





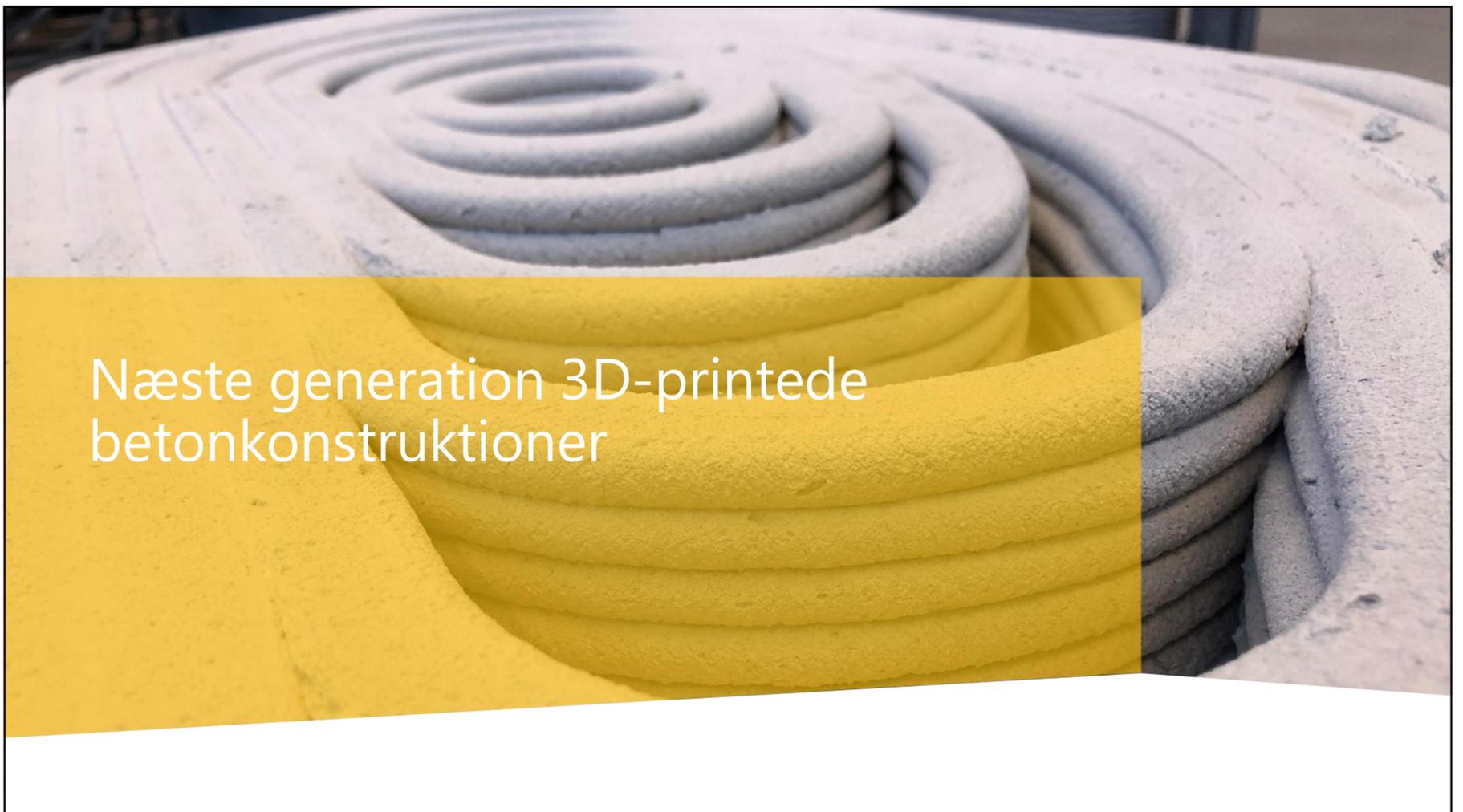
Næste generation 3D-printede betonkonstruktioner

Understanding a challenging material

Uden form – men ikke bare form for formens skyld!

What about reinforcement?

3



Næste generation 3D-printede  
betonkonstruktioner

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PensionDanmark A/S  
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PRODUCENTER

CRH Concrete A/S  
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Innovationsfonden  
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UDVIKLERE

Teknologisk Institut  
Danmarks Tekniske  
Universitet  
Syddansk Universitet

Bjarke Ingels Group  
A/S  
Henning Larsen  
Architects A/S



ARKITEKTER

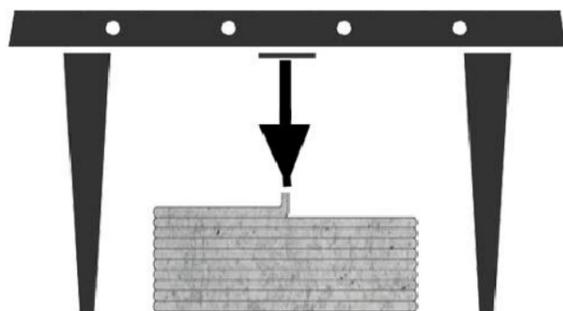
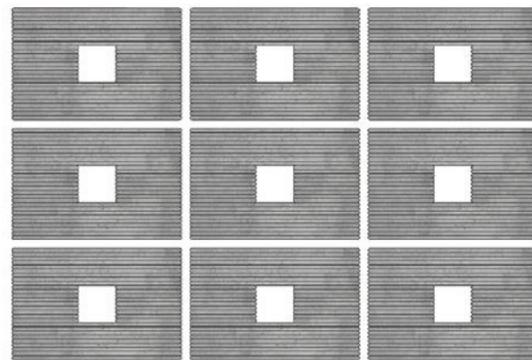
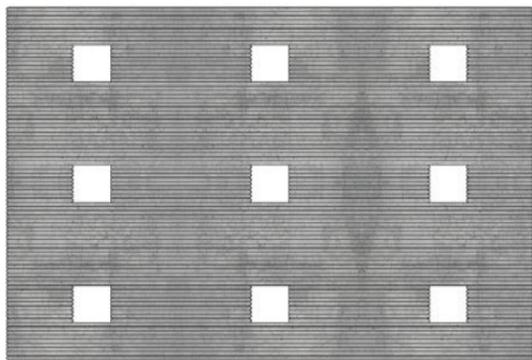


UDFØRENDE

NCC Danmark A/S



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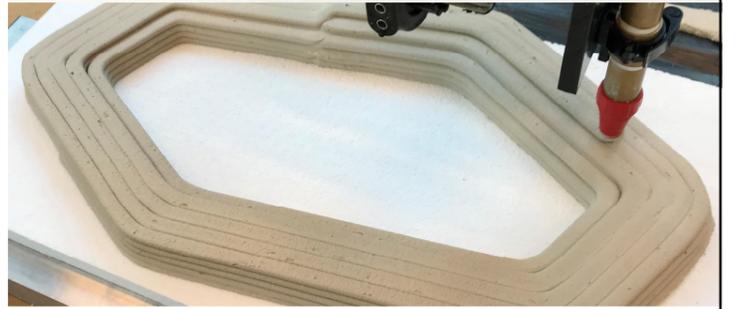
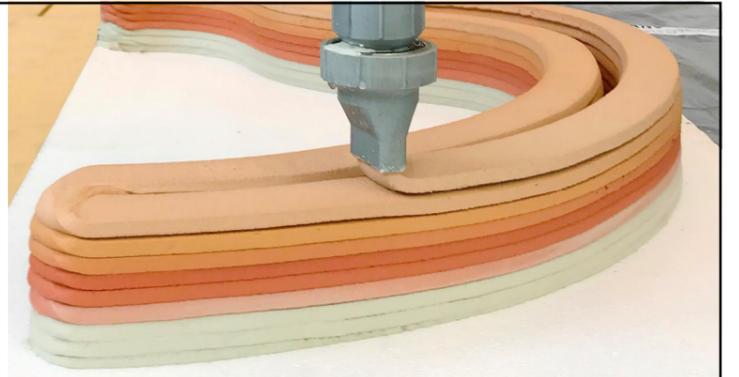




Bæredygtig opskalering  
Innovative designkoncepter  
Robuste fremstillingsmetoder



**Bæredygtig opskalering**  
Innovative designkoncepter  
Robuste fremstillingsmetoder



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Foto: The US Army Corps of Engineers (USACE)

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NEXTOR



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Bæredygtig opskalering  
**Innovative designkoncepter**  
Robuste fremstillingsmetoder

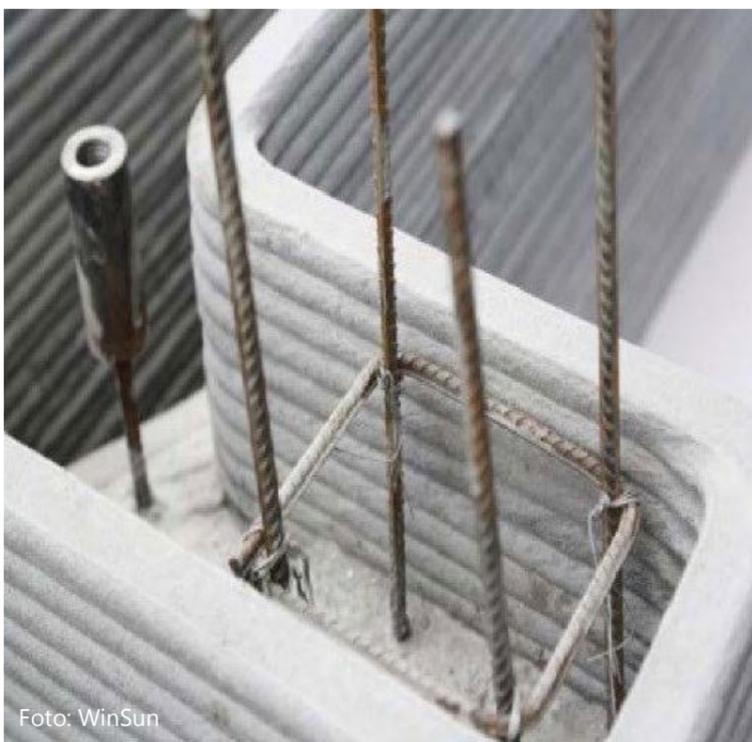


Foto: WinSun



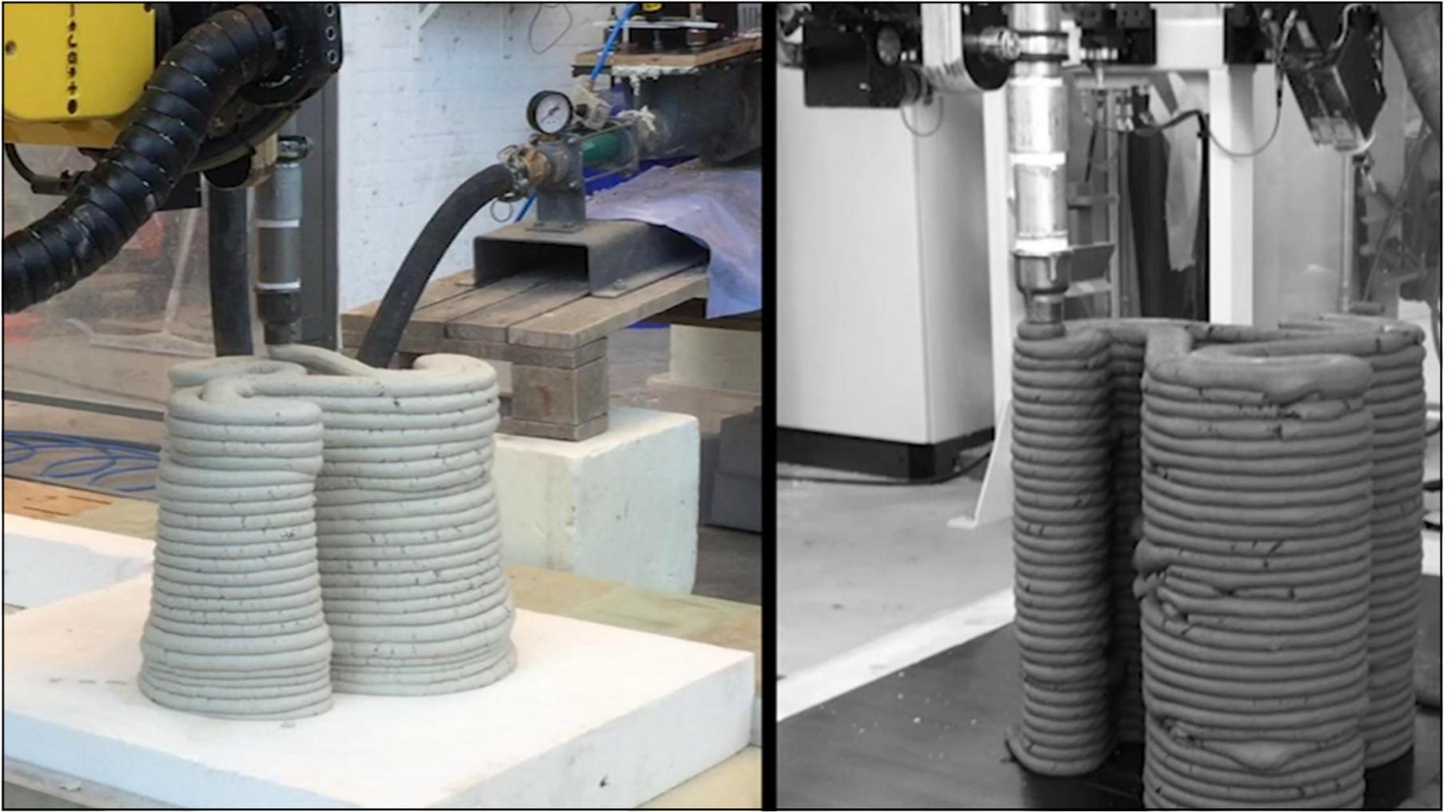
Fotos: HuaShang Tengda



Illustration: Future Architecture Platform



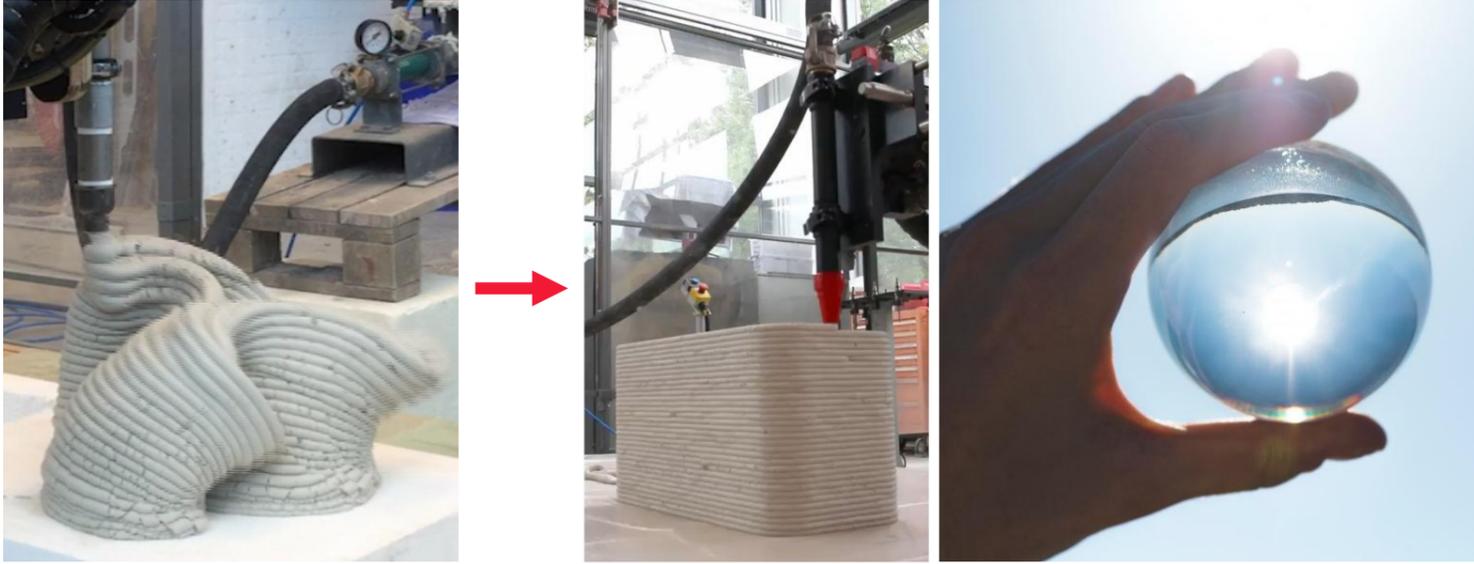
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**HEATON**



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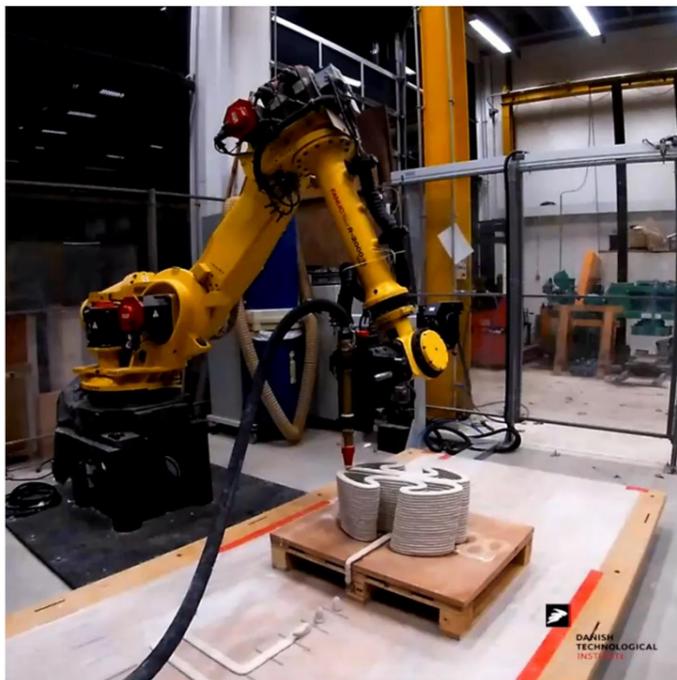




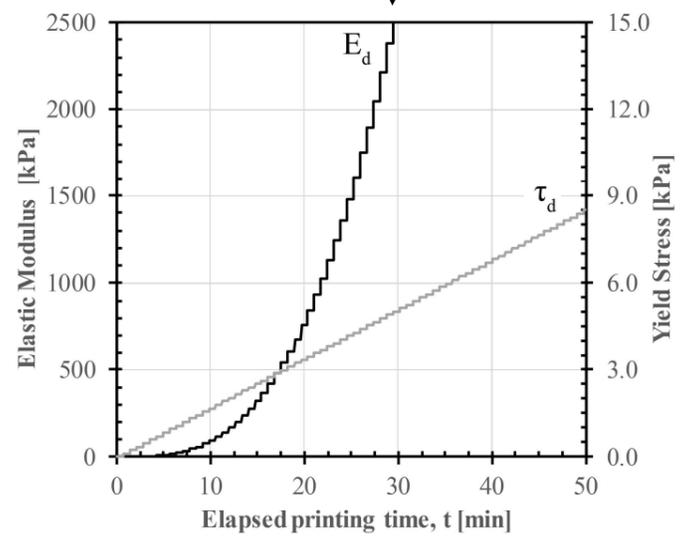
### "Conflict of interest"! (pumping × extrusion × stability)



### How to link design to process to estimate the materials requirements?



$$E_d(t) = 3 \cdot \rho \cdot g \cdot \dot{H}^3 \cdot \Delta t / 2 \cdot w^2$$



$$\tau_d(t) = \rho \cdot g \cdot \dot{H} \cdot \Delta t / \sqrt{3}$$



## How to characterize material properties that change so quickly?

### Strength measurements



Modulus



Viscous

Visco-elastic

Elasto-plastic

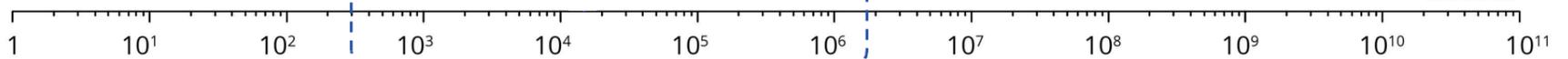


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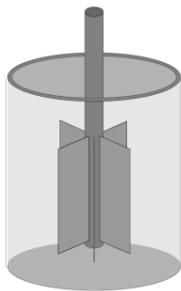
5 to 10min



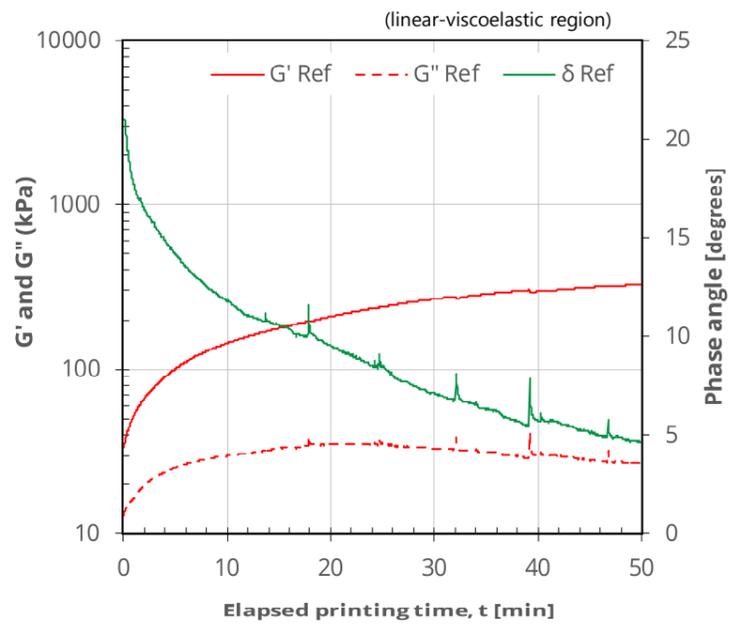
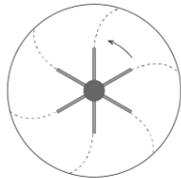
### Material characterization: Oscillatory Rheometry (visco-elastic material)

#### Vane geometry

Lateral view:



Cross-section:

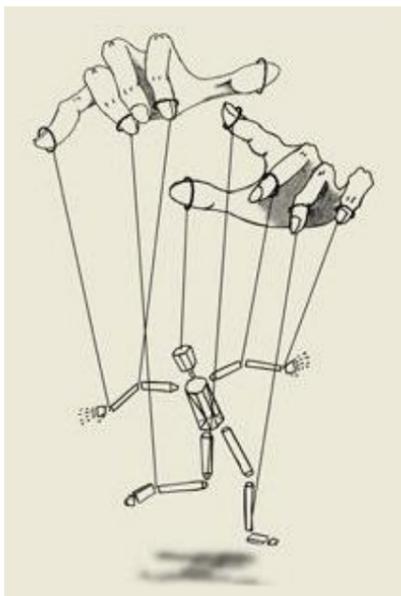


- G': Storage modulus
- G'': Loss modulus



$$E_C(t) = 2 \cdot G(t) \cdot (1 + \nu)$$

$$\tau_C(t) = G(t) \cdot \gamma_C(t)$$

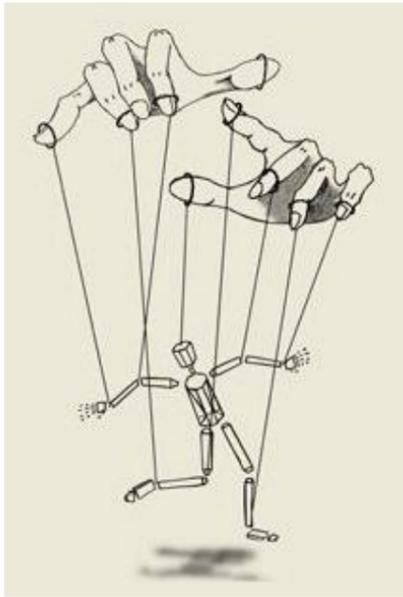


#### “Strings” → Material properties

- Dormant period
- Structural build-up rate
- Strength development

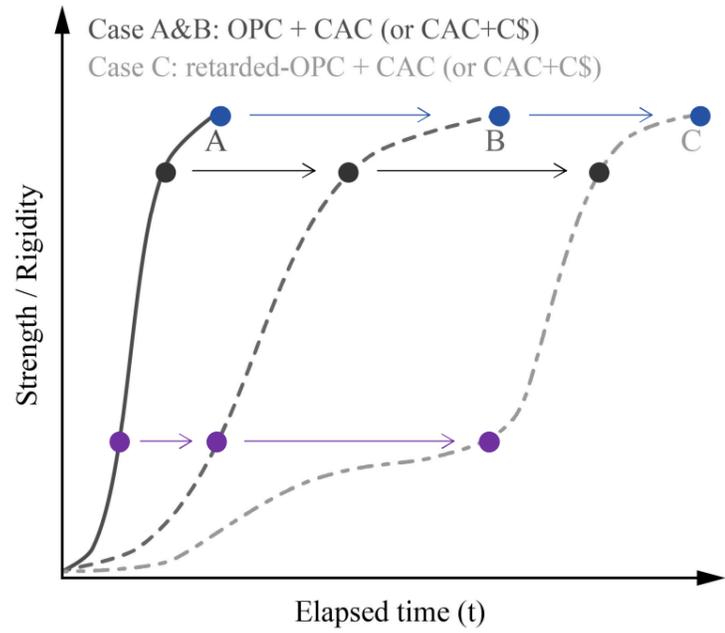


## Binary and Ternary-blended binder systems

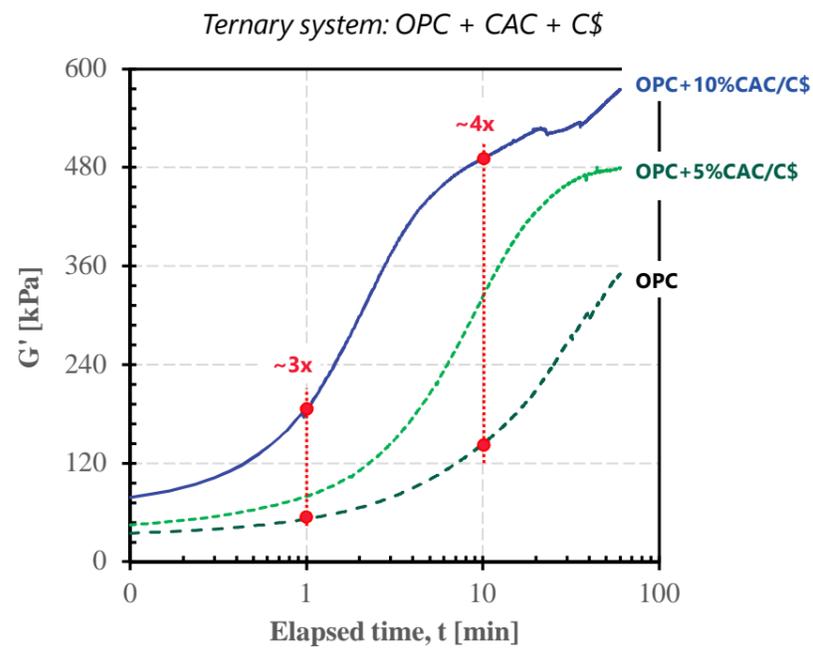


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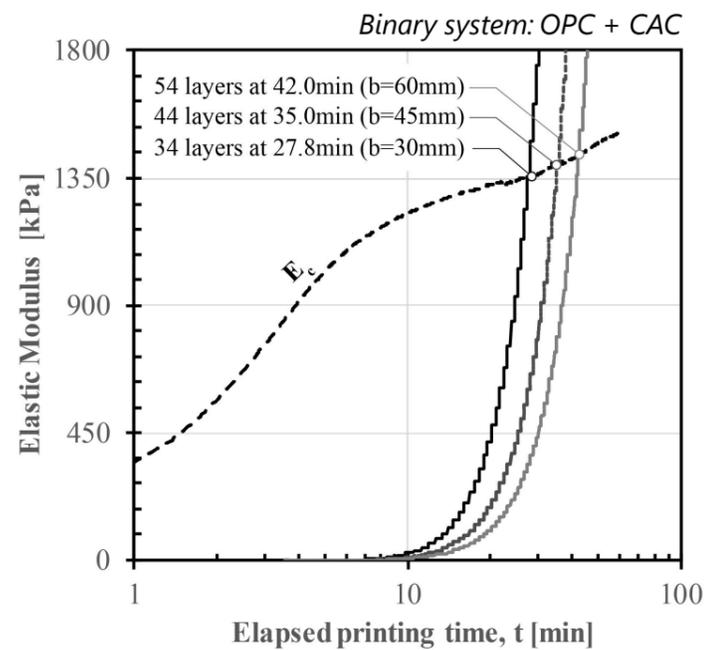
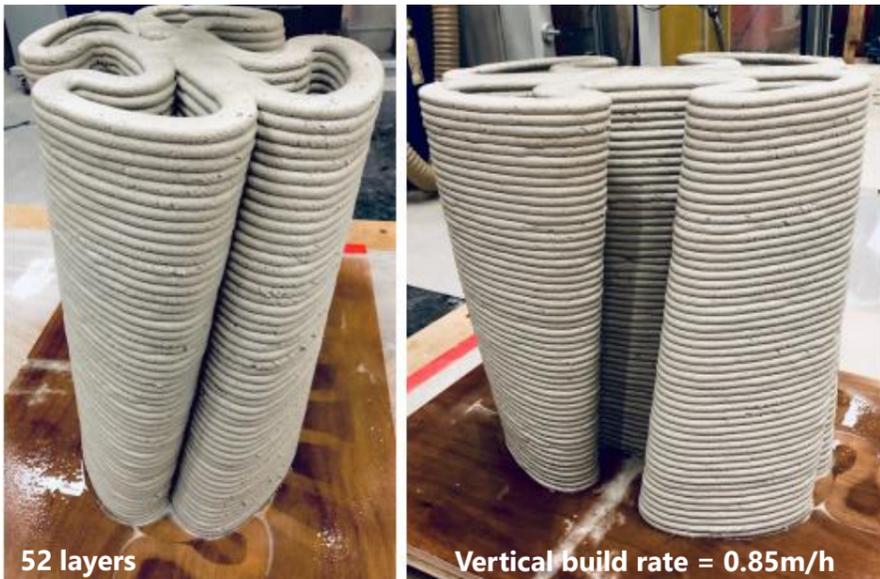


## Examples of applications in a 3DCP context





### Examples of applications in a 3DCP context



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### Key takeaway on material development for 3DCP applications

- Very-early age concrete properties (scale: **minutes** rather than hours)
- "**Conflict of interest**" between pumping x extrusion x shape stability
- New paradigm in **material characterization** and formulation
- Linking **material** to **process** is key for a **sustainable development** of 3DCP

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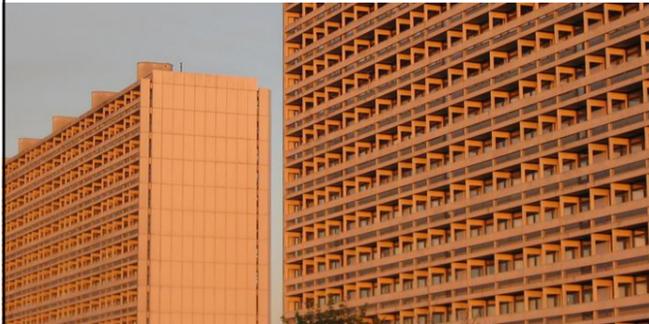
*Sustainability goes beyond the material itself...*



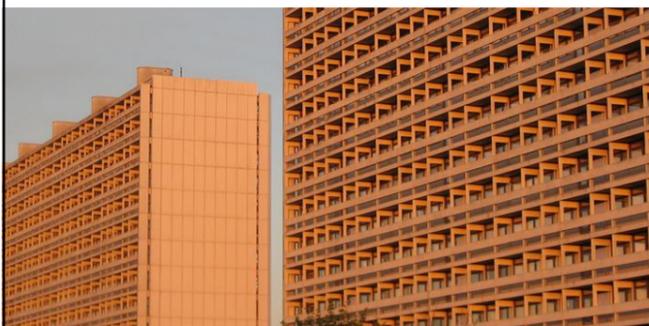
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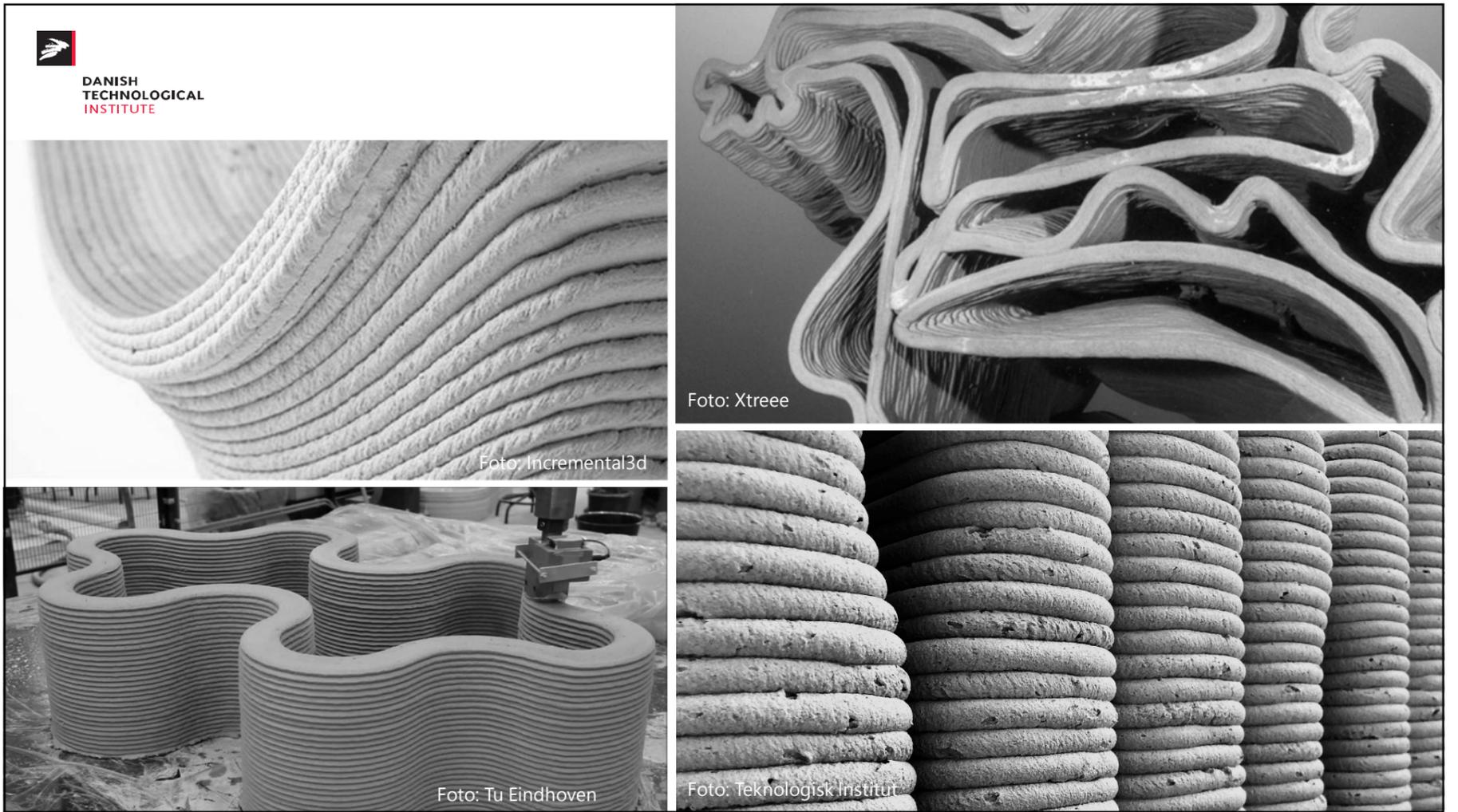
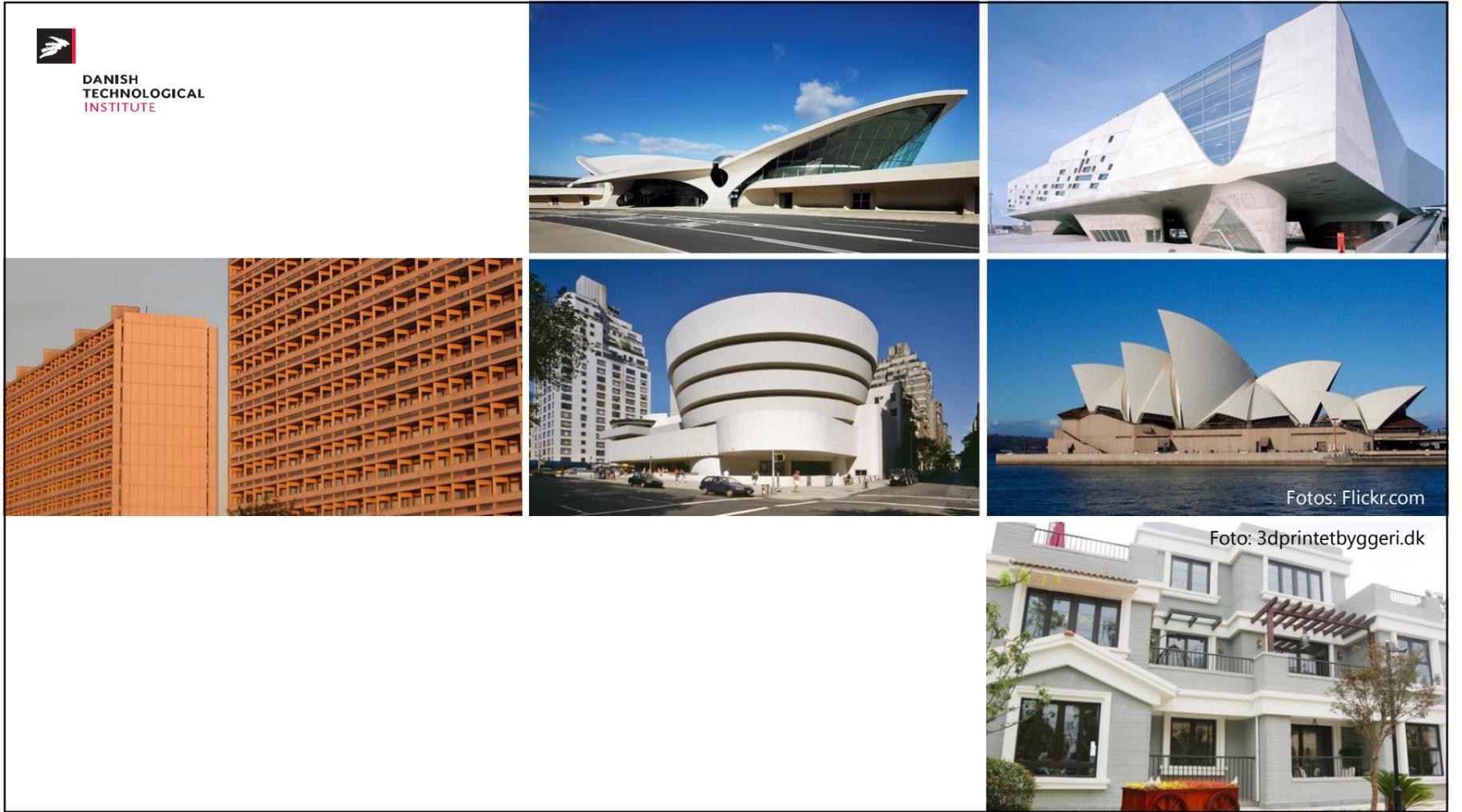
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Fotos: Flickr.com





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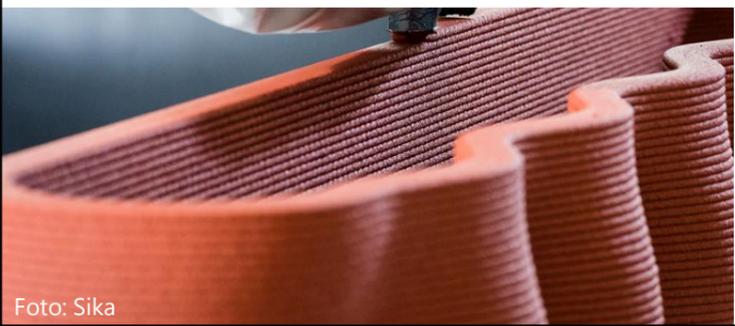
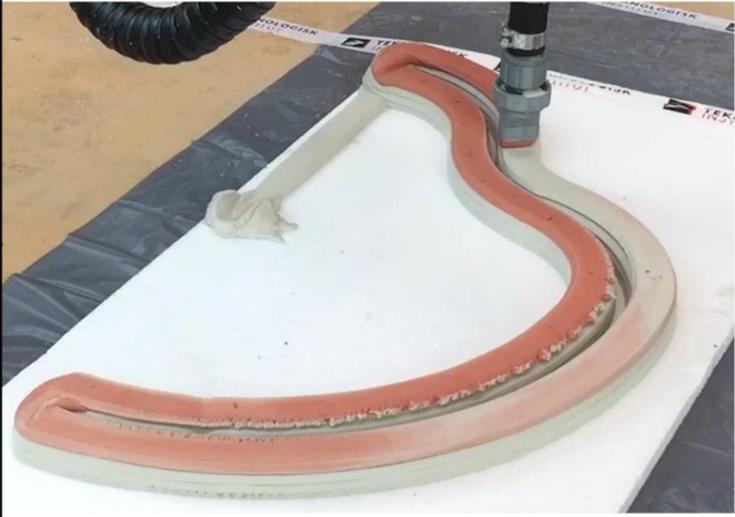
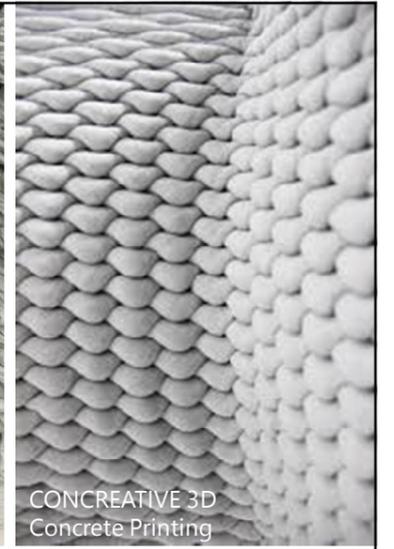


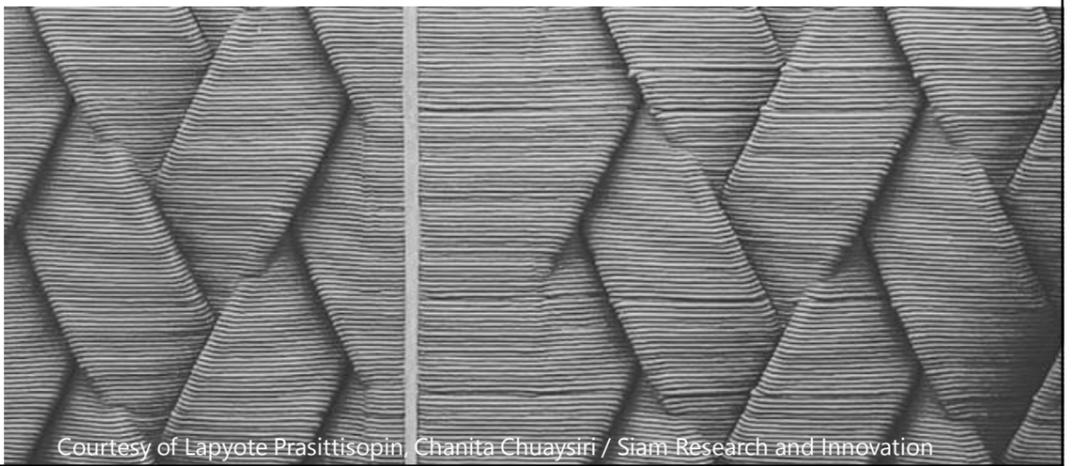
Foto: Sika



3dprint.com/164245/concrete-3d-printed-firewall/



CONCREATIVE 3D  
Concrete Printing



Courtesy of Lapyote Prasittisopin, Chanita Chuaysiri / Siam Research and Innovation



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Foto: Icon



Foto: COBOD



Foto: Cybe Construction



Foto: Apis Cor



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Fotos: Bruil



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Foto: BAM

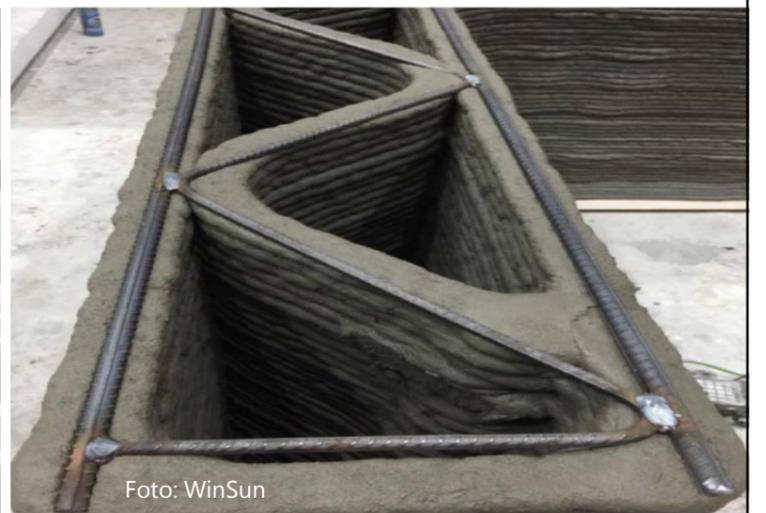
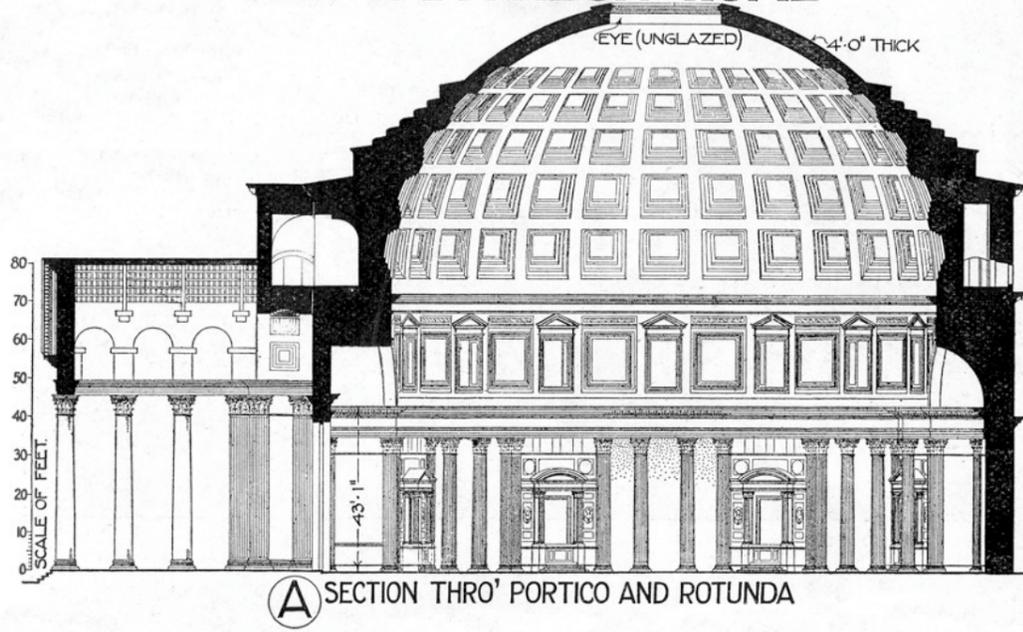


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# THE PANTHEON: ROME



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[Image: Mike Jazdyk]





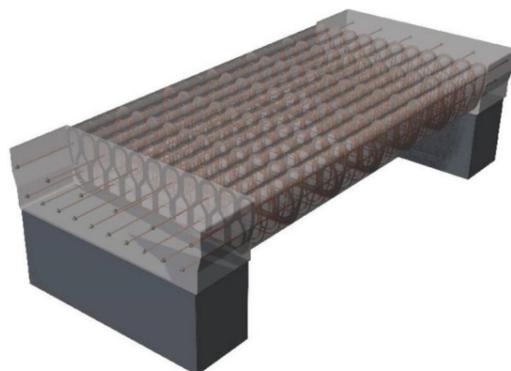
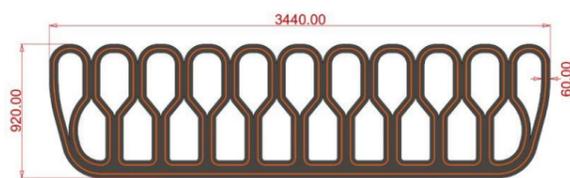
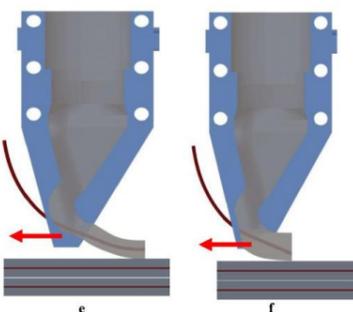
### External stainless-steel tendons



D. Asprone, F. Auricchio, C. Menna, V. Mercuri. 3D printing of reinforced concrete elements: Technology and design approach. Construction and Building Materials, 165: 156-218, 2018



### Multi-material 3DCP: Cable-reinforced layers + Post-tensioning



Salet T.A., Ahmed Z.Y., Bos F.P., Laagland H.L.. Design of a 3D printed concrete bridge by testing. Virtual and Physical Prototyping, 13: 222-236, 2018



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### 3DCP Formwork (with conventional concrete casting + steel rebars)



Students' 3D-printed Concrete Choreography pillars provide a stage for dancers – ETH Zurich (<https://youtu.be/Ksh1cR-egQ>)



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### 3DCP Formwork (with conventional concrete casting + steel rebars)



Obayashi Corporation: <http://ieiri-lab.jp/it/2019/08/obayashi-3d-printer.html>



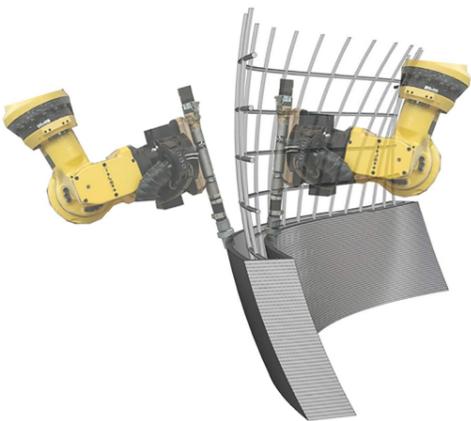
### Concrete extrusion on steel rebars



HuaShang Tengda: <http://www.hstdgm.com/>

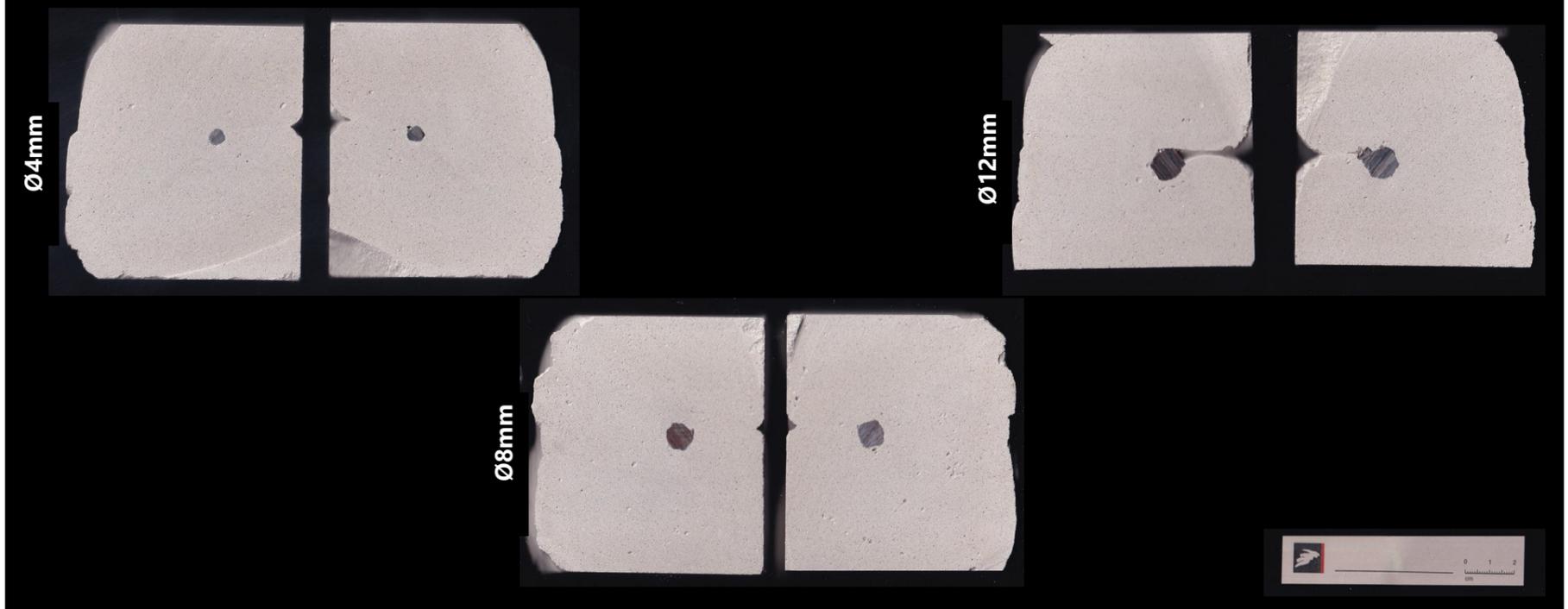


### CURRENT CHALLENGE: To develop a fully-integrated reinforcement concept





## Preliminary studies at N3XTCON... (cross-section of printed samples)



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## Key takeaway on reinforcement solutions for 3DCP structures

- The **reinforcement challenge** has not being solved yet!

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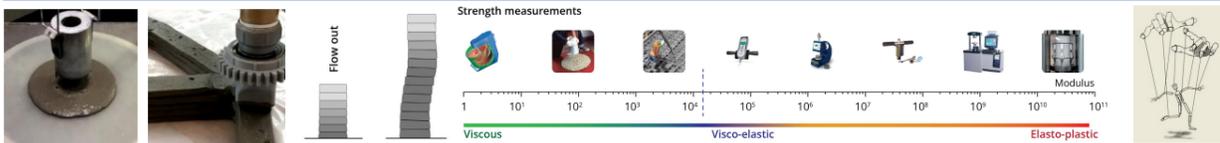
## Næste generation 3D-printede betonkonstruktioner



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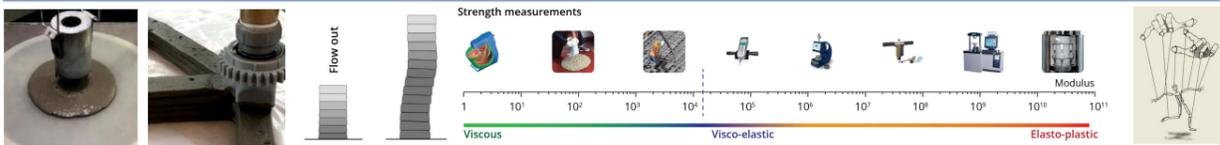
## Understanding a challenging material



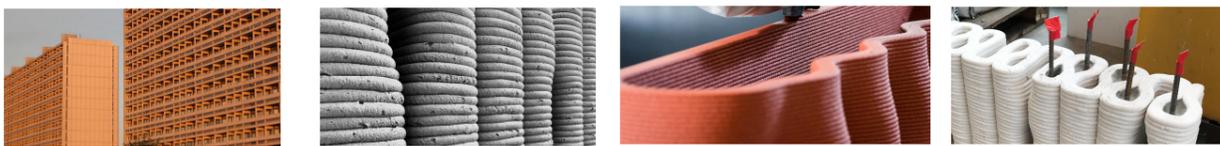
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### Understanding a challenging material



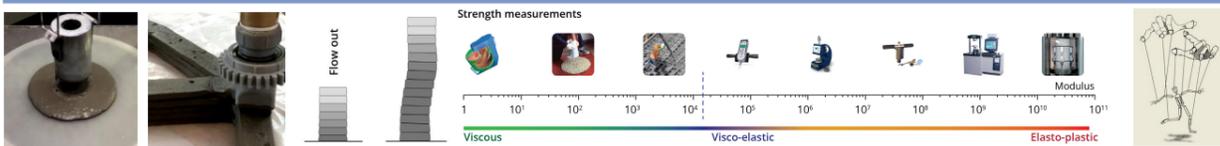
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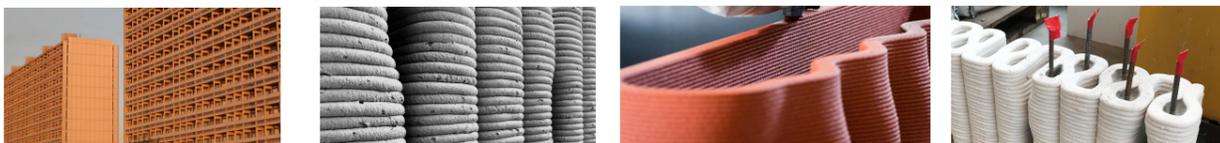
## Næste generation 3D-printede betonkonstruktioner



### Understanding a challenging material



### Uden form – men ikke bare form for formens skyld!



### What about reinforcement?





**Tak for opmærksomheden!**

[tja@teknologisk.dk](mailto:tja@teknologisk.dk) / [wrls@teknologisk.dk](mailto:wrls@teknologisk.dk)