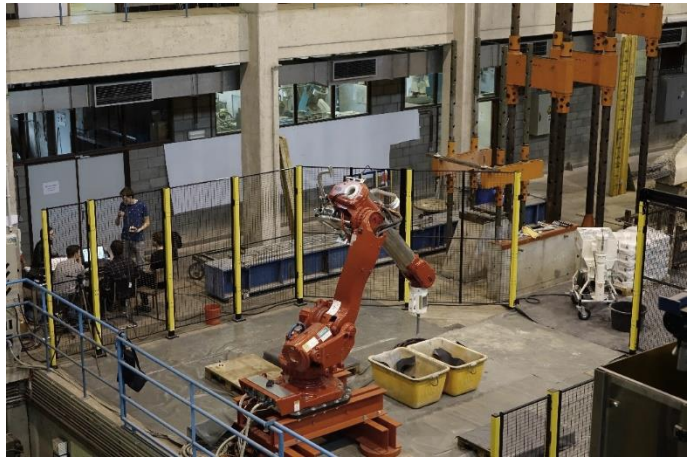
# Prof. Wouter De Corte, Ghent University

# Case study
# 3D printing of a small bridge

# 3D concrete printing

## 3D Concrete Printing

Refers to a technology that uses robotic concrete extrusion processes in order to fabricate functional building and construction components.

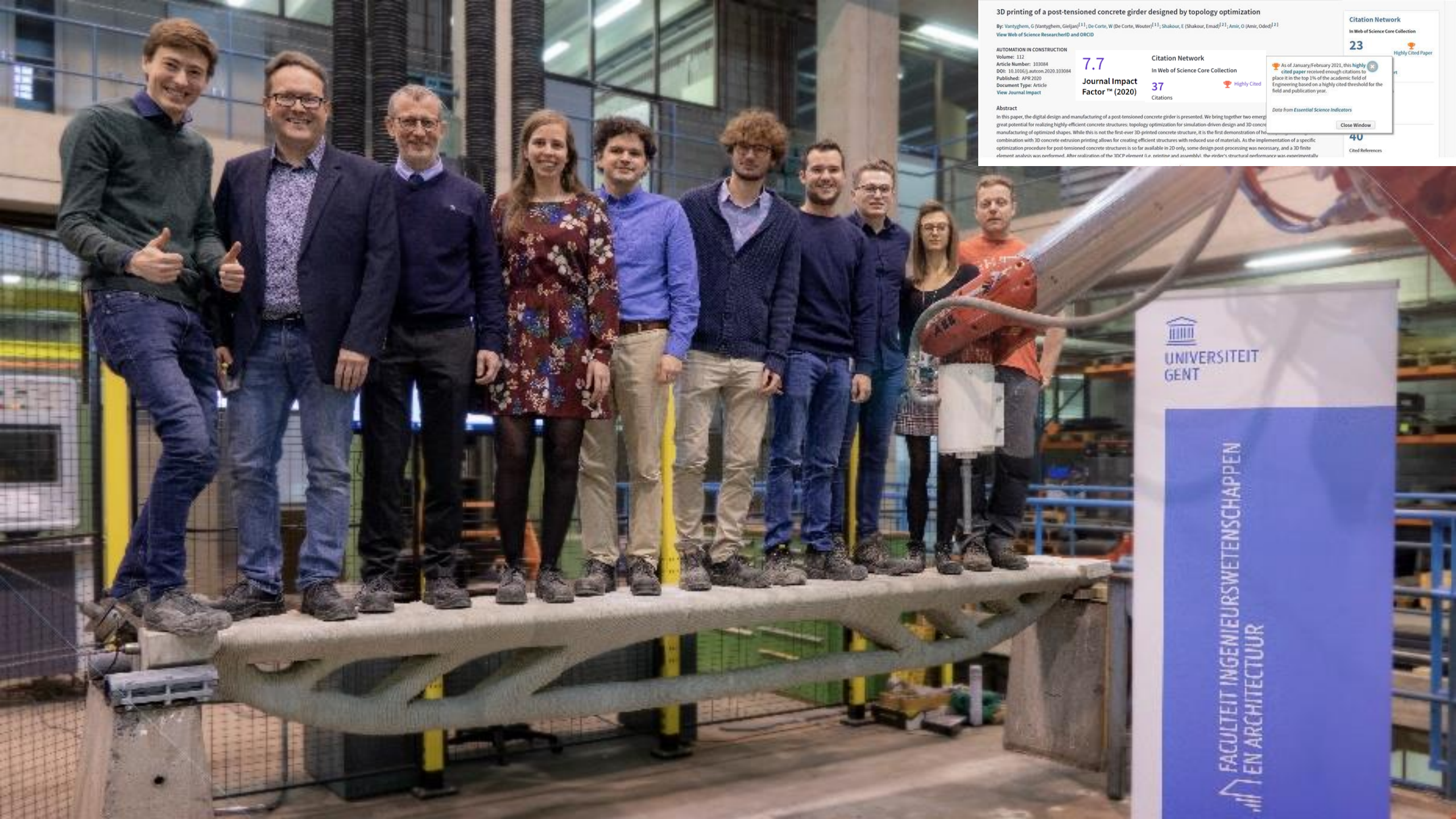


→ **Robotic technology** (mixing, pumping, control of robotic arm..)
→ **Material science** (rheology, viscosity…)
→ **Topology Optimization** (shape, design optimization…)

# 3D concrete printing : a team effort

Many thanks to :

- dr. ing. Gieljan Vantyghem : driving force behind ‘printing of a small bridge’
- ing. Ticho Ooms : conceptual 2D to 3D study
- colleagues from the 3D group (Prof. De Schutter, Prof. Van Tittelboom, Prof. Boel)
- Laboratory staff
- External partners


3D printing of a post-tensioned concrete girder designed by topology optimization
By: Vantyghem, G (Vantyghem, Gieljan)[1]; De Corte, W (De Corte, Wouter)[1]; Shakour, E (Shakour, Emad)[2]; Amir, O (Amir, Oded)[2]
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AUTOMATION IN CONSTRUCTION
Volume: 112
Article Number: 103084
DOI: 10.1016/j.autcon.2020.103084
Published: APR 2020
Document Type: Article
View Journal Impact
7.7
Journal Impact Factor ™ (2020)
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As of January/February 2021, this highly cited paper received enough citations to place it in the top 1% of the academic field of Engineering based on a highly cited threshold for the field and publication year.
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Abstract
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NOT ALL WHO WANDER
ARE LOST

# 3D concrete printing of a small bridge

Basic idea

Building further on the work of Amir & Shakour

Printing

Assembling

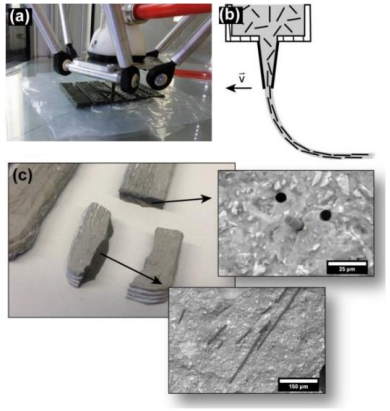
Non destructive testing

# 3D concrete printing of a small bridge

## Basic idea

### How to tackle the need for rebar?

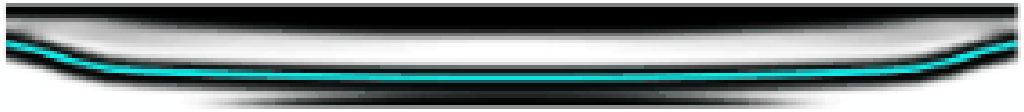
- Installation
- Co-printing
- Fibers
- Post-tensioning



# 3D concrete printing of a small bridge

## Building further on the work of Amir & Shakour

### Can we integrate topology optimisation and post-tensioning?



$$\min_{[\rho,\mathbf{P}]} \phi = (\mathbf{f}_{ext}^{T}\mathbf{u}_{total})^2$$

$$\text{s.t.: } g = \frac{\sum_{e=1}^{N_E} \rho_e v_e}{\sum_{e=1}^{N_E} v_e} - V^{*} \le 0$$

$$0 \le \rho_e \le 1, \qquad e = 1,\ldots,N_E$$

$$\underline{\mathbf{P}} \le \mathbf{P} \le \overline{\mathbf{P}}$$

$$\mathbf{K}\mathbf{u}_{total} = \mathbf{f}_{ext} + \mathbf{f}_{pre}$$

### Topology optimization of post-tensioned concrete beams by Oded Amir and Emad Shakour

Figure 2: Optimized topology and tendon layout of a simply-supported beam, constant pre-stressing force $T_{pre}^{0} = 625$

Figure 6: Optimized topology and tendon layout of a two-span beam, variable pre-stressing force $T_{pre} = 842.941$ and a curvature constraint $\overline{\kappa} = 0.0035$

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23 juni 2022

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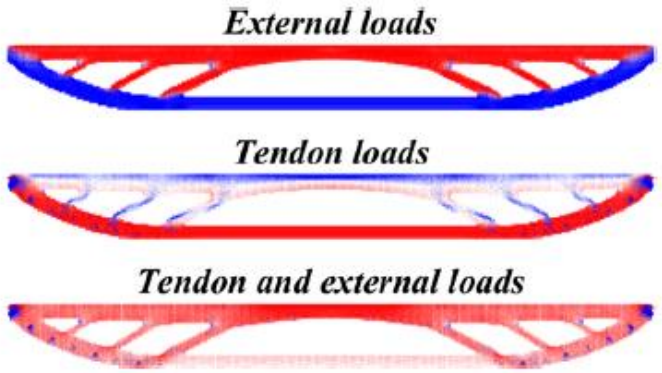
# 3D concrete printing of a small bridge

## Building further on the work of Amir & Shakour

### Can we integrate topology optimisation and post-tensioning?



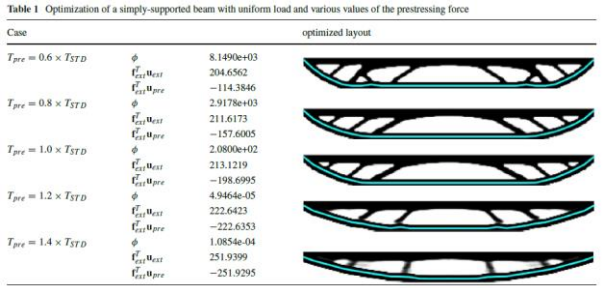
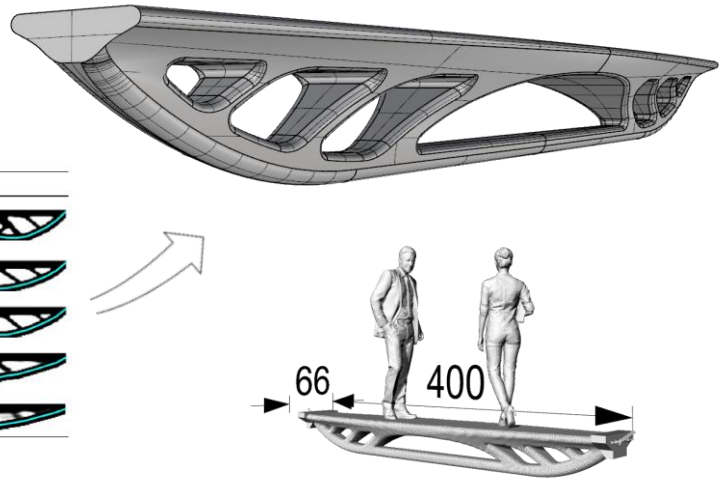



Table 1 Optimization of a simply-supported beam with uniform load and various values of the prestressing force

| Case | | | optimized layout |
|---|---|---|---|
| $T_{pre} = 0.6 \times T_{STD}$ | $\phi$ | 8.1490e+03 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{ext}$ | 204.6562 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{pre}$ | −114.3846 | |
| $T_{pre} = 0.8 \times T_{STD}$ | $\phi$ | 2.9178e+03 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{ext}$ | 211.6173 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{pre}$ | −157.6005 | |
| $T_{pre} = 1.0 \times T_{STD}$ | $\phi$ | 2.0800e+02 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{ext}$ | 213.1219 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{pre}$ | −198.6995 | |
| $T_{pre} = 1.2 \times T_{STD}$ | $\phi$ | 4.9464e-05 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{ext}$ | 222.6423 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{pre}$ | −222.6353 | |
| $T_{pre} = 1.4 \times T_{STD}$ | $\phi$ | 1.0854e-04 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{ext}$ | 251.9399 | |
| | $\mathbf{f}_{ext}^T \mathbf{u}_{pre}$ | −251.9295 | |

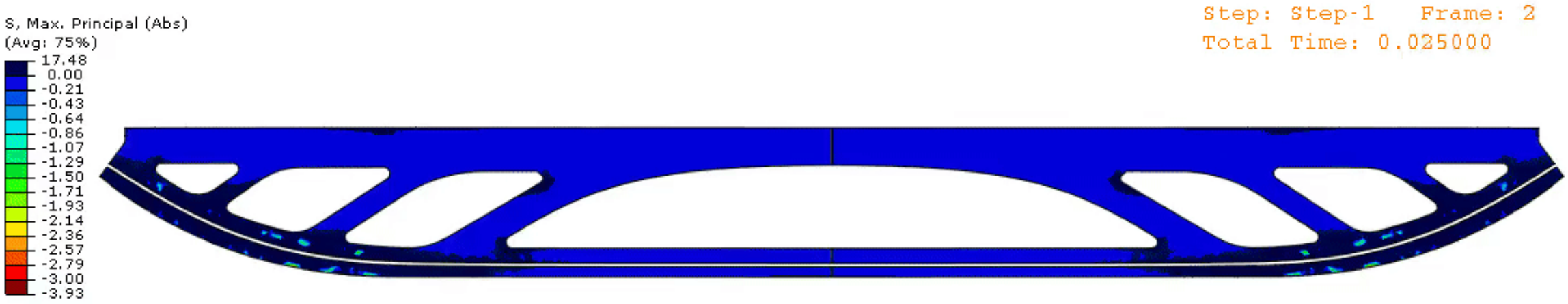
### Post processing 2D – 3D



# 3D concrete printing of a small bridge

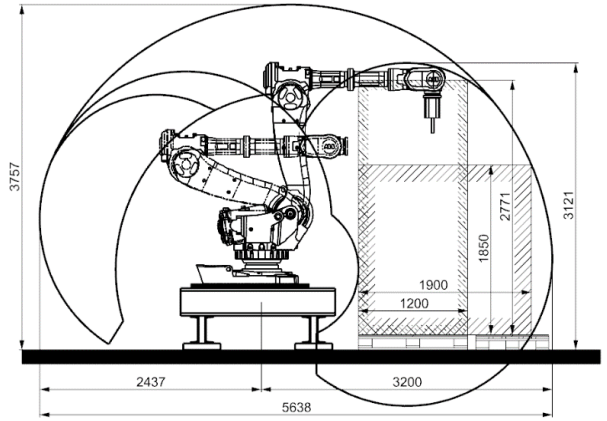
## Building further on the work of Amir & Shakour

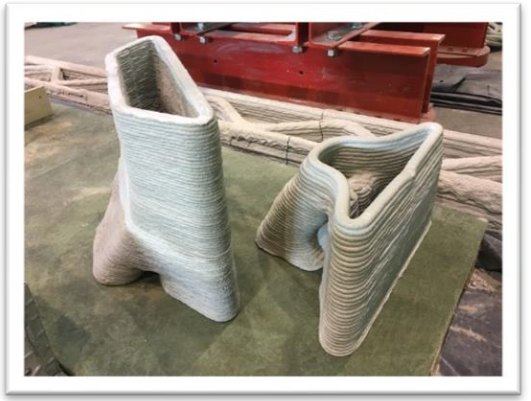
### 3D finite element analysis (Abaqus)

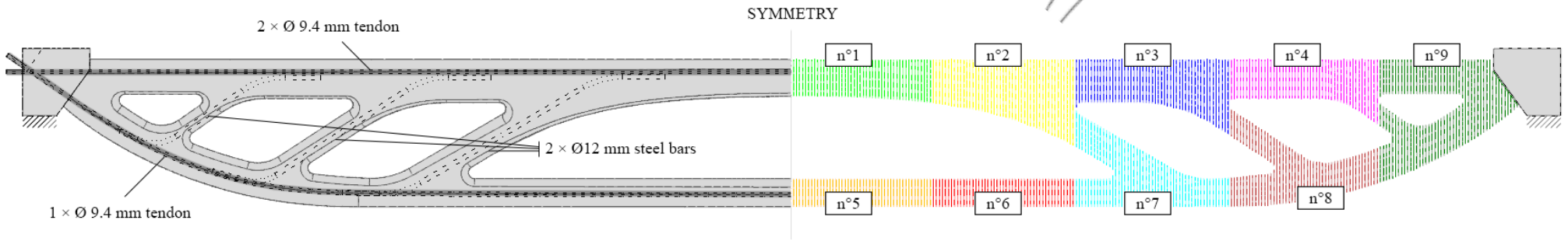


# 3D concrete printing of a small bridge

## Printing





# 3D concrete printing of a small bridge

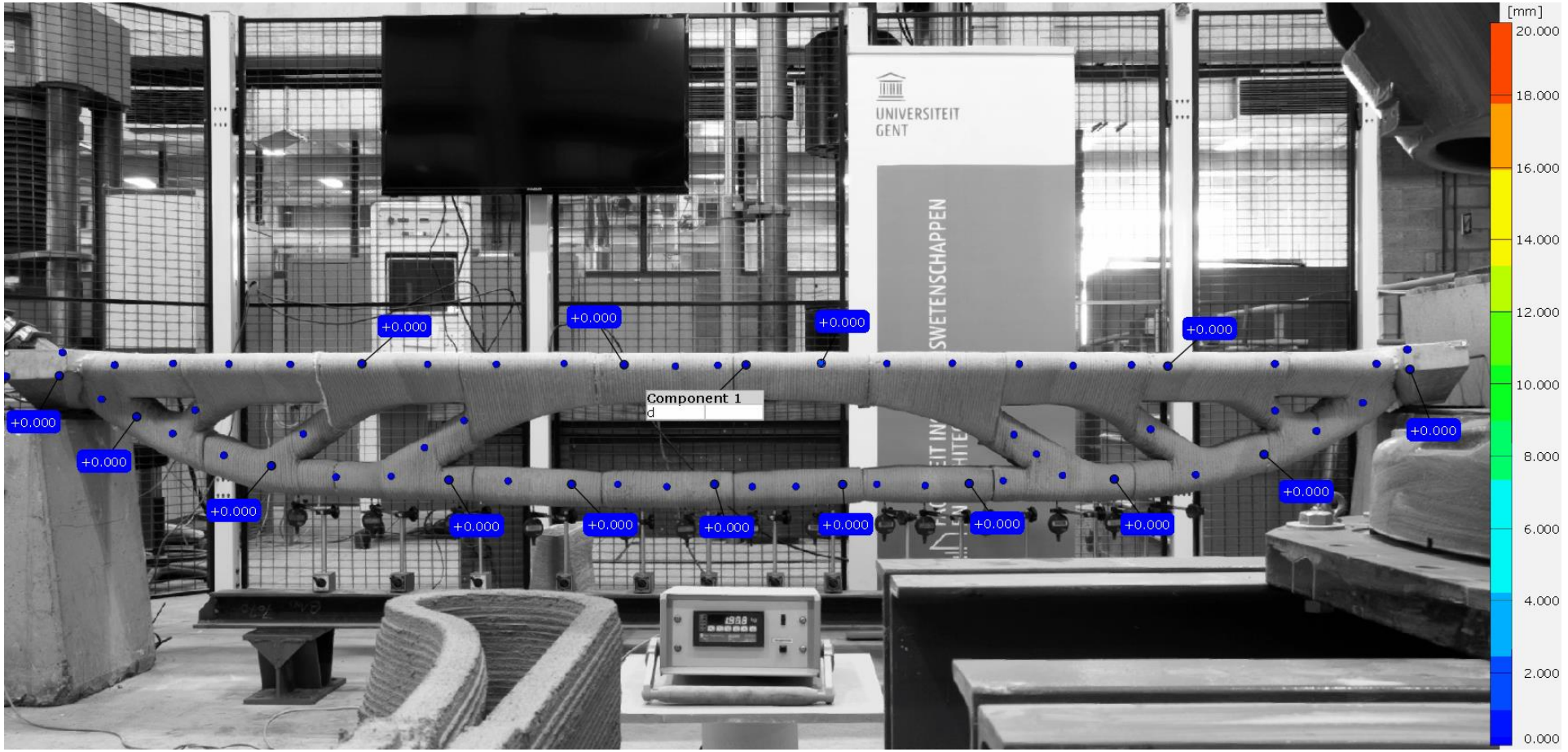
## Assembling

# 3D concrete printing of a small bridge

## Assembling

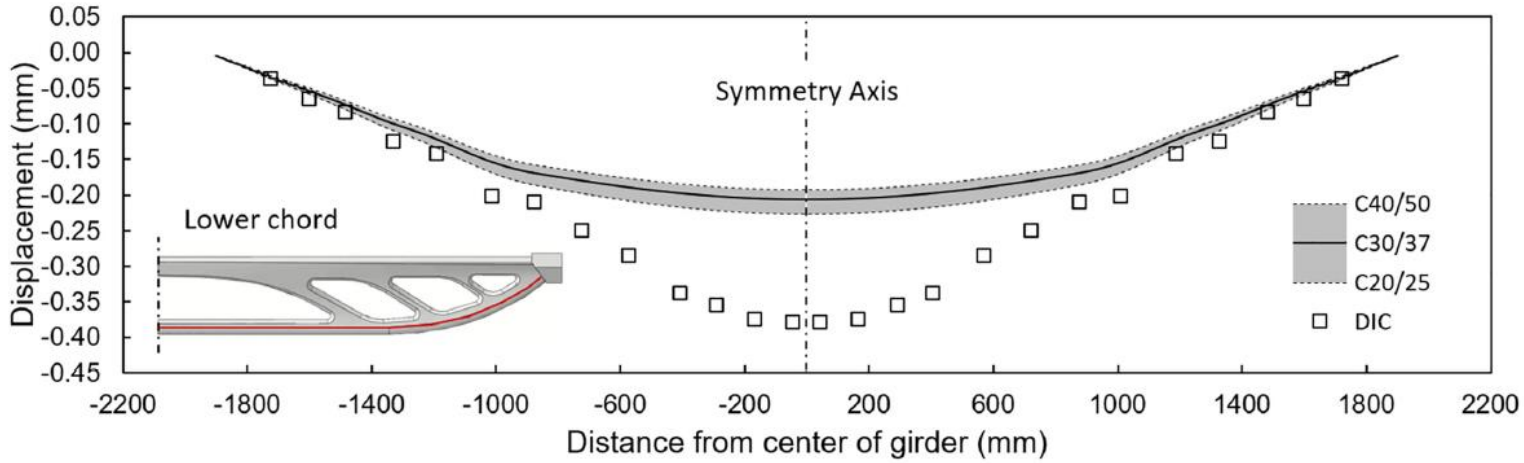
# 3D concrete printing of a small bridge

## Non destructive testing



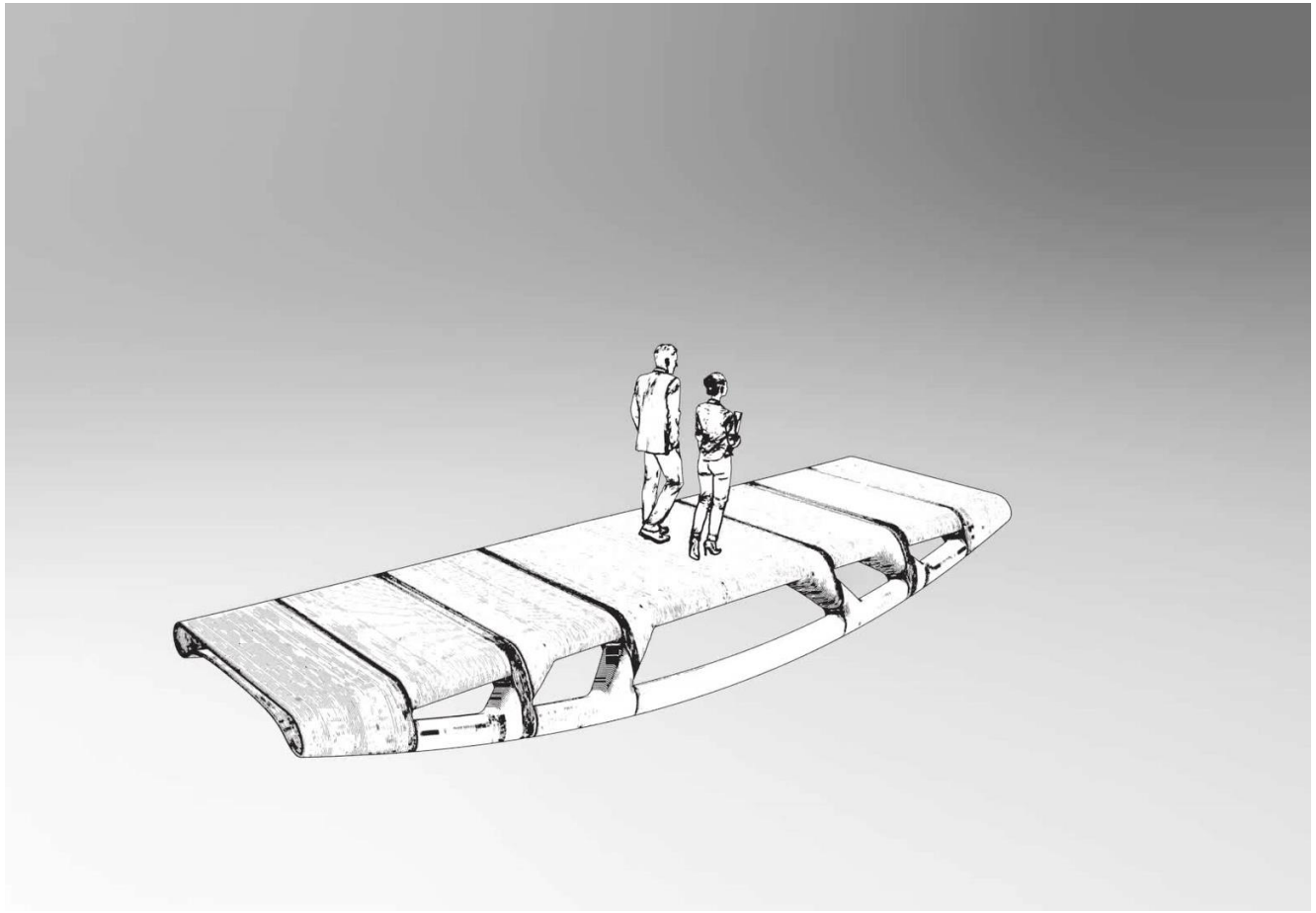
# 3D concrete printing of a small bridge

## Non destructive testing



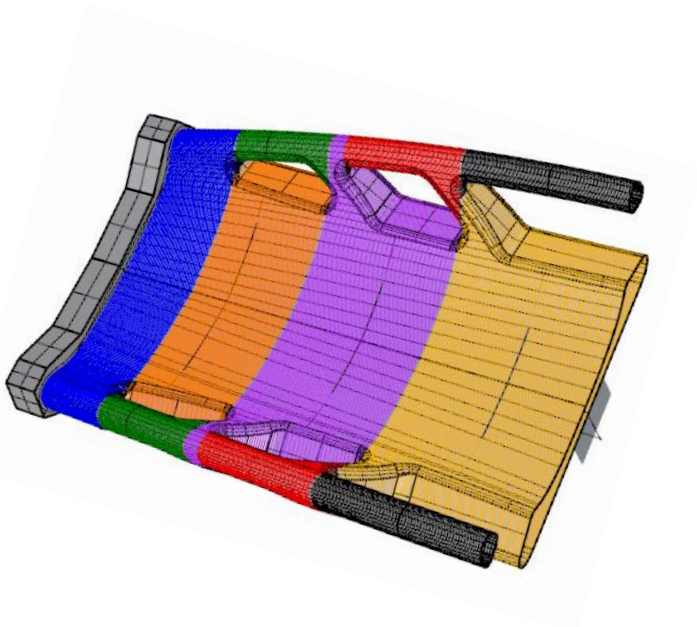
# 3D concrete printing of a slightly larger bridge

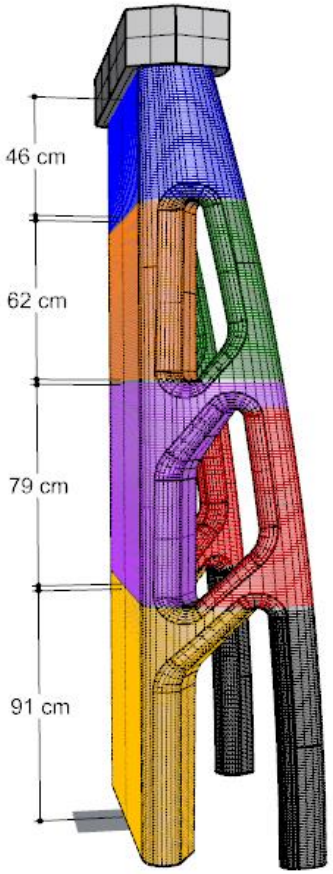
## Bridge 2.0

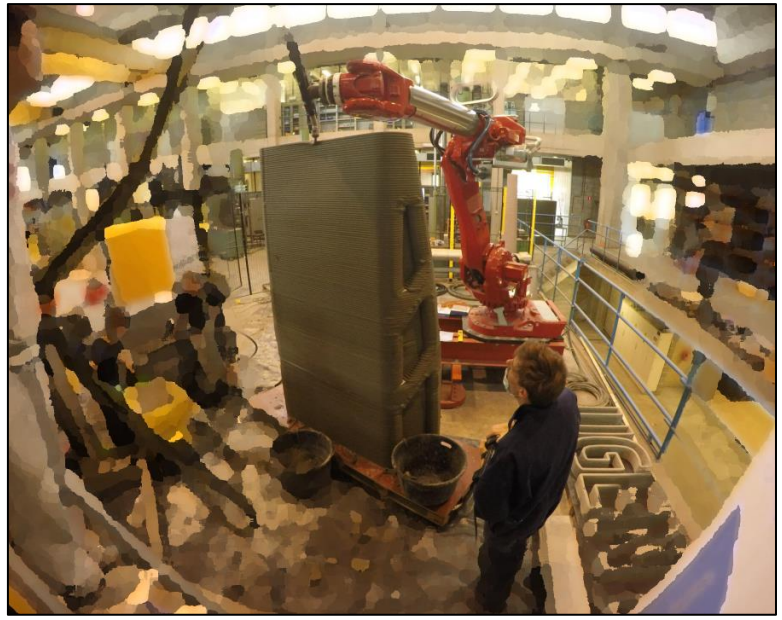


# 3D concrete printing of a slightly larger bridge

## Bridge 2.0





# 3D concrete printing of a slightly larger bridge

## Bridge 2.0

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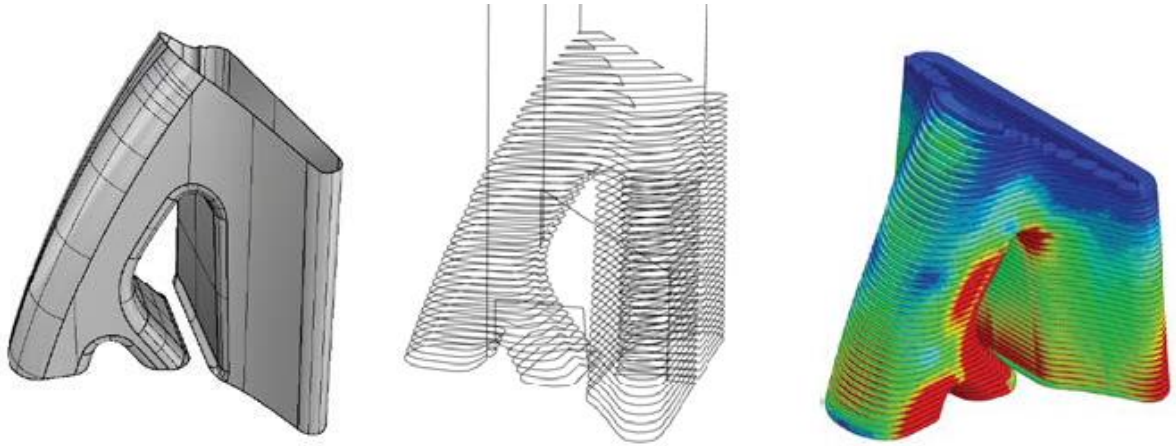
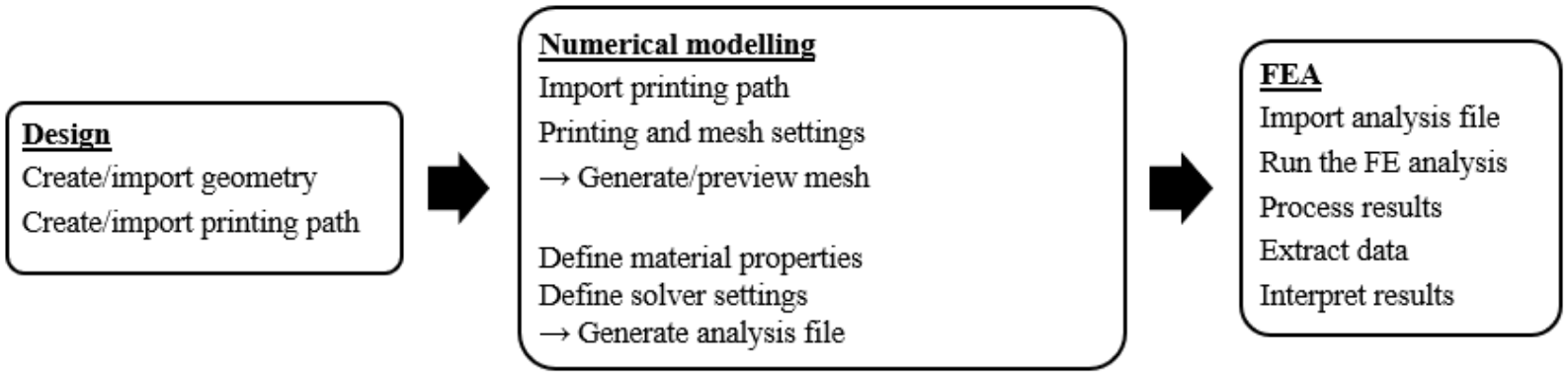
# 3D concrete printing of a slightly larger bridge

## Bridge 2.0

# 3D concrete printing simulation

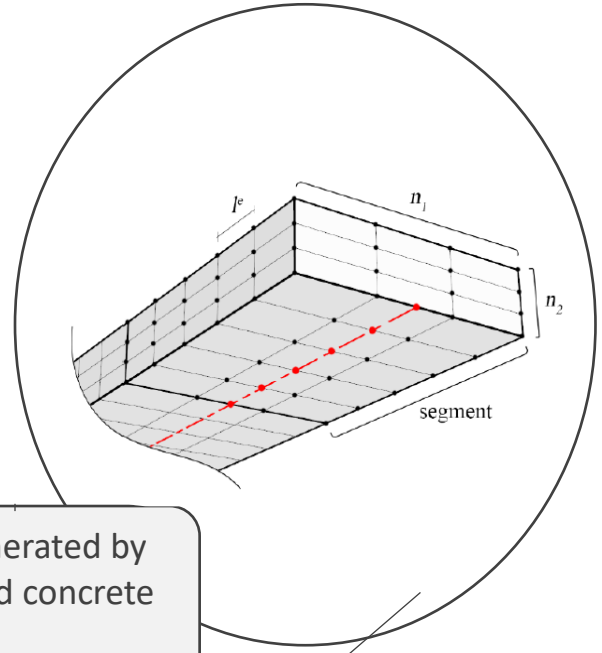
- ✓ FEM-based numerical simulation model
- ✓ Builds upon the work of Wolfs et al. (2018)
  - Layer-wise activation
  - Time-dependent material behaviour





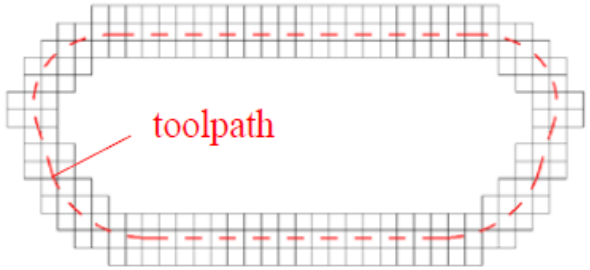
# 3D concrete printing simulation

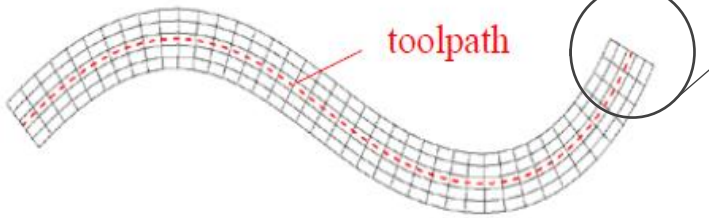
- ✓ FEM-based numerical simulation model
- ✓ Two novel strategies to process complex shapes




*VoxelPrint:* uses voxels to represent the 3D-printed structure. Voxels are the 3D equivalent of pixels.

*CobraPrint:* a structured mesh is generated by sweeping a cross-section of the printed concrete layer along the print path



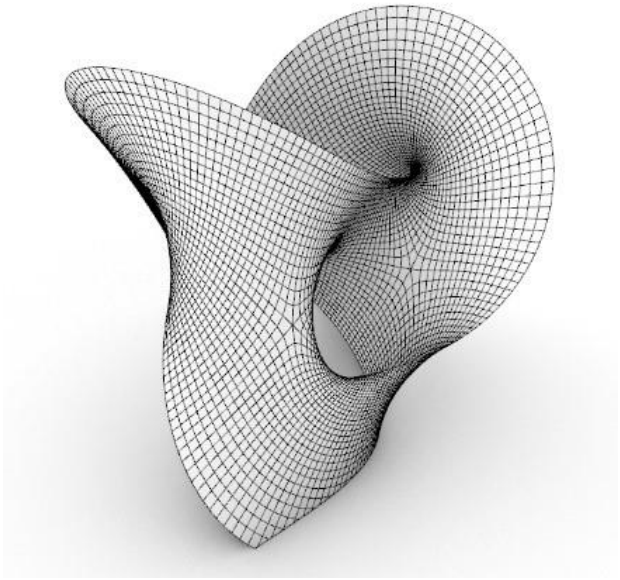




**Journal paper:** Vantyghem, G., Ooms, T., De Corte, W. 2021. VOXELPRINT: A Grasshopper plug-in for voxel-based numerical simulation of concrete printing. Automation in Construction 122 103469

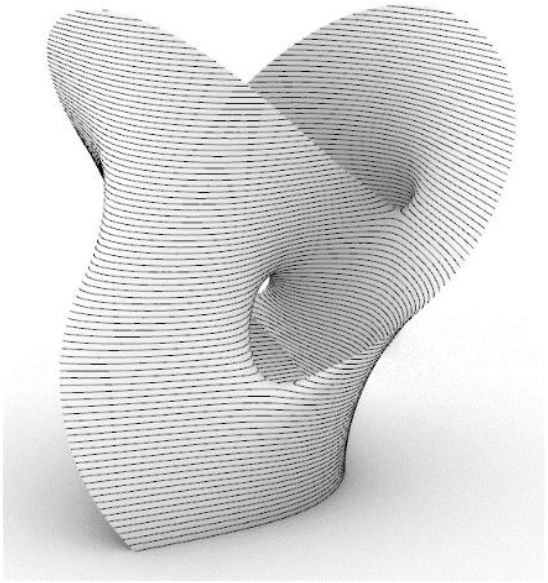
**Journal paper:** Ooms, T., Vantyghem, G., Van Coile, R., De Corte, W. 2021. A parametric modelling strategy for the numerical simulation of 3D concrete printing with complex geometries. Additive Manufacturing 38 101743

# 3D concrete printing simulation of complex objects

A non-orientable mesh, approximating a minimal surface was chosen as a benchmark to compare the *VoxelPrint* and *CobraPrint* modelling techniques

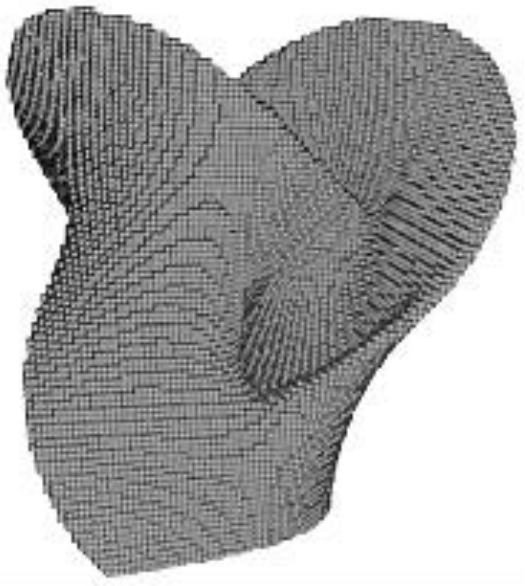


original object



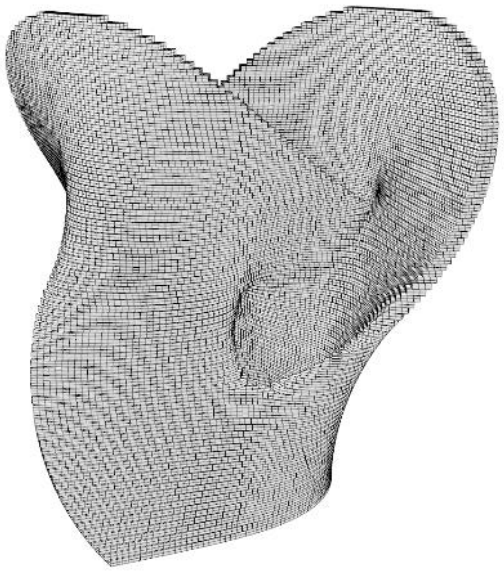
print path

(Grasshopper/Rhino)



voxelized mesh

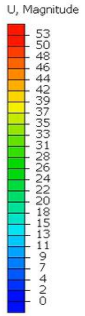
(Voxelprint)

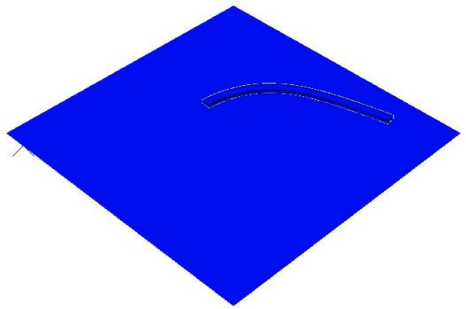


extrusion based mesh

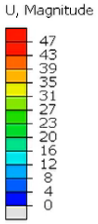
(CobraPrint)

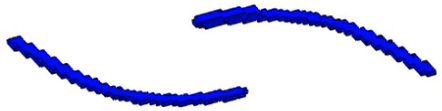
# 3D concrete printing of complex objects



Cobraprint 505

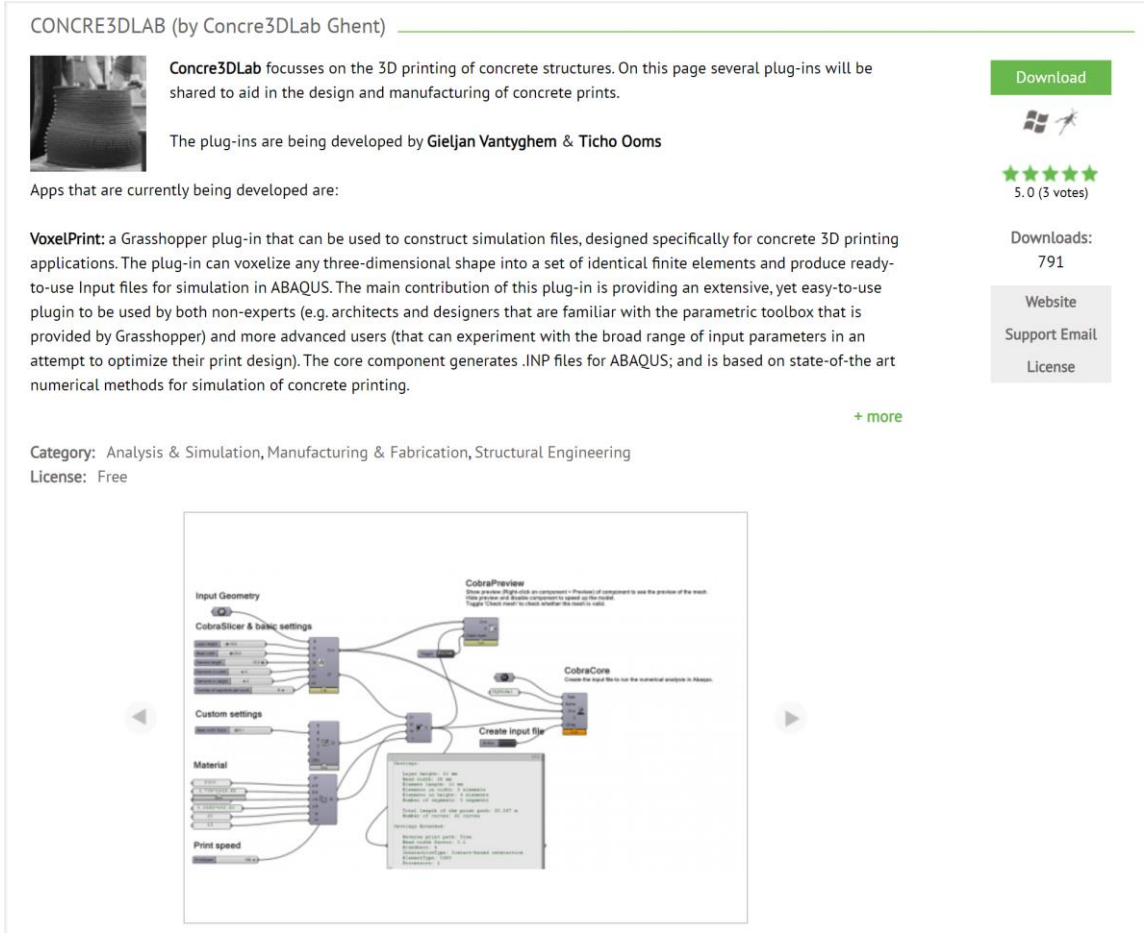


Voxelprint 505

# 3D concrete printing of complex objects

- ✓ Voxelprint & Cobraprint are available for educational and academic use (noncommercial)
- ✓ Concre3DLab - Food4Rhino
- ✓ food4rhino.com/app/concre3dlab



# 3D concrete printing of a small bridge
# Conclusions

2 realisations have been presented

- a small bridge
- a slightly larger bridge

Challenges

- design
- execution
- acceptance : Eurocode 0

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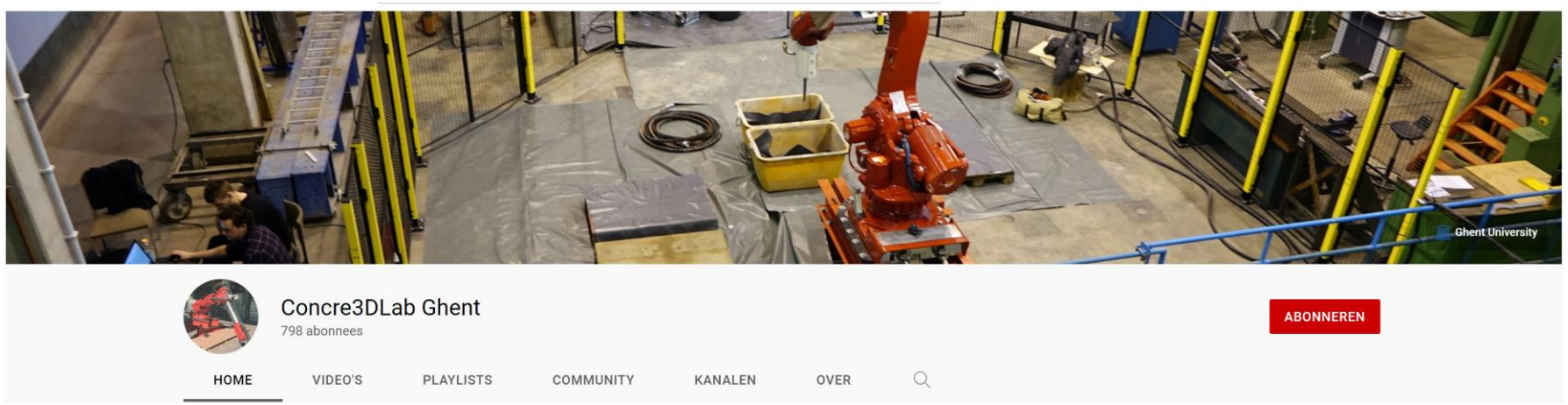
wouter.decorte@ugent.be

# Thank you !