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Building Affordable Housing using 3D Concrete Printing

PJ Kruger
26 May 2023

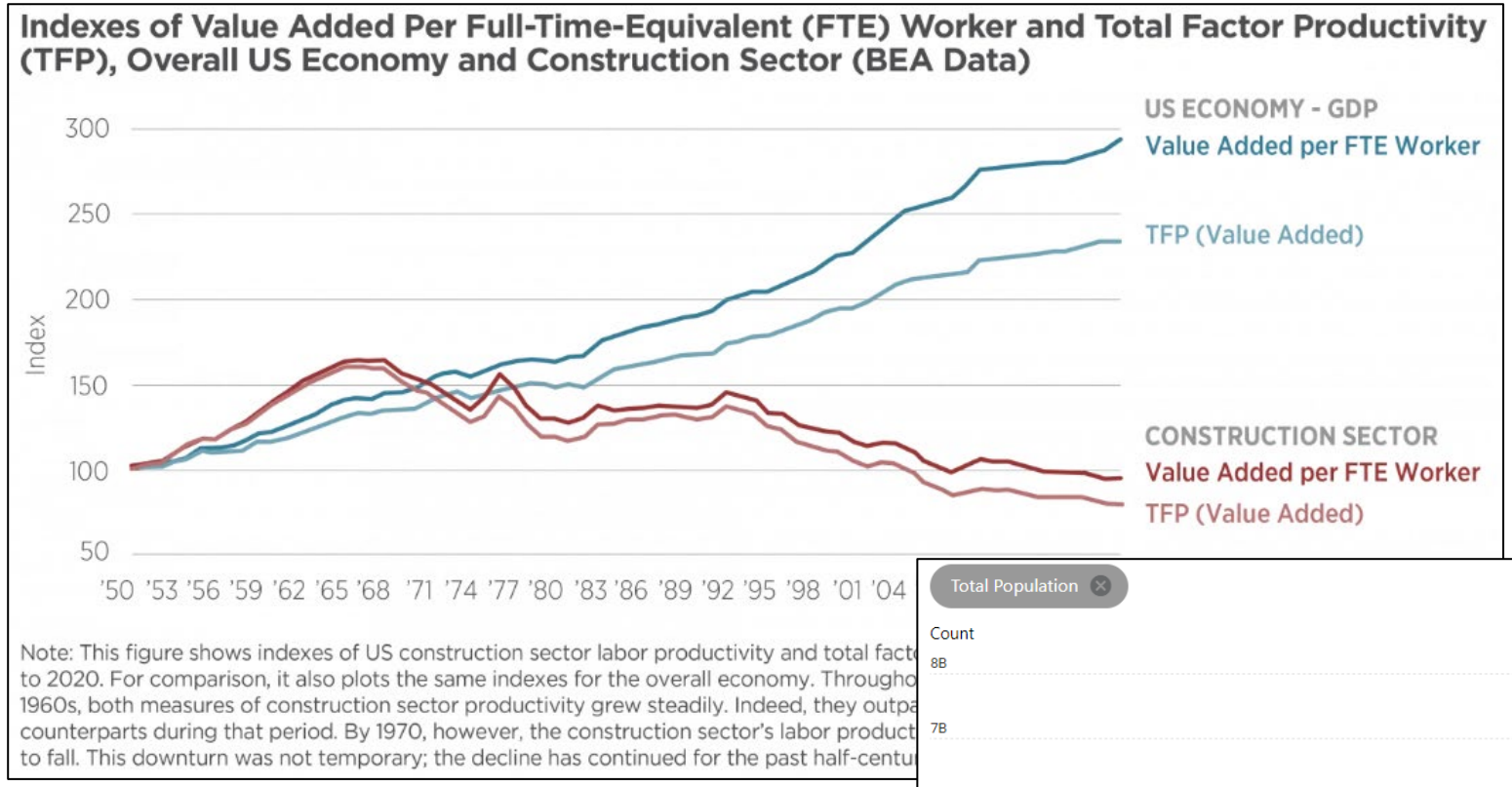
Photo by Stefan Els

Austin, TX, USA – By ICON Build (2018):

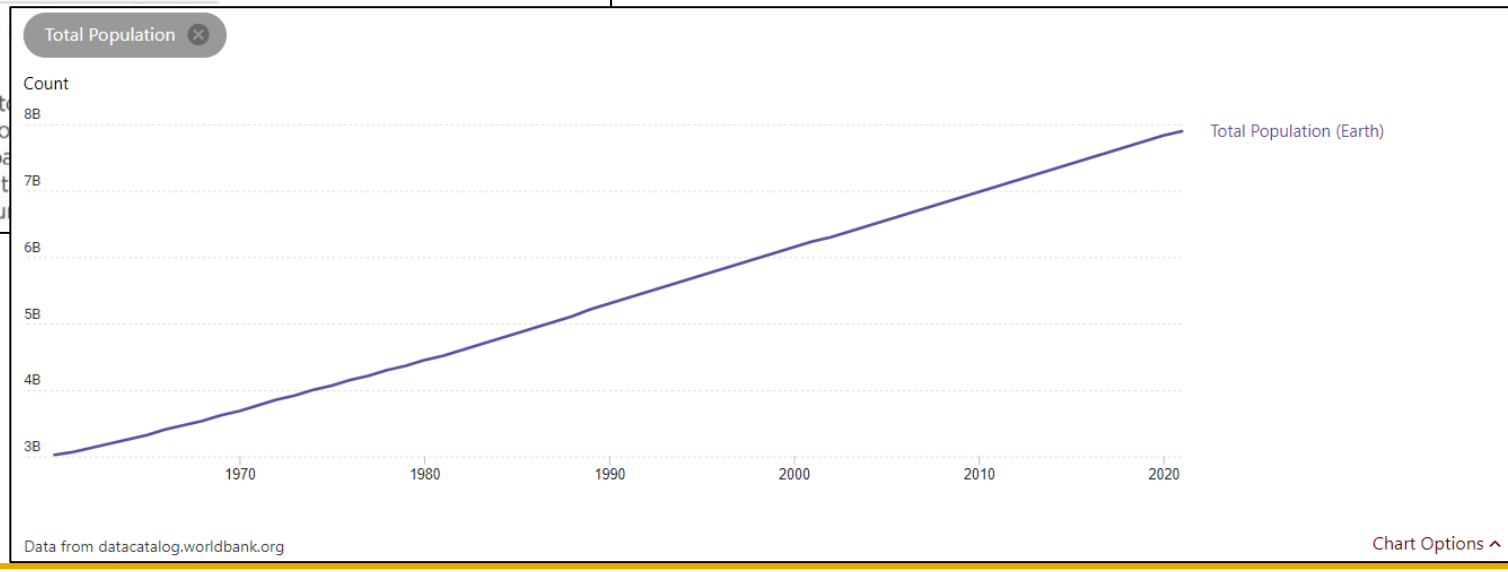
- 32 m^2
- 24 Hours (Walls)
- ≈ R150 000 (Foundation & Walls)
- ≈ R600 000 (Finished)

Wallenhausen, Germany – By PERI Group (2020): 380 m^2 3DP in 21 Days

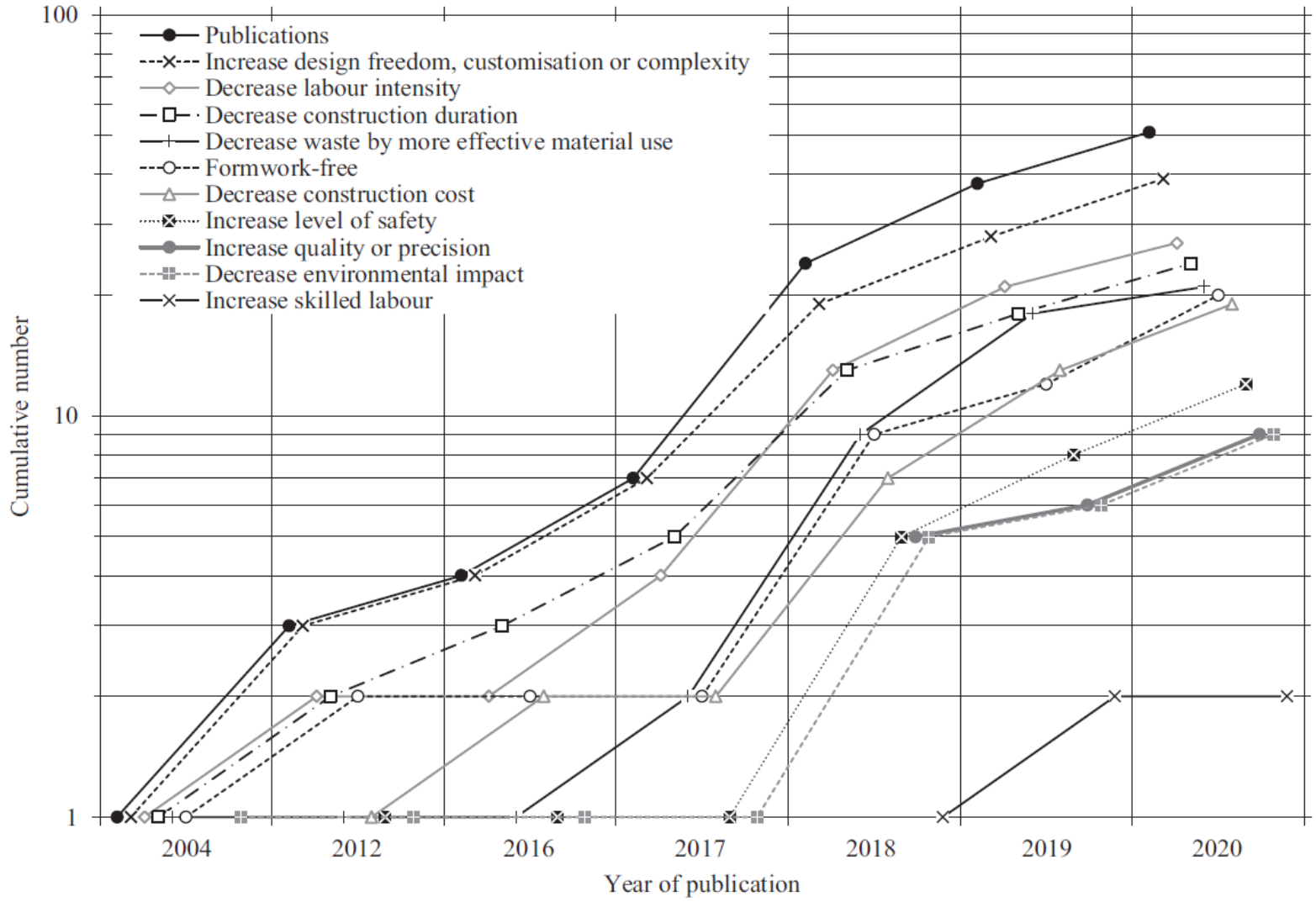
Why Automate Construction?



$$TFP = \frac{Output}{Input}$$



Why 3D Concrete Printing?

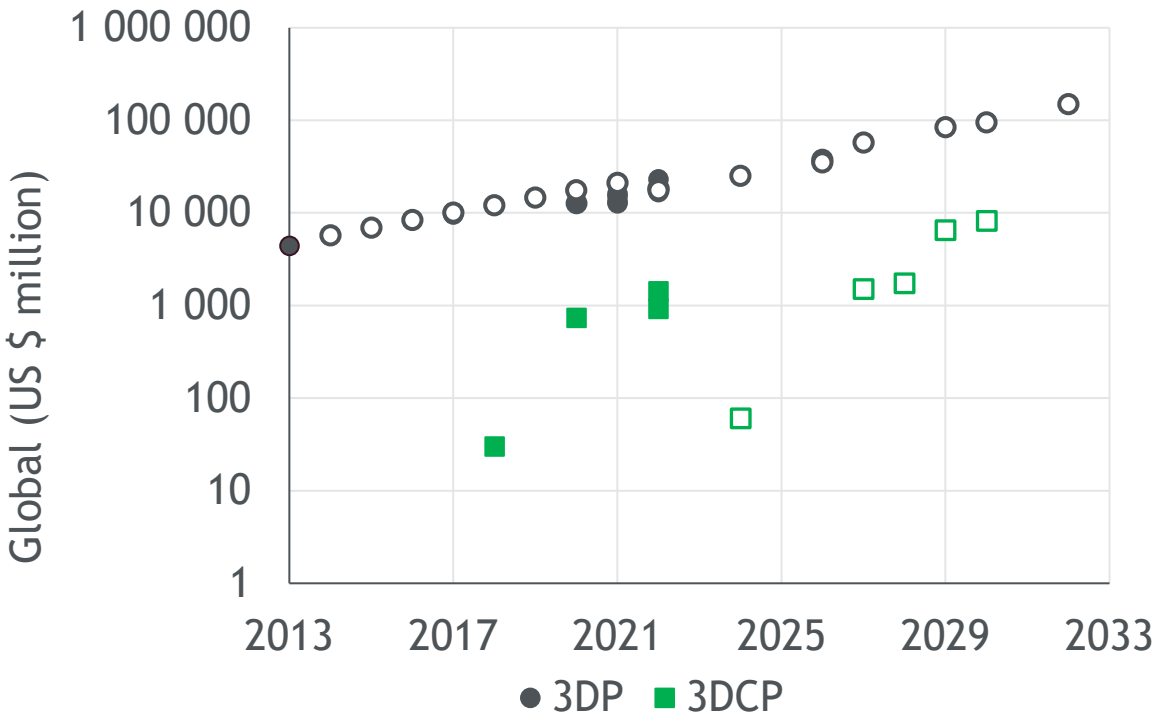


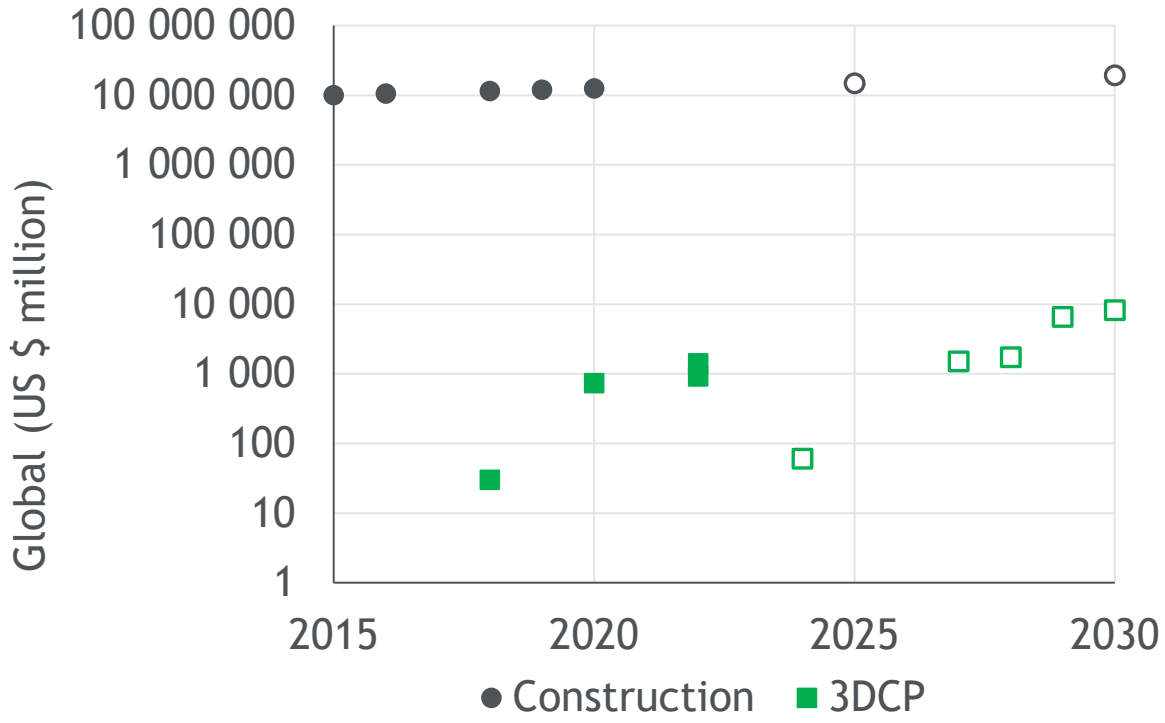
Faster

Cheaper

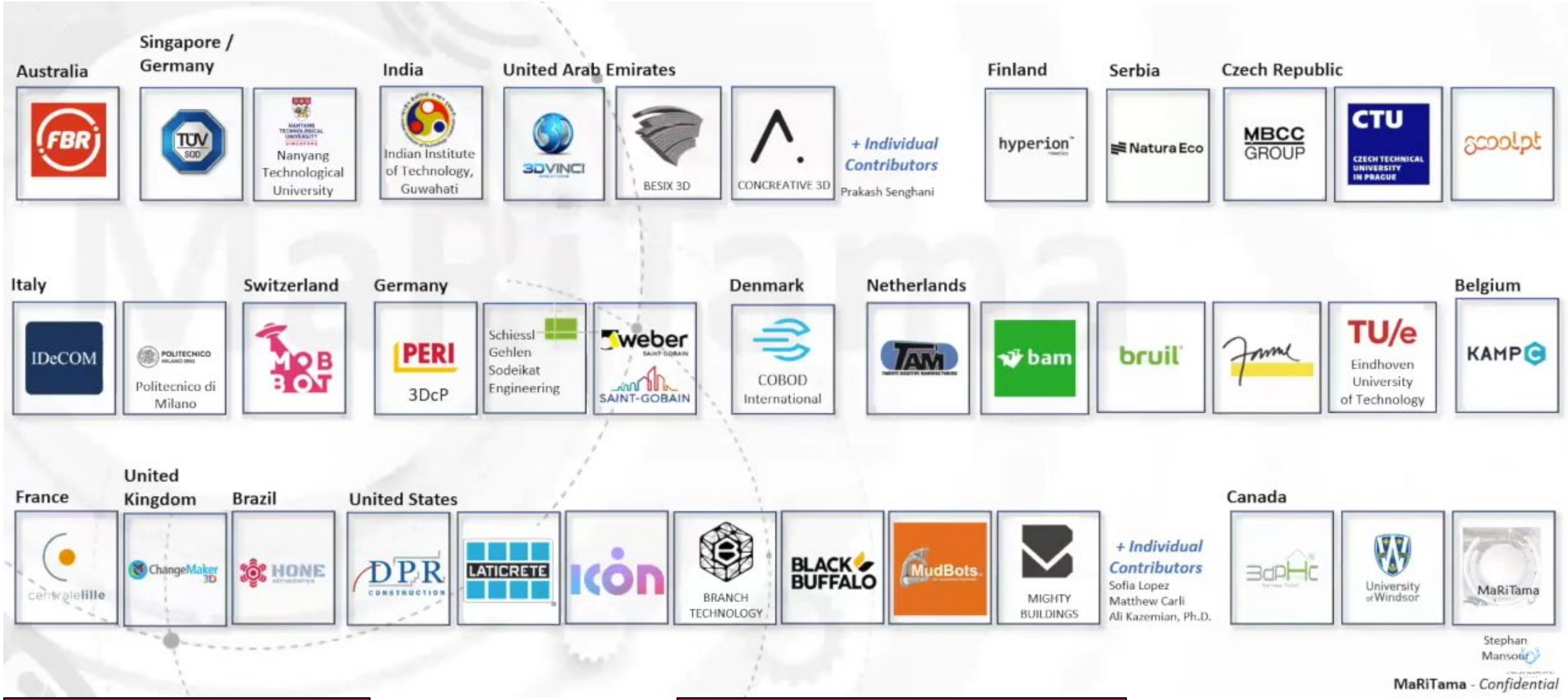
Increase in Quality

3D Concrete Printing Market Share





3DCP Entities

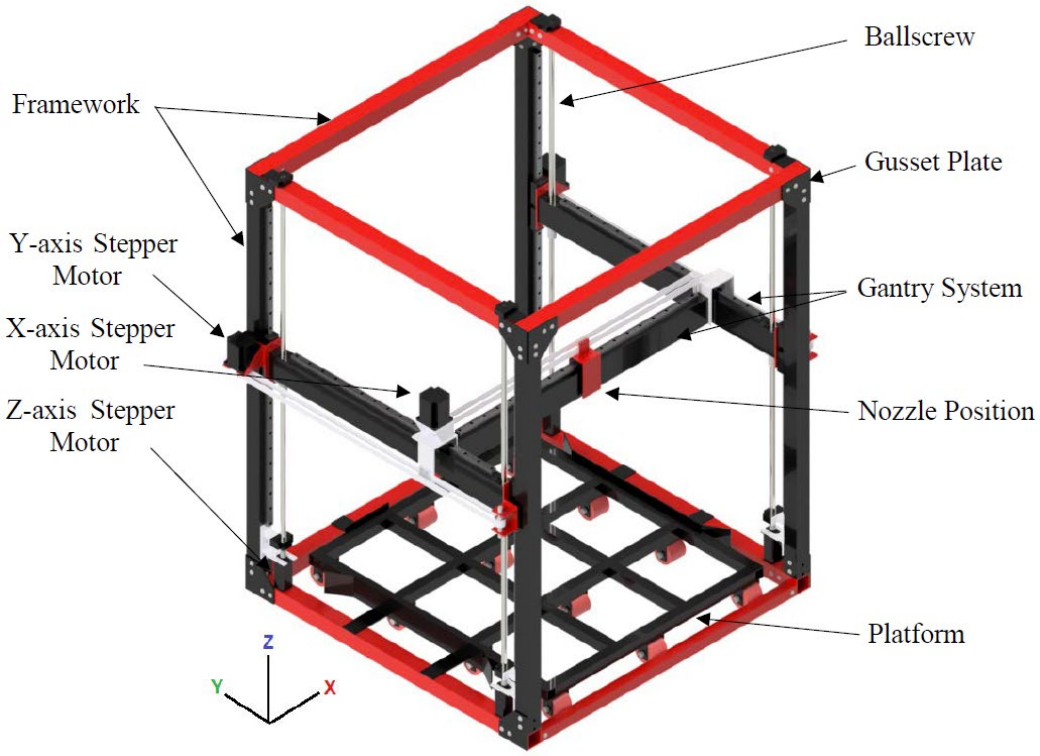


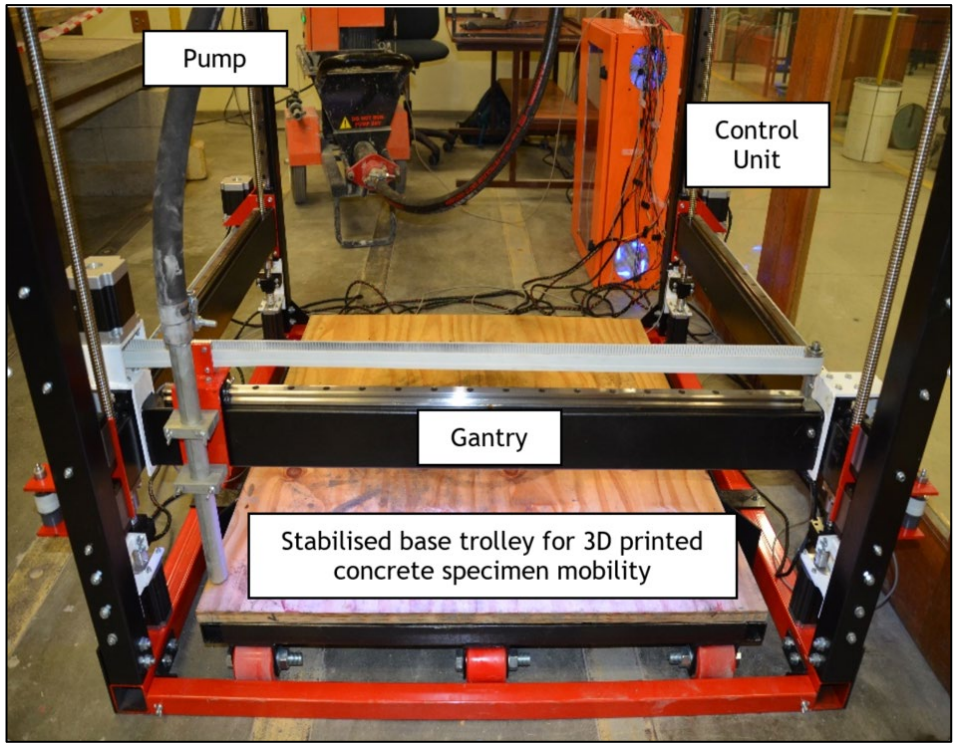
Africa - Kenya: 14Trees

80 Known Companies in 2022

2022

3D Concrete Printing at SU

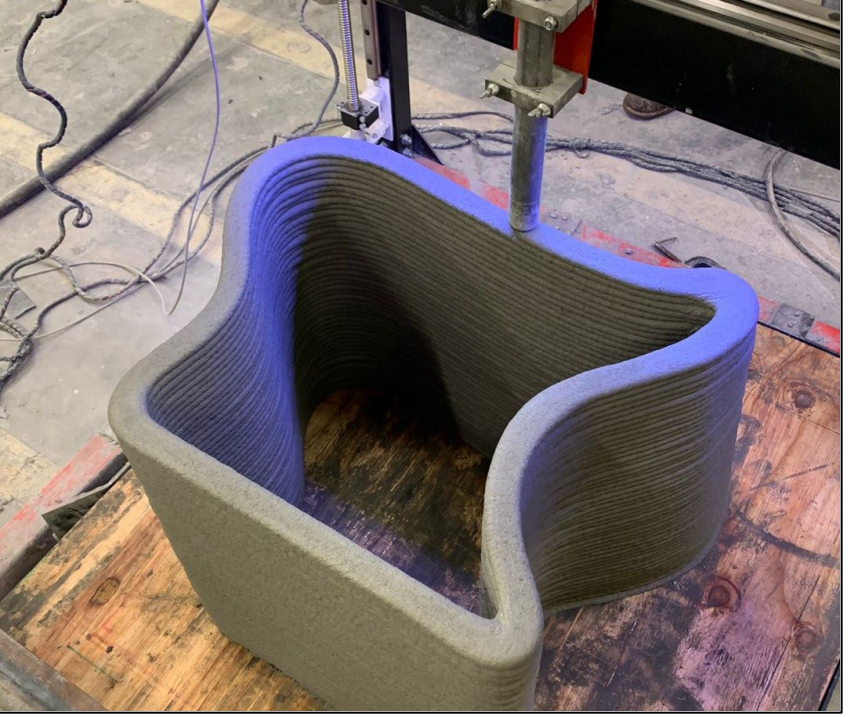




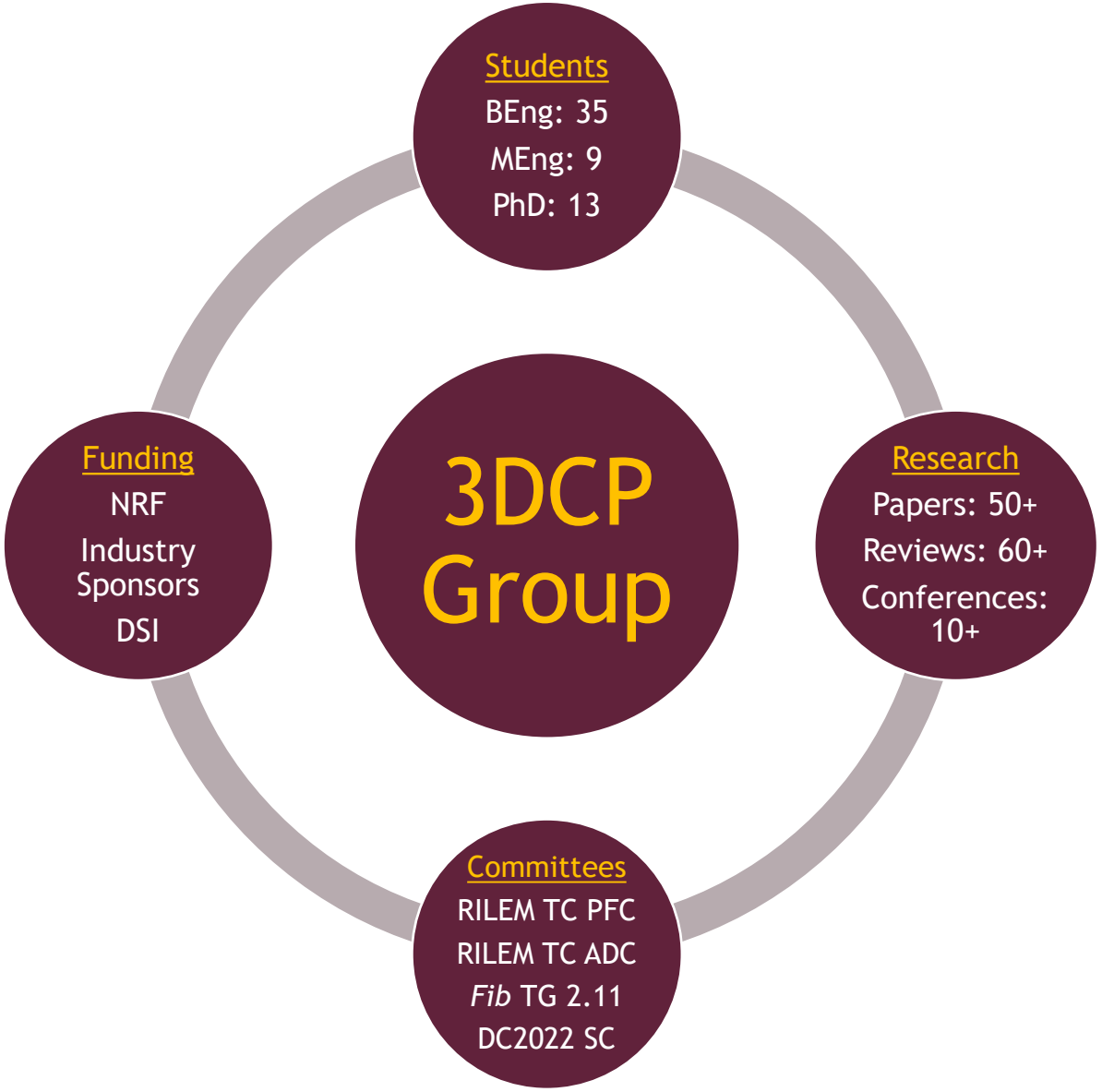
- Designed, Procured & Manufactured at SU (Completed 2018)
- 1 m^3 Build Volume
- Coupled with Positive Displacement Pump for Batch Mixing
- Print Speeds up to 150 mm/s
- Used for Most of our Research to Date

3D Concrete Printing at SU

- Designed, Procured & Manufactured at SU (Completed 2022)
- 16 m^3 Build Volume
- All Items Sourced Locally, except Pump (Germany)
- Continuous Mixing Pump
- Automated 4 m^3 Silo
- End Effector for On-Demand Chemical Dosing (Soon)
- Used for Large-Scale Printing



Output since 2017

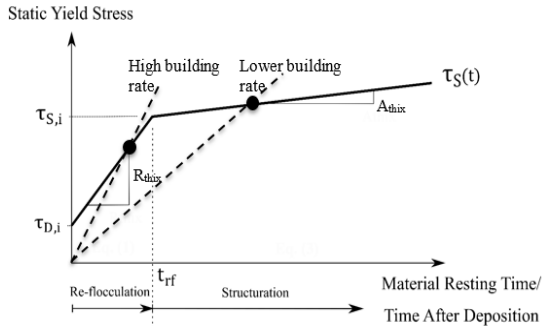


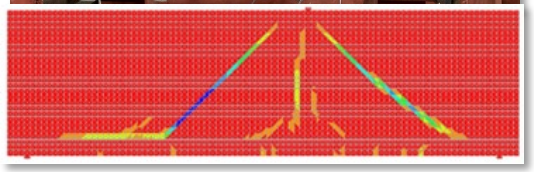
Alumni

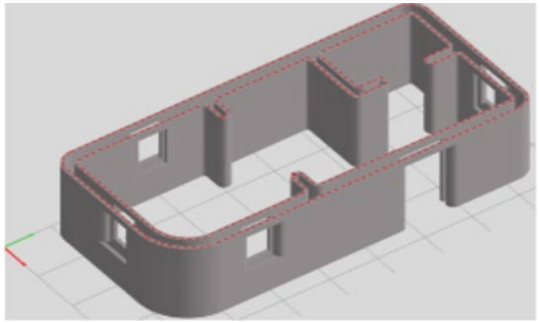
- **Dr Stephan Zeranka** – Head of Materials Research & Development at COBOD
- **Dr Gerius Moelich** – Global Head of Material Services at COBOD
- **Dr Marchant van den Heever** – Chief Technology Officer at Harcourt Technologies
- **Mr Jandré Oosthuizen** – Materials Engineer at Harcourt Technologies
- **Mr Frederick Bester** – Head Research & Development at 14Trees
- **Dr Seung Cho** – Research Fellow at UNIST

The Roadmap

2016 — 2019 — 2022 — 2025







Materials

Rheology & tests. FRC, FC, LC^3, GPC

Carbon footprint. Recycling. Circularity in 3DCP

Interfaces for strength and durability

Structural

Mechanical tests, anisotropy

Computational models

Reinforcement

Durability carbonation, corrosion, fire behaviour

Buildings

Façade heat transfer, passive design

Off-site 3DCP construction

Residential construction

3DP Full Scale House

Research: Material Level

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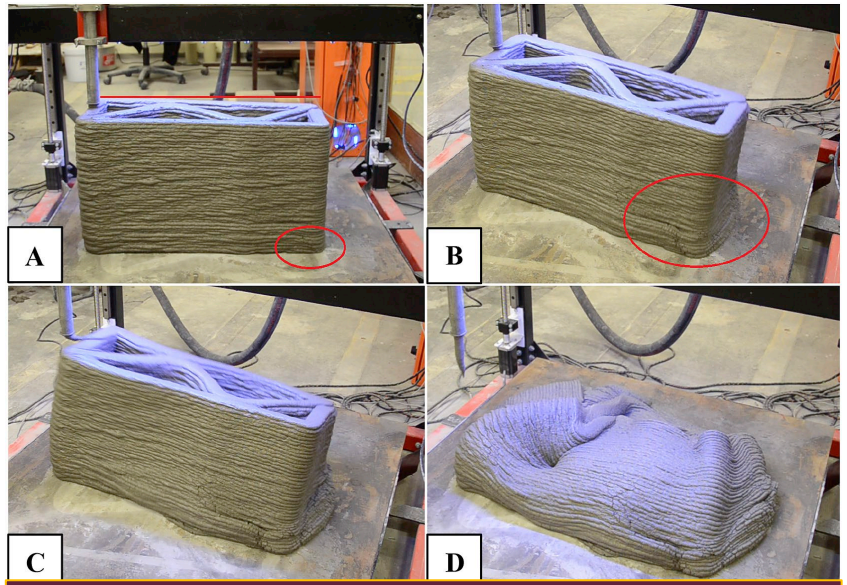
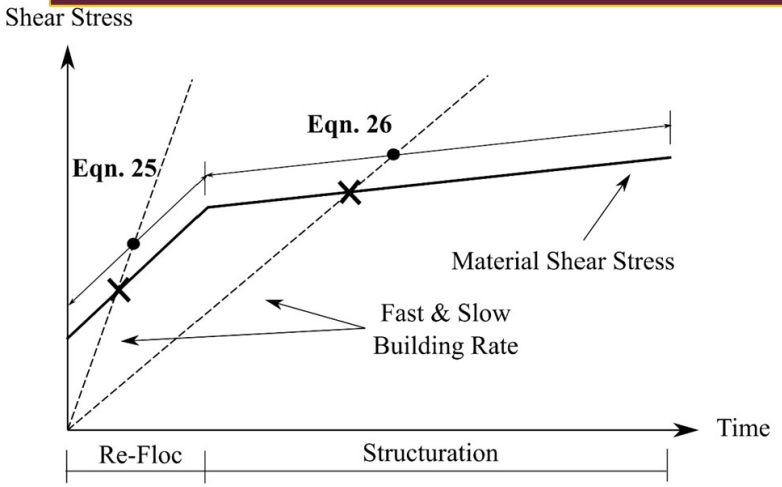


Constructability

Rheometry

Fresh State Workability Tests



$$\text{If } \frac{d}{dt}\left(\frac{\rho.g.h_1^*.v^*.10^{-3}}{2.l_p.F_{AR,expl}}.t\right) \geq \frac{\tau_{S,i}.R_{thix}}{\tau_{S,i}-\tau_{D,i}}$$

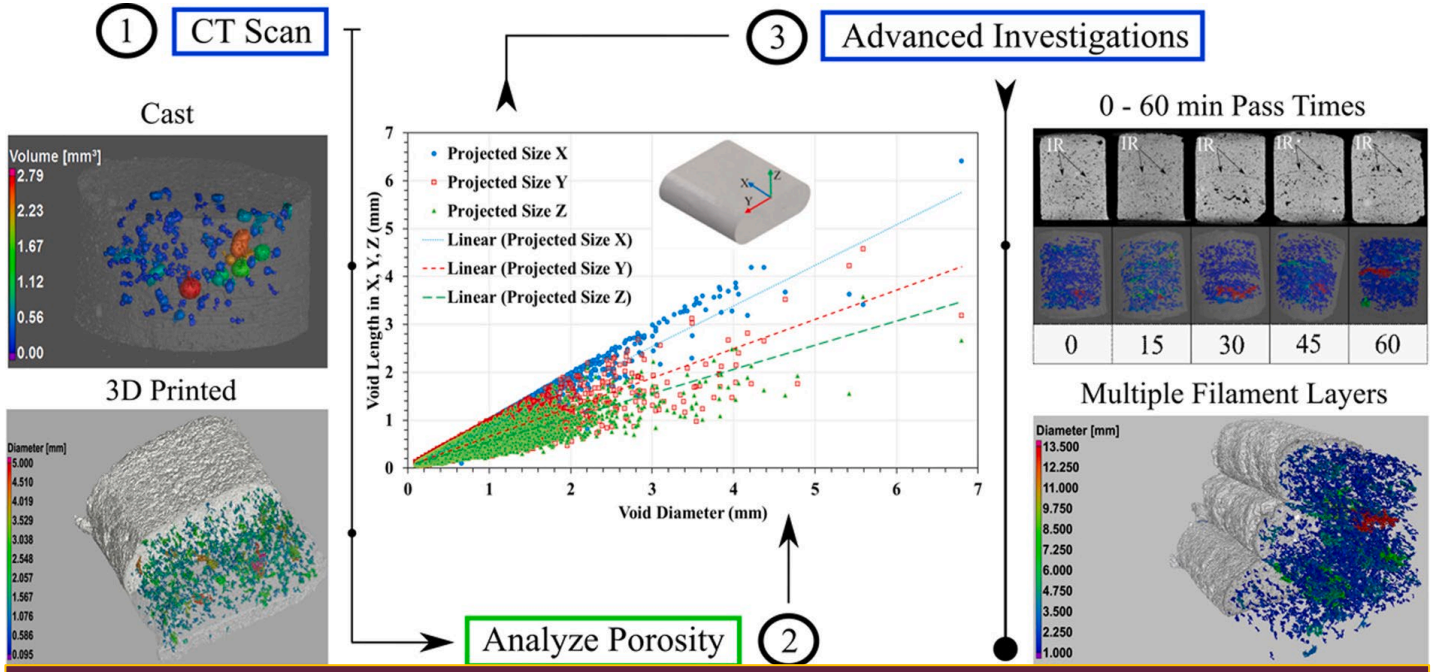
$$\text{Then use } H_{predicted} = \left[\frac{h_1^*.\tau_{D,i}}{\left(\frac{\rho.g.h_1^*}{2.10^3.F_{AR,expl}}\right)-\left(\frac{R_{thix}.l_p}{v^*}\right)}\right]$$

$$\text{Else use } H_{predicted} = \left[\frac{h_1^*.\left(\frac{\tau_{S,i}}{\gamma_{M,1}}+\left(\frac{A_{thix}.\left(\tau_{D,i}-\frac{\tau_{S,i}}{\gamma_{M,1}}\right)}{R_{thix}.\gamma_{M,2}}\right)\right)}{\left(\frac{\rho.g.h_1^*}{2.10^3.F_{AR,expl}}\right)-\left(\frac{A_{thix}.l_p}{v^*.\gamma_{M,2}}\right)}\right]$$

Material Models / Analytical Modelling / Buildability

Fresh State Mechanical Tests

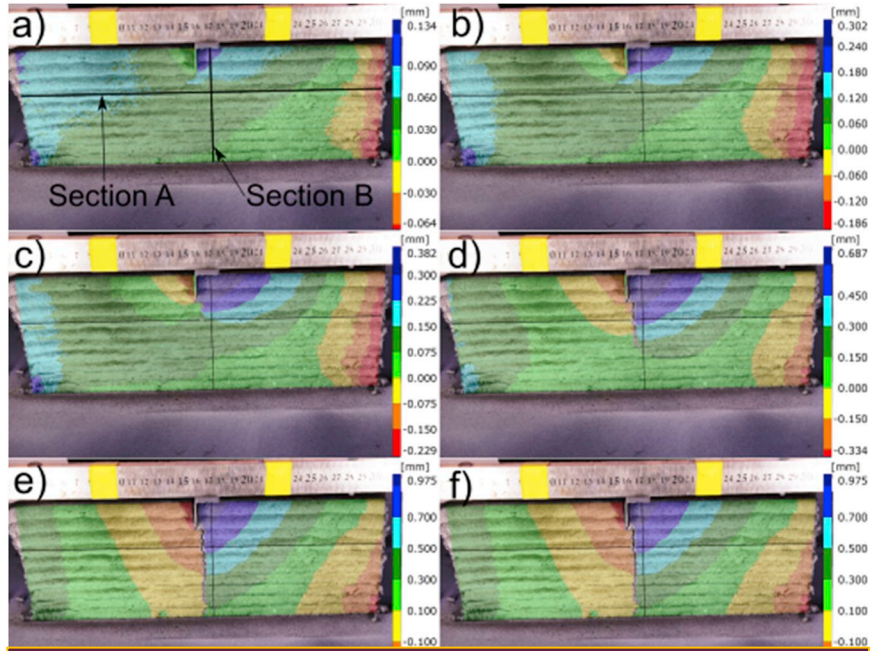
Research: Material Level



Microstructural Investigations using Computed Tomography

Interlayer Bond Strength Enhancement / Nozzles

Circularity



Plastic Shrinkage Cracking

Research: Structural Level

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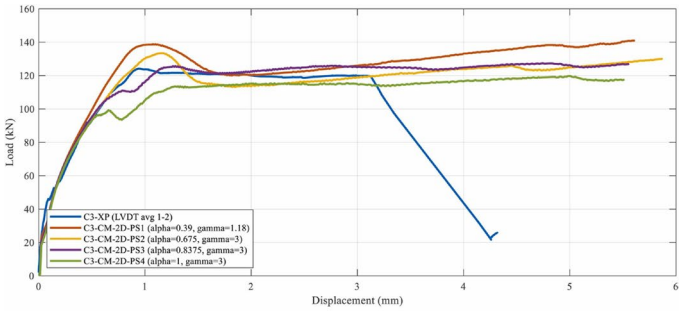
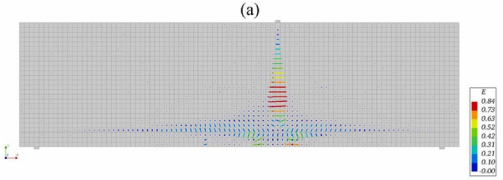
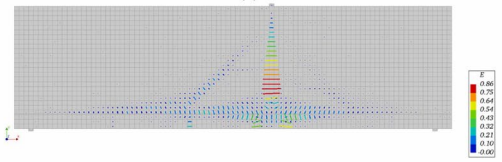
Discrete and Continuum FE Modelling



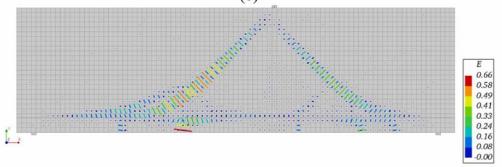
(a)



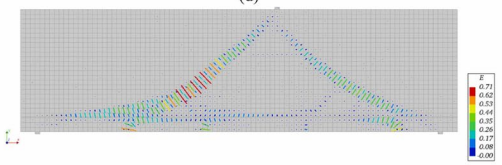
(b)



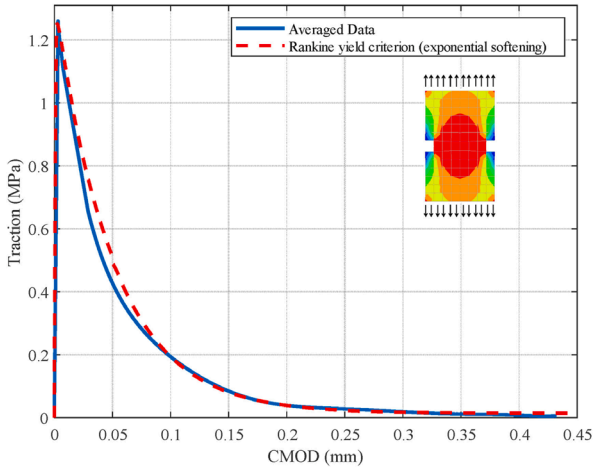
(c)

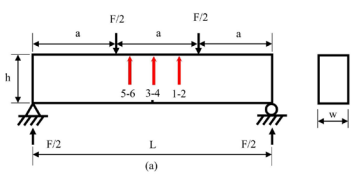


(d)

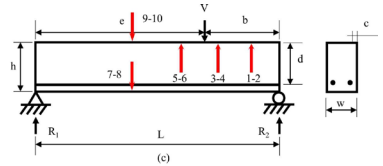


(e)





(a)



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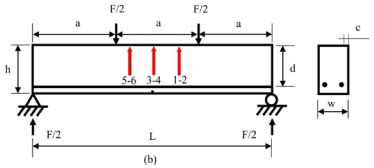

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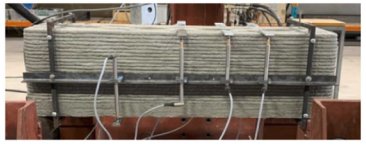
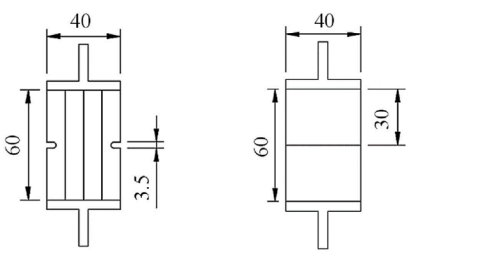
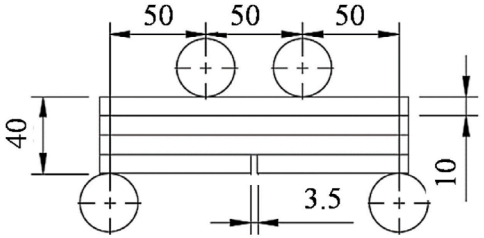


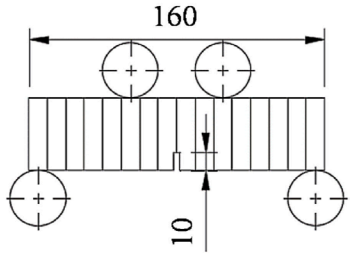
(d)

Hardened State Mechanical Tests / Anisotropy



(a) (b) (c) (d)





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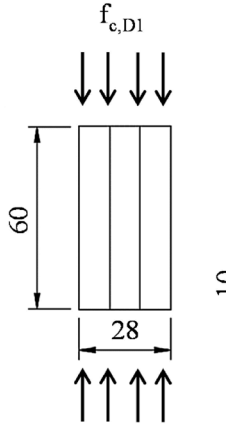
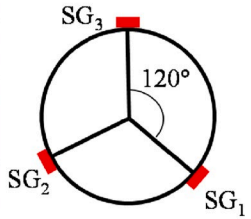
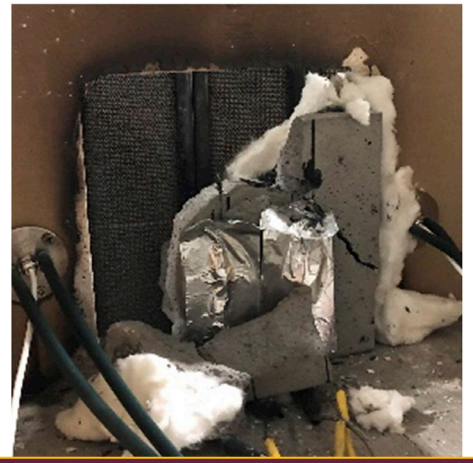


(a) (b)

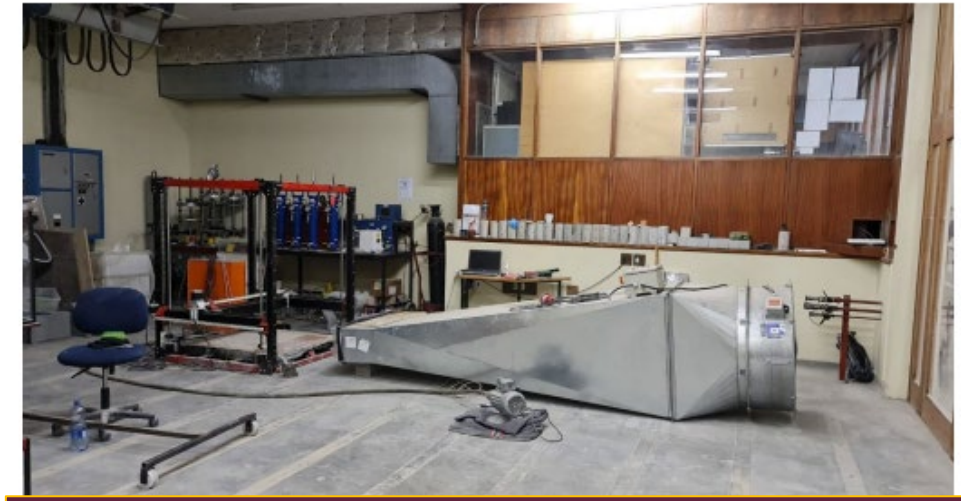


Large Scale Experimental Testing

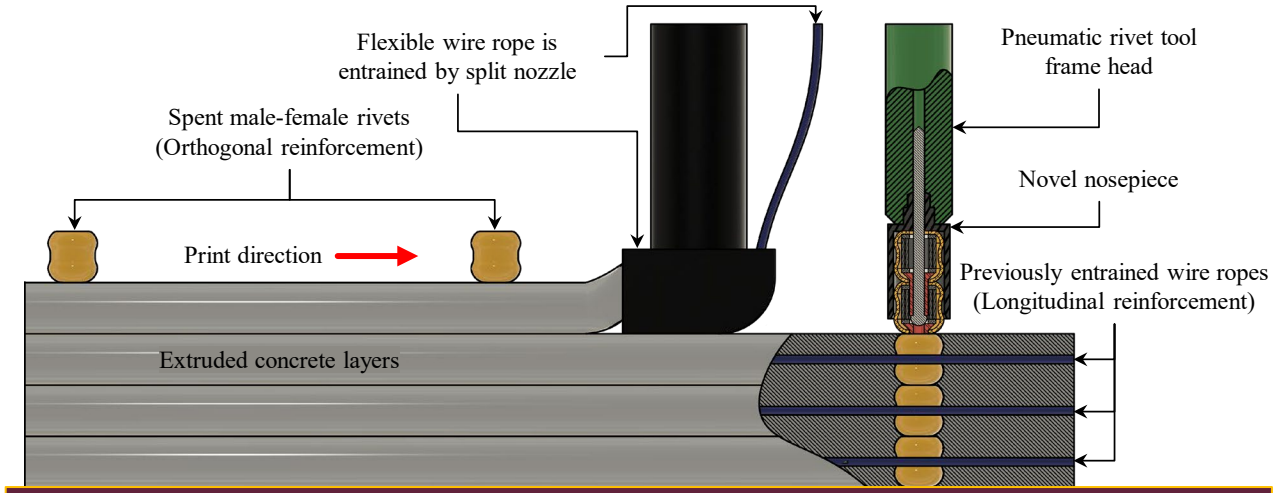
Research: Structural Level



Fire Performance Tests



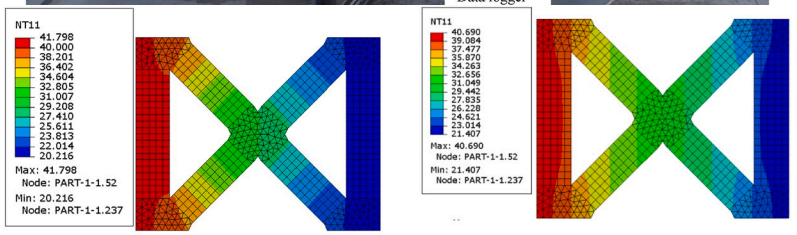
Environmental Effects / Curing



Novel Reinforcement Techniques

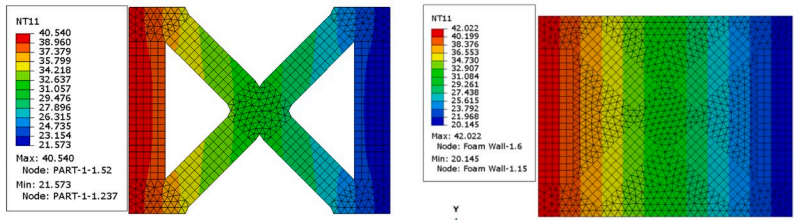
Durability Tests / Carbonation

Research: Building Level



(a) Case A

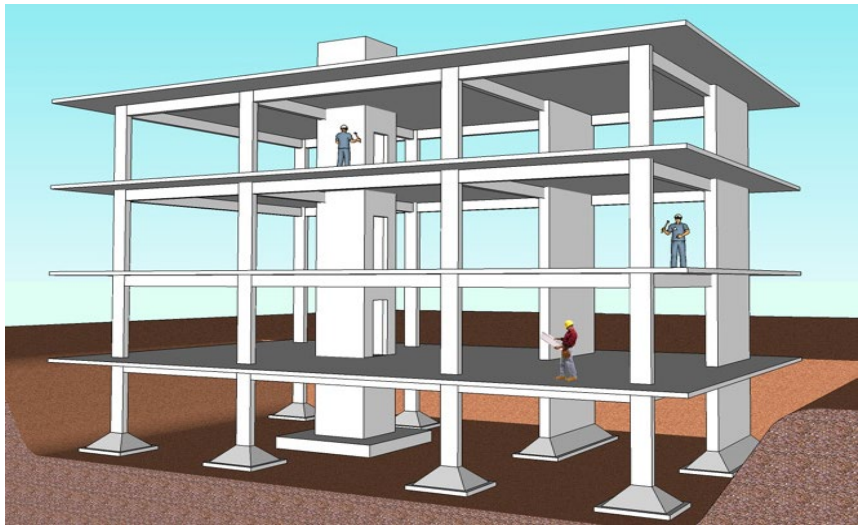
(b) Case B

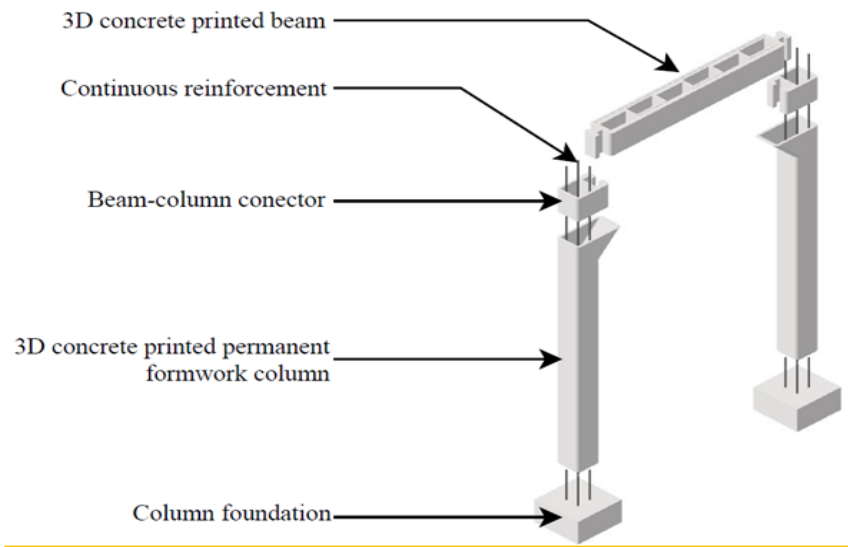


(c) Case C

(d) Case D

Thermal Conductivity / Insulation





Off-Site Construction / Prefabrication

Construction Model

Two Options

- Prefabrication / Off-Site
- On-Site (Walls & Roof)

Conventional Methods

1x  /Time Period

3DCP

3x  /Time Period

Higher Productivity = Lower Turnaround Time
Affordable = Keeping up with Population Growth (≠ Cost)

What's Next?

3D Print Full Scale House [±40-60 m^2] in 2025 by Partnering with Industry and Statutory/Regulatory Entities

Aim?

1. Demonstrate Technology Readiness Level (TRL) in RSA Context [6 to 9] (Show)
2. Facilitate Industry Adoption of 3DCP Technology (Grow)
3. Ensure Safe and Sustainable Implementation (Lead)

Our aim is to unlock the true potential of Additively Manufactured Concrete Technologies and transform the largely unindustrialized global construction sector into a smart, sustainable and lucrative industry.

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Thank you
Enkosi
Dankie

Photo by Stefan Els