# Digital Betong

– ett forskningsprojekt om 3D-printteknikens möjligheter att optimera användningen av betong i väggkonstruktioner

# PROJECT GROUP:

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# REFERENCE GROUP:

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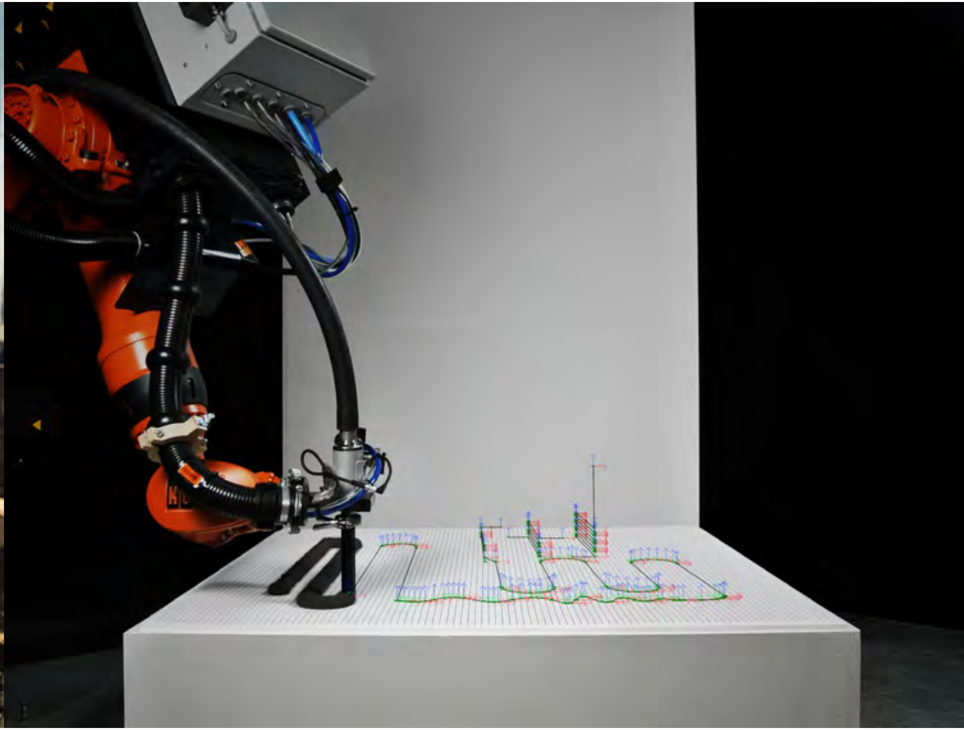
| Svensk Processteknik | Wolfram Oettel, FoU chef/ R&D manager, Svensk Processteknik AB |

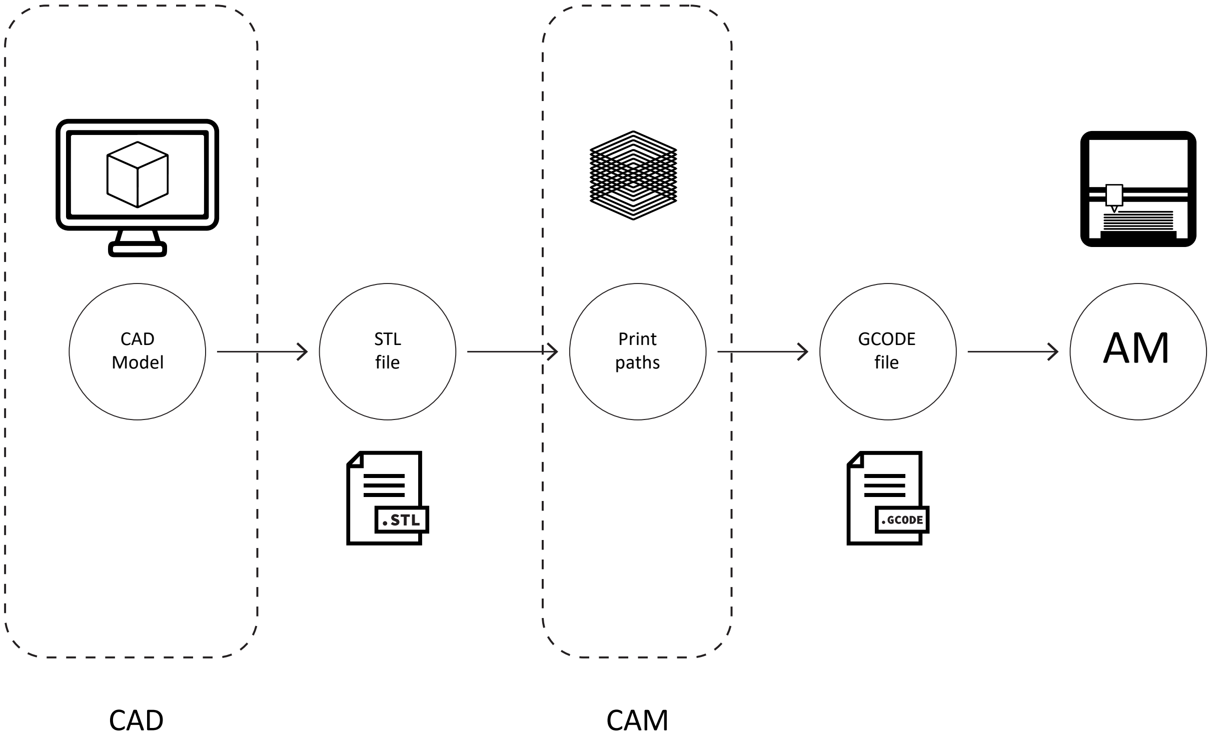
# 01/ Casting versus 3DCP


*Casting concrete*



*3D Concrete Printing [3DCP]*

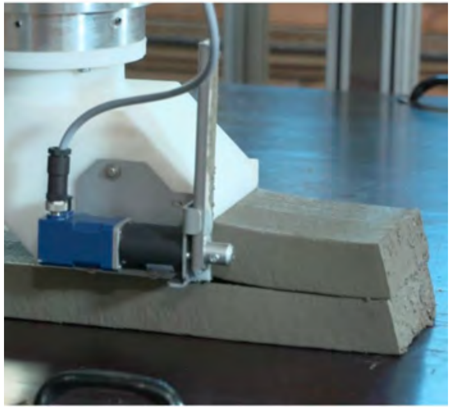
# 01/ Digital workflow (design to manufacturing)




*From 3D model to physical object: a standard 3D printing workflow*

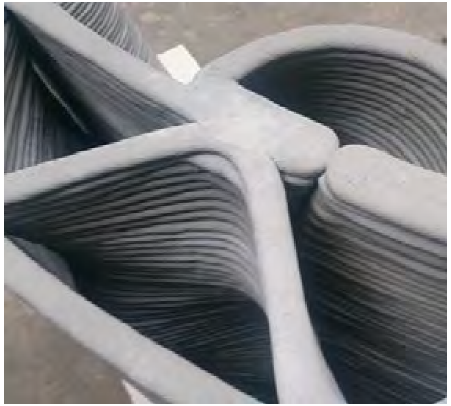
# 01/ Freedom of form

# 01/ Printing resolution



CONPRINT 3D
TU Dresden

150 x 50 mm

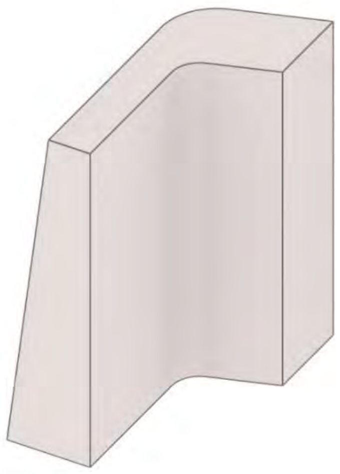


XtreeE
France

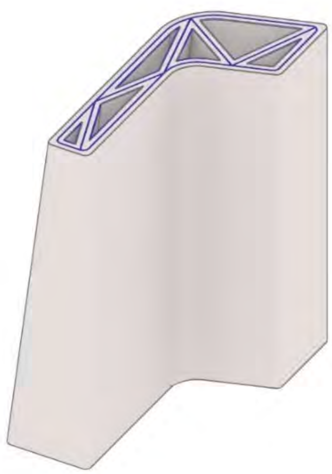
20 mm

Concrete Printing
Loughborough University

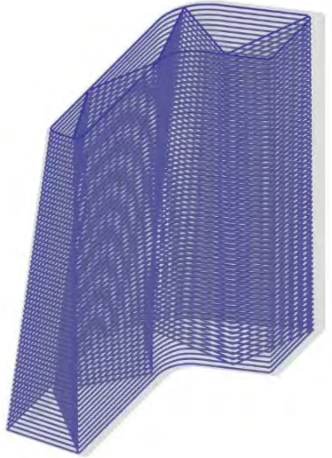
9 mm



Global design



Material distribution

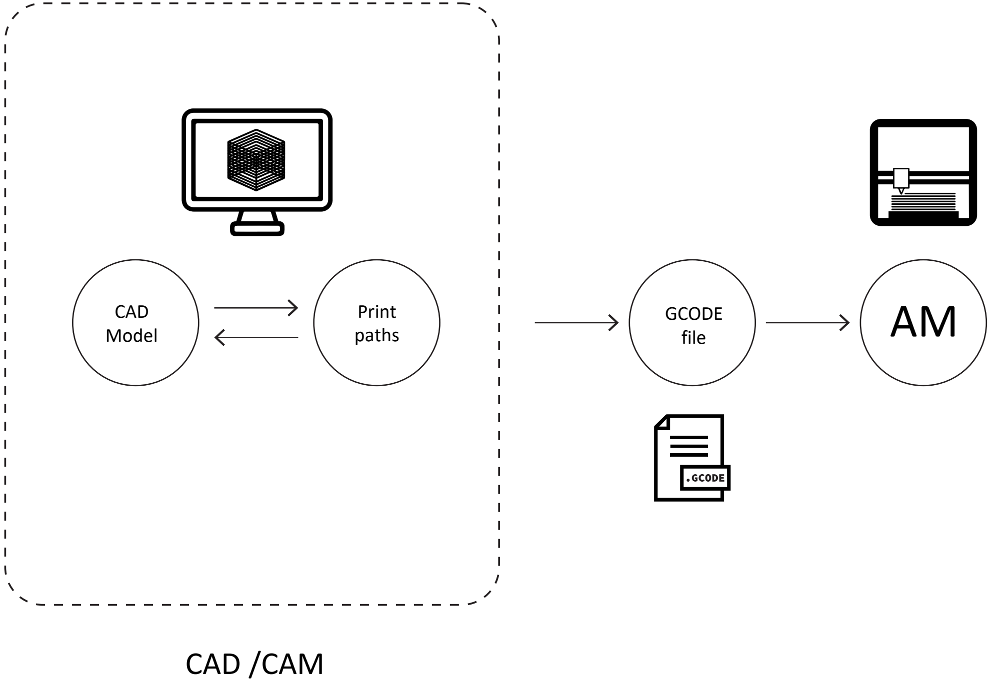


Printpath planning

# 01/ Printing resolution

*3DCP objects, various sources*

# 01/ New workflow




*From 3D model to physical object: our approach*

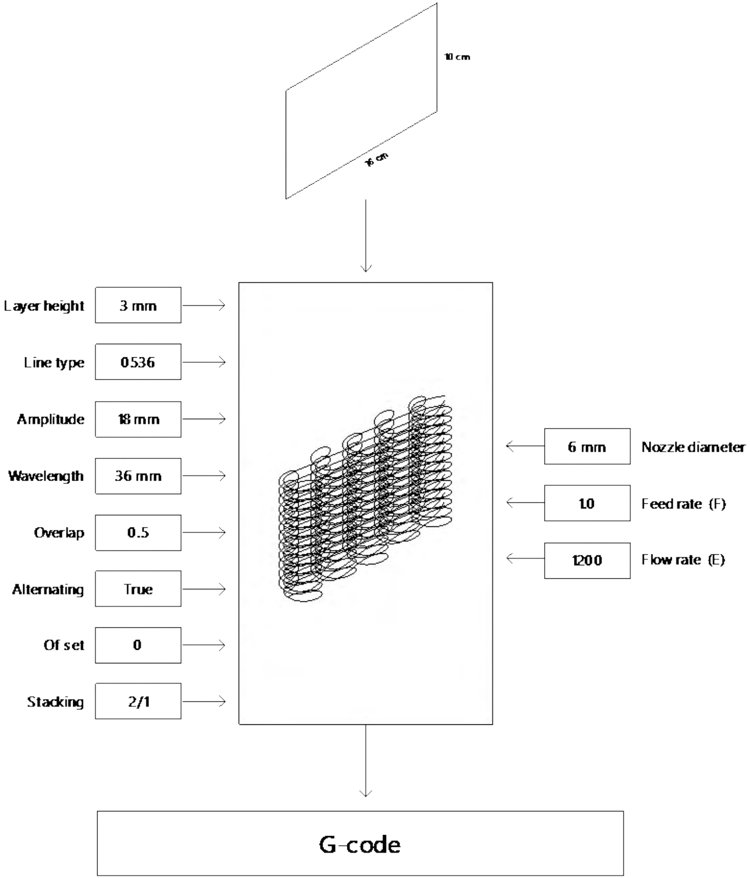
# 01/ Previous work

# 01/ Development of a design tool

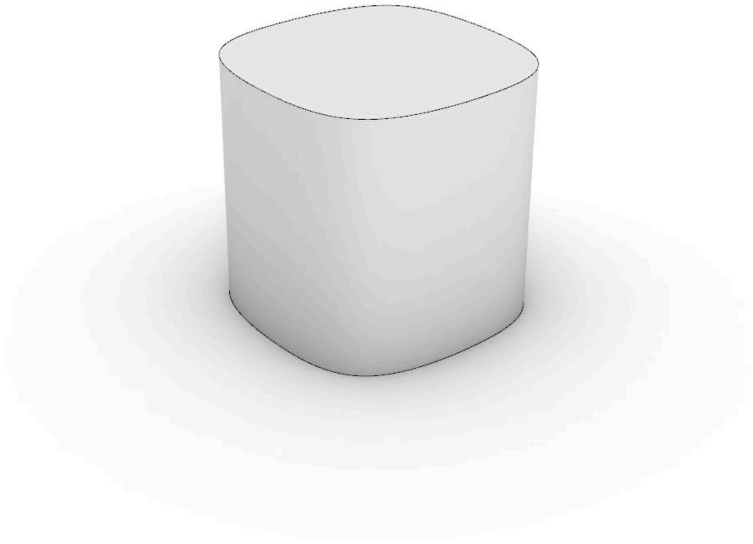








# 01/ Knitting concrete



## Knitting Concrete


Helena Westerlind(✉) and José Hernández

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**Abstract.** Due to concrete's traditional role as a casting material its appearance as a uniform solid mass is one of the material's most distinct traits. When poured in a mould fresh concrete adheres to the shape of the formwork and material distribution is not adaptable at a more detailed level. This paper explores how deposition-based additive manufacturing opens up new opportunities for controlling the distribution of concrete at a previously neglected intermediate scale - the meso-scale. By adopting principles of knitting to toolpath planning, the paper presents a computational method for varying the density, porosity, and surface articulation of the material, previously inconceivable due to the limitations of formwork.



**Keywords:** Additive manufacturing · 3D printing · Toolpath generation · Knitting · Material structures · Material scales


### 1 Introduction

In its traditional role as a cast material, the use of concrete in the built environment is fundamentally conditioned by the inverted relationship that exist between the material and formwork. Any work of cast concrete is essentially the positive imprint of a negative mould, and as the historian Peter Collins remarked, 'To design a concrete structure is to design the formwork' [1]. When poured in a mould, fresh concrete adopts the shape of its container, and at surface level, the impact of the mould remains visible in the imprint left by the surface character of the opposing formwork. As a result, concrete's appearance as a uniform solid mass is one of its most distinct traits.

The process of shaping concrete by deposition signifies a fundamental departure from existing formwork-based techniques. Instead of being shaped by the constraint and control imposed by a static mould, the material is deposited along a programmable path, performed by a numerically controlled machine. The former singular operation of the "pour" is replaced with a dynamic "choreographed flow", in which the role of the line shifts from representing the perimeter of form to constituting the path along which the material "performs".

Advantages of this emerging form of concrete manufacturing have so far been explored in the form of non-standard building components [2], the integration of services [3] and hollow wall typologies [4]. Yet, an overview of research in the field reveals a strong focus on technical feasibility with relatively few projects addressing added value in terms of design applications [5]. This project aims to contribute to counteracting this tendency by focusing on a relatively unexplored advantage of the


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Westerlind, Helena, and Jose Hernández Vargas. "Knitting Concrete." In Proceedings of DC 2020: Second RILEM International Conference on Concrete and Digital Fabrication, July 6-9, 2020, 988–97.

# 02/ Casting versus 3DCP

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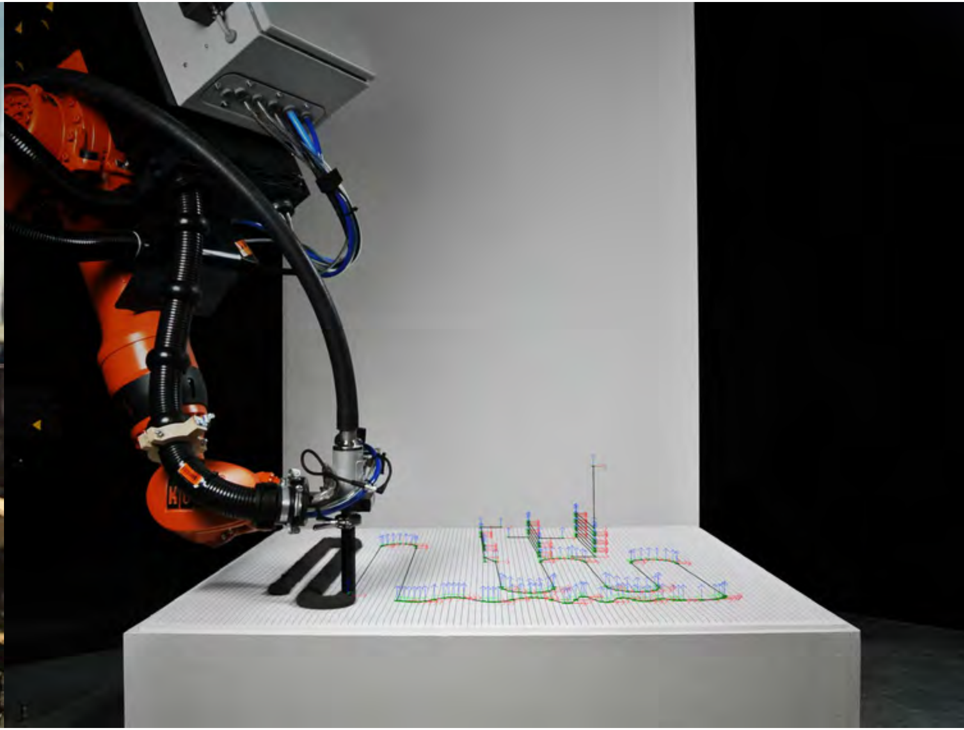
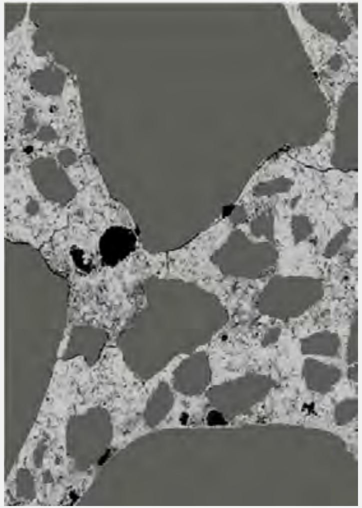


*3D Concrete Printing [3DCP]*

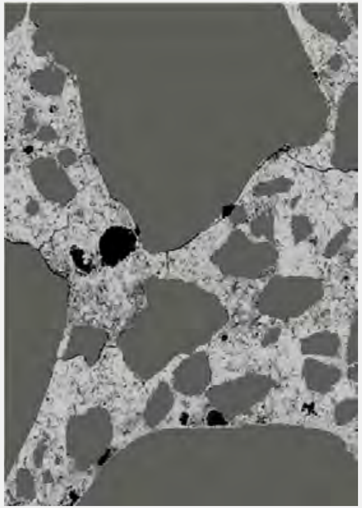
# 02/ Concrete scales



Micro scale
$\leq 10^{-2}$ m

Macro scale
$> 10^{0}$ m

# 02/ The meso scale

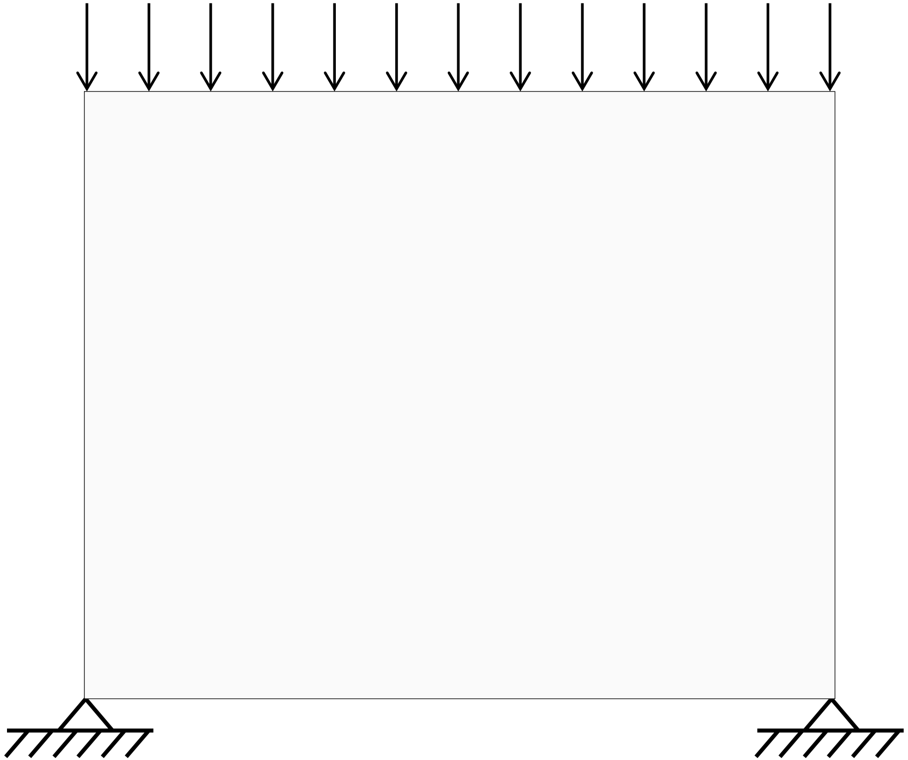


Micro scale
$\leq 10^{-2}$ m

Meso scale
$10^{-2} – 10^{0}$ m

Macro scale
$> 10^{0}$ m

# 02/ Research objectives



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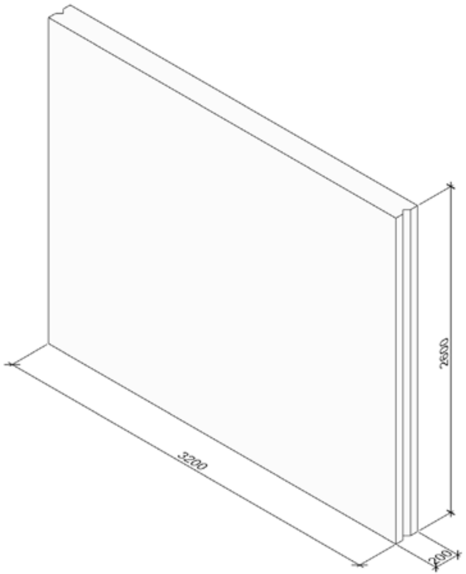


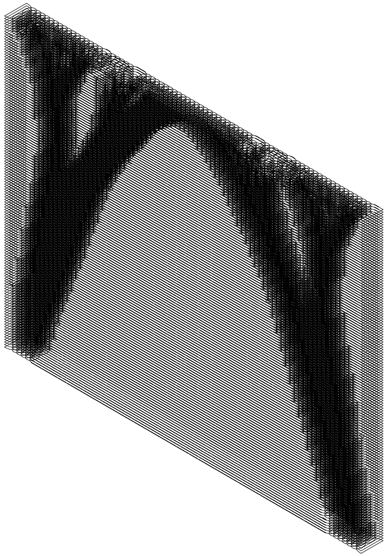

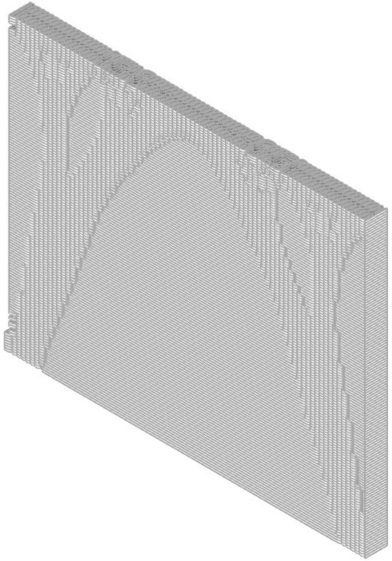

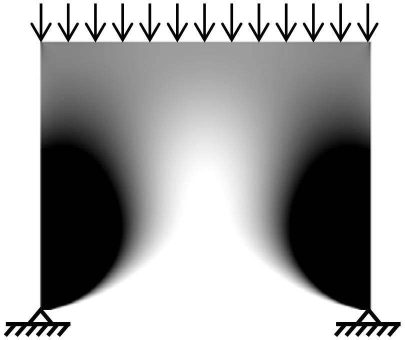

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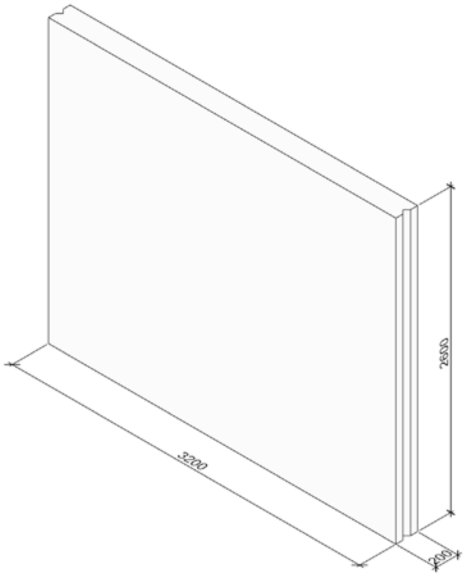
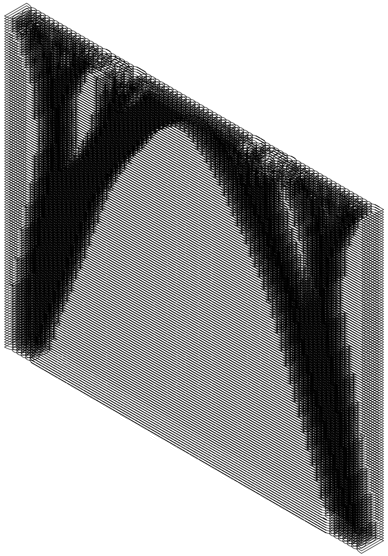
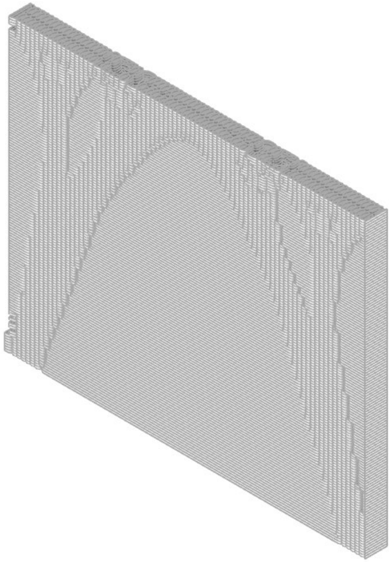
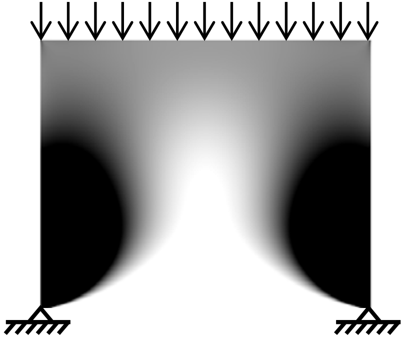


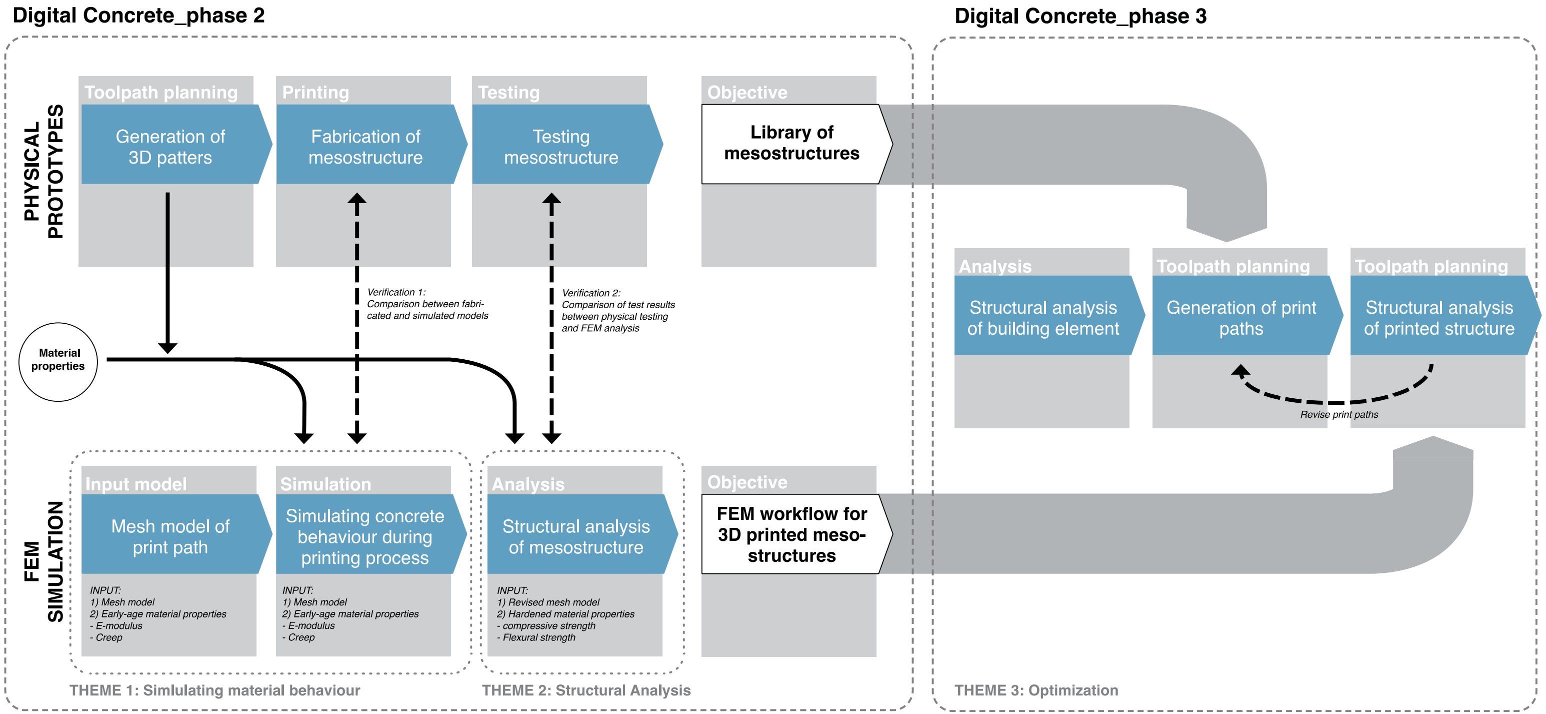




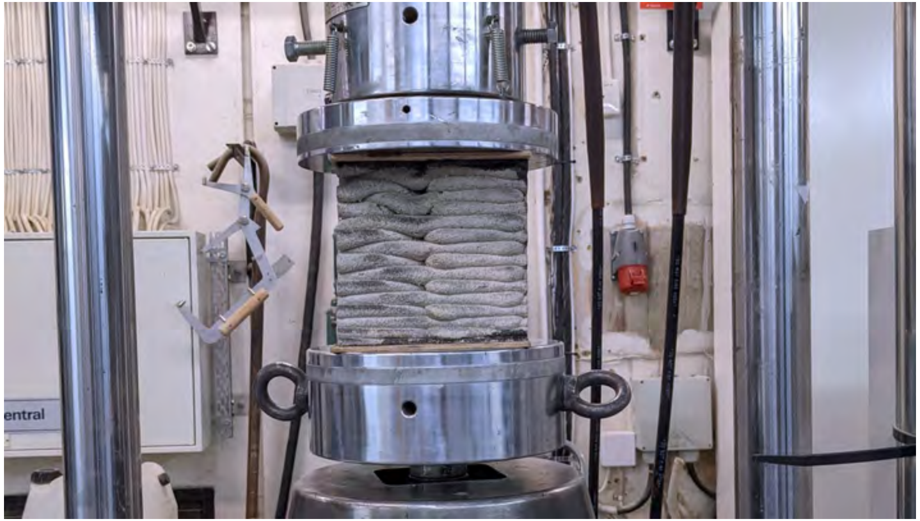
PROJECT GOAL:

*To develop new means to optimize the use of concrete in wall elements by locally adapting printpaths and material distribution at the meso scale according to local design criteria.*

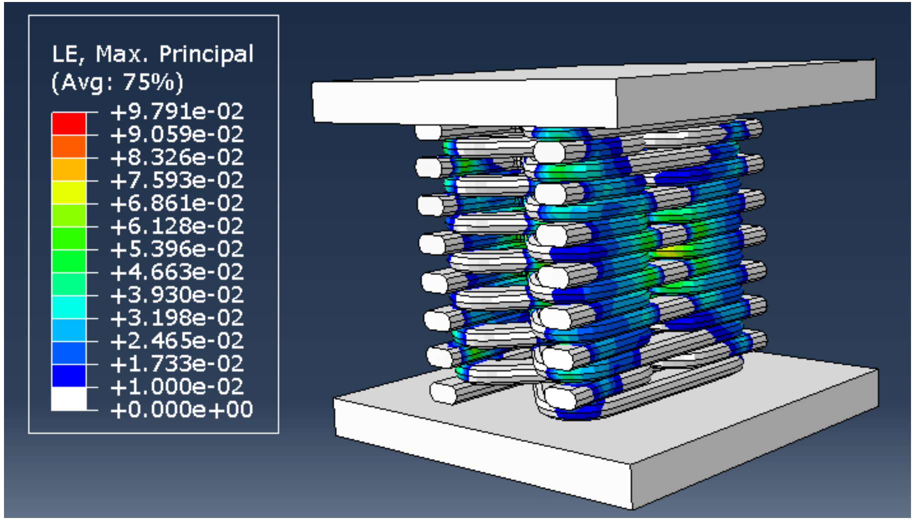
# 03/ Digital Concrete



# 03/ Evaluation of mesostructures

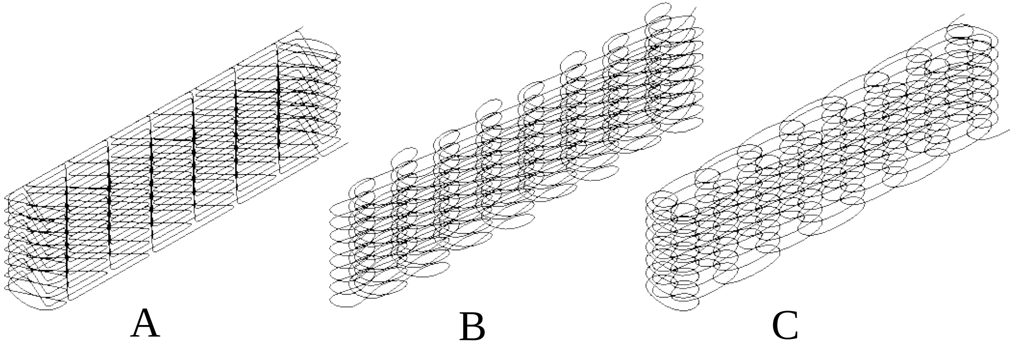



*Physical testing*



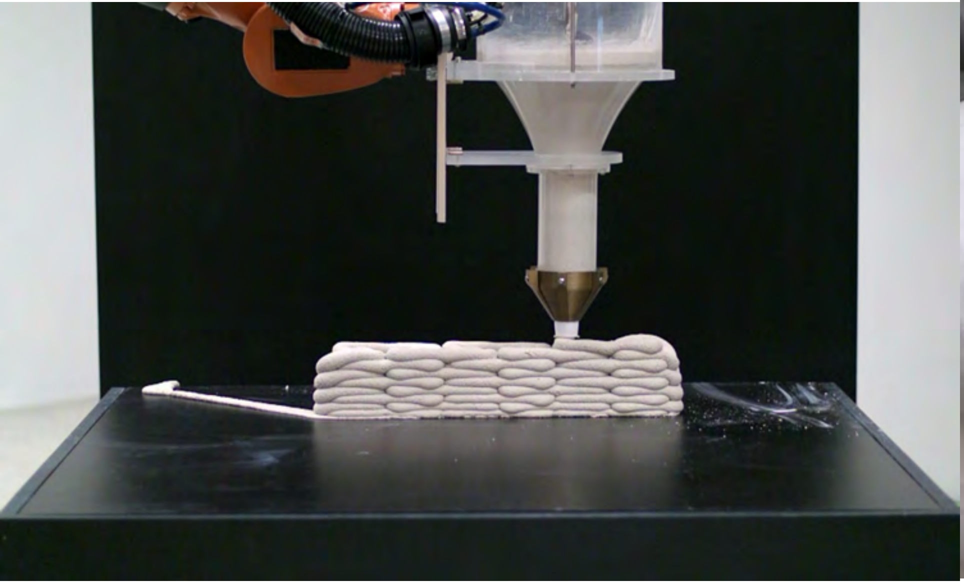

*Computer simulation (FEM)*

# 03/ Print pattern generation

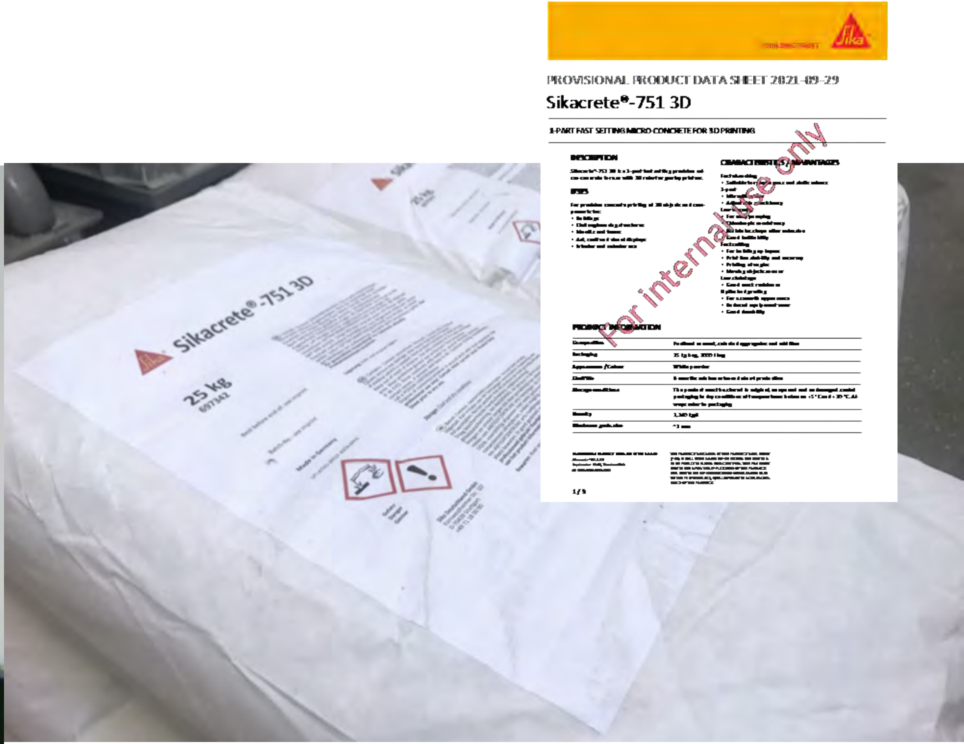



| Pattern | Stitch | Line type | Stacking | Layer height [mm] | Nr. of Layers | Amplitude [mm] | Wavelength [mm] | Total length of path [mm] |
|---|---|---|---|---|---|---|---|---|
| A | 8833 | | 1/1 | 10 | 15 | 40 | 150 | 2924 |
| B | 0536 | | 1/1 | 10 | 15 | 40 | 150 | 3010 |
| C | 8204 | | 1/1 | 10 | 15 | 40 | 150 | 2315 |

# 03/ Fabrication of prototypes

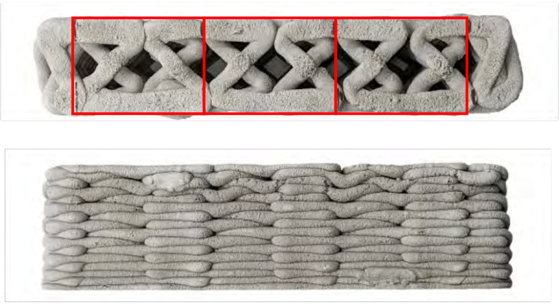


*Robotic setup at KTH School of Architecture*



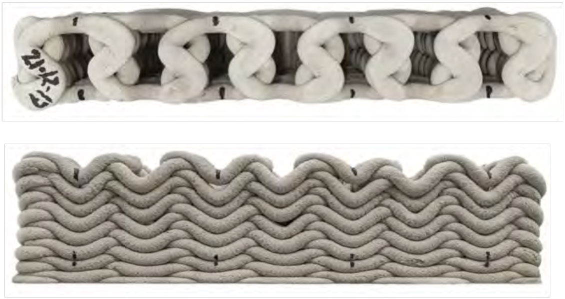

*Concrete mix = Sikacrete-751 3D + 15% water (53 MPa after 28 days)*

# 03/ Printed prototypes and extraction of test specimens

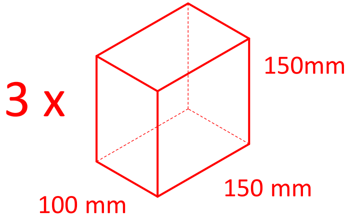


Pattern A

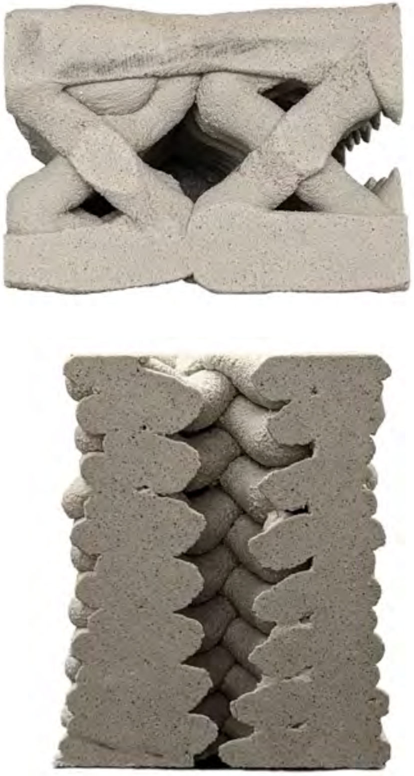
Pattern B



Pattern C



# 03/ Test specimen



Test specimen A.3

Test specimen B.3

Test specimen C.2

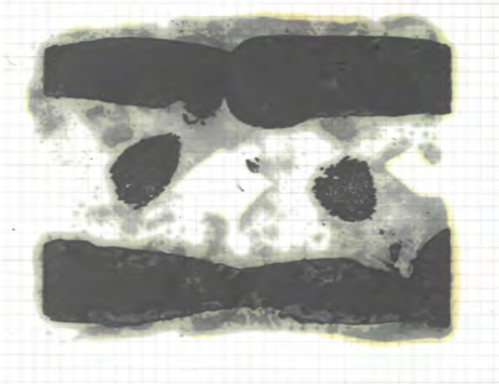
# 03/ Preparation of test specimen

STEP 1: Flattening of top and base surfaces


STEP 2: Length measurements

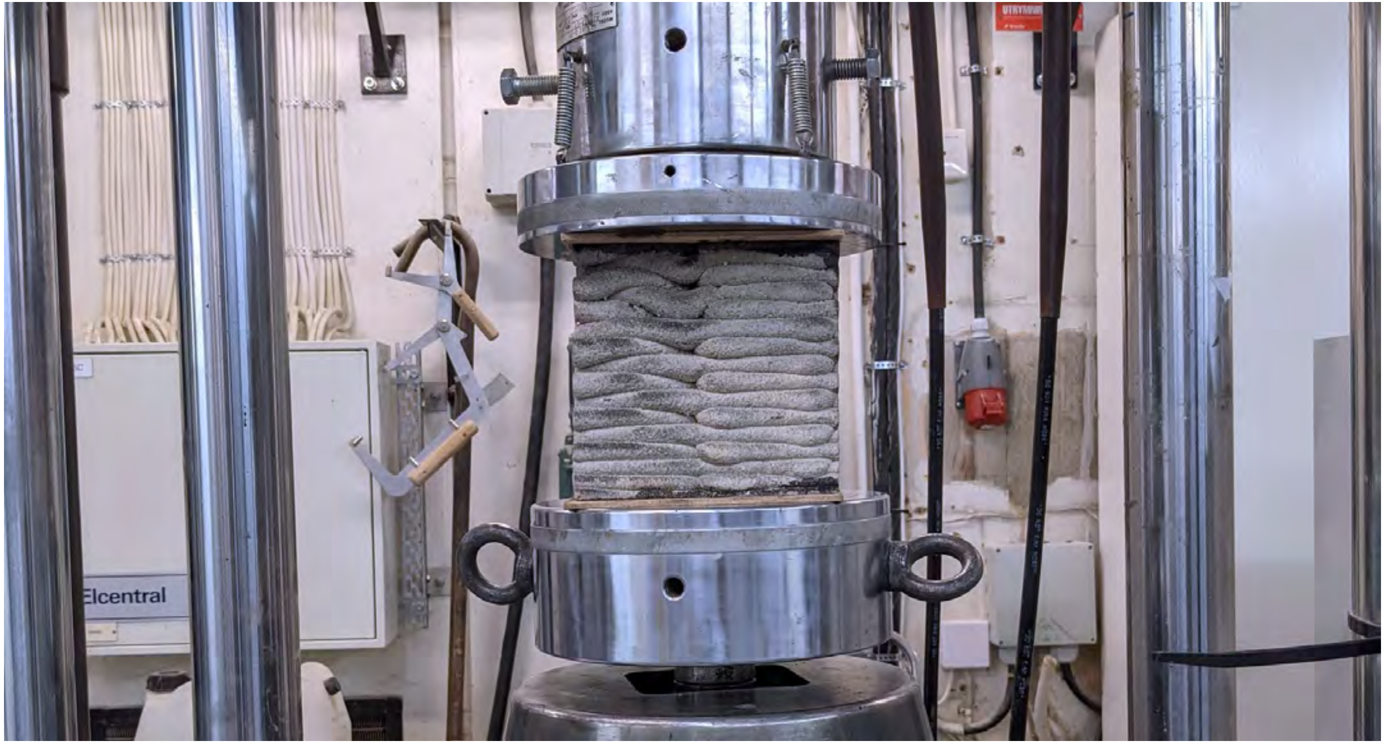

STEP 3: Mass measurement

STEP 4: Measuring volume of specimen



STEP 5: Calculating top and base surface areas

# 03/ Compression testing



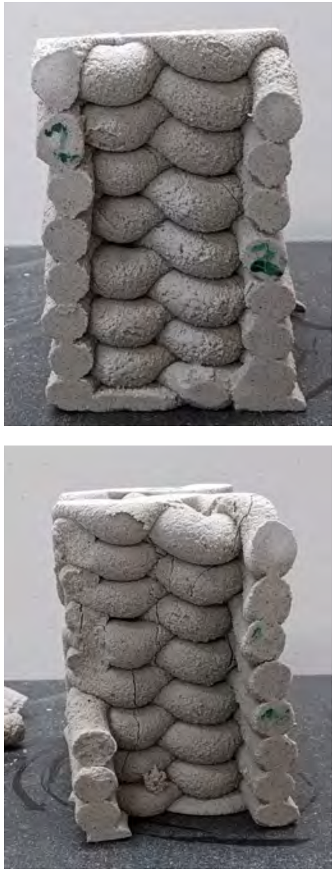

*Test specimen A.3*

- Compressive test after 28 days.
- The samples were loaded perpendicularly to the print direction under constant displacement control at 0,1 mm/s

# 03/ Cracking behaviour

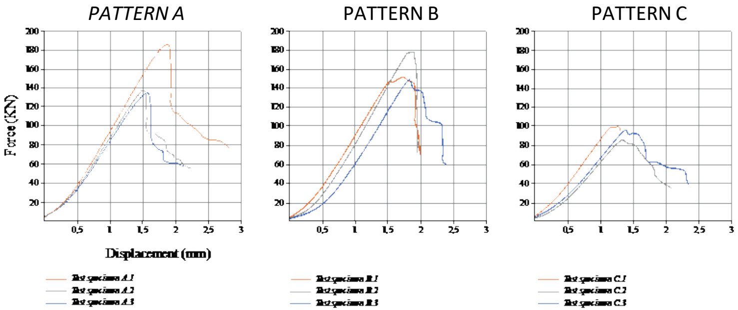
Test Specimen A.3

Test Specimen B.3

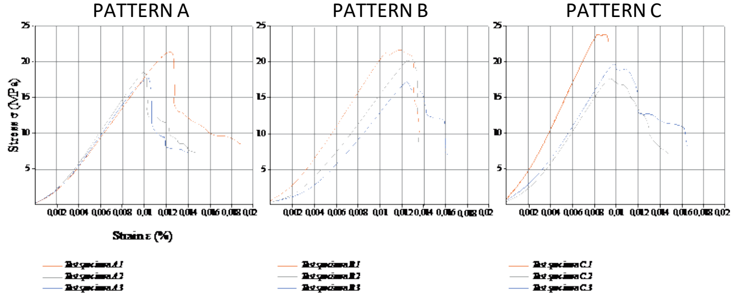


Test Specimen C.2

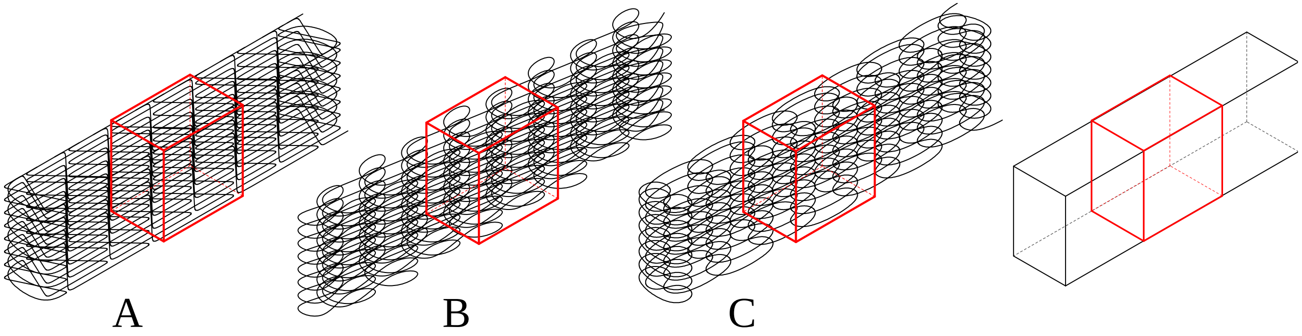
LOAD – DISPLACEMENT




STRESS – STRAIN CURVES



# 03/ Conclusions

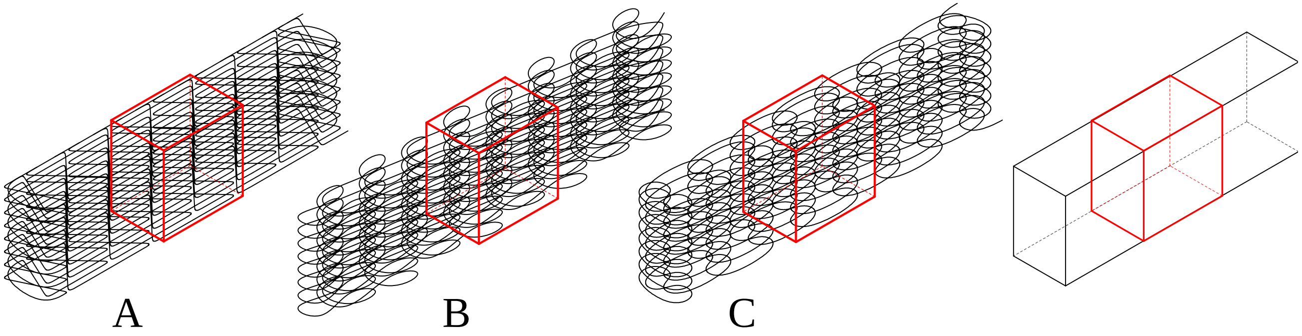



| | | Mesostructure A | Mesostructure B | Mesostructure C | Cast specimen *[reference]* |
|---|---|---|---|---|---|
| Mass | g | 3625,9 | 3442,5 | 2539,3 | 4815 |
| Volume | $cm^3$ | 1717,1 | 1607,6 | 1194,3 | 2250 |
| Length | mm | 150,4 | 150,4 | 150,2 | 150 |
| Width | mm | 105,1 | 104,9 | 96,1 | 100 |
| Height | mm | 144,7 | 145,3 | 140,3 | 150 |
| Area [top] | $mm^2$ | 7774 | 8146 | 4535 | 15000 |
| Area [bottom] | $mm^2$ | 16466 | 11092 | 11873 | 15000 |
| Max load | KN | 151,4 | 157,8 | 92,0 | 800,8 |
| Comp. strength | MPa | 19,4 | 19,5 | 20,6 | 53,39 |
| Bulk density | $kg/m^3$ | 1580 | 1500 | 1250 | 2140 |
| Strength/weight | MPa/kg | 5,34 | 6,67 | 8,11 | 11,1 |

*Table 2. Mean values of test results*

# 03/ Conclusions

- Density versus bulk density (unit weight of concrete over the printed volume)
- Bulk densities 1250-1580 kg/m$^3$
- Mesostructure C was the most efficient in filling a given volume with the lowest amount of material

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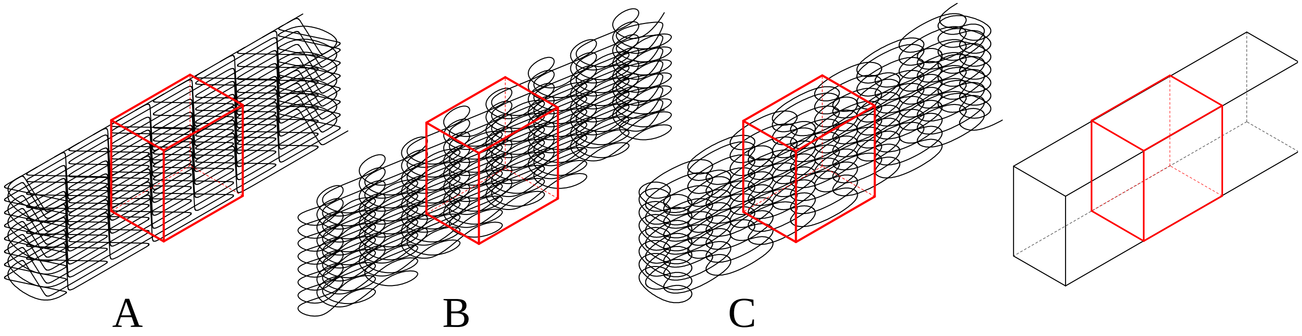
# 03/ Conclusions

- Mesostructure C was able to withstand a significantly lower load than pattern A and B
- But when also considering the given cross-sectional surface area it actually performed the best in terms of compressive strength
- Structural performance found to be less than half of conventional cast concrete

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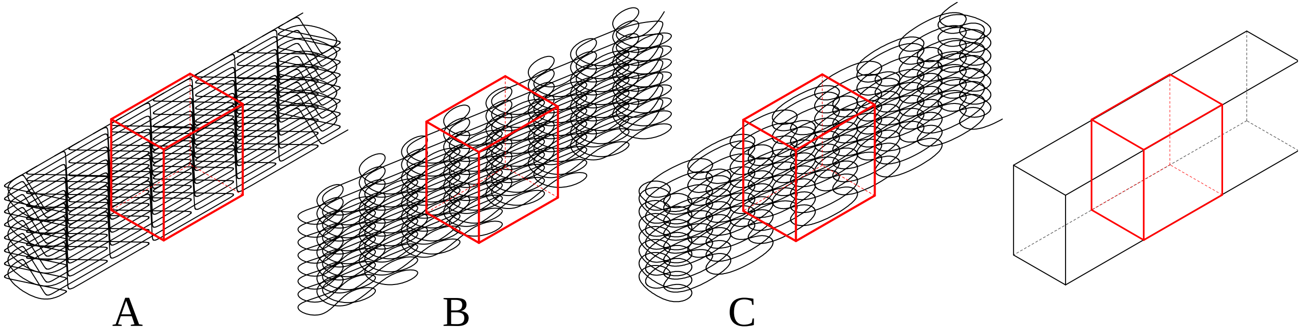
- But when also considering the given cross-sectional surface area it actually performed the best in terms of compressive strength
- Structural performance found to be less than half of conventional cast concrete
- When also taking account the lower bulk density of the pattern (strength/weight) the load bearing capacity of mesostructure C performed significantly better at 73% of the capacity of cast concrete

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# 03/ Main take aways

The placement of concrete through the programming of print paths represents a new way of controlling the bulk density and load bearing capacity of this traditionally massive material.

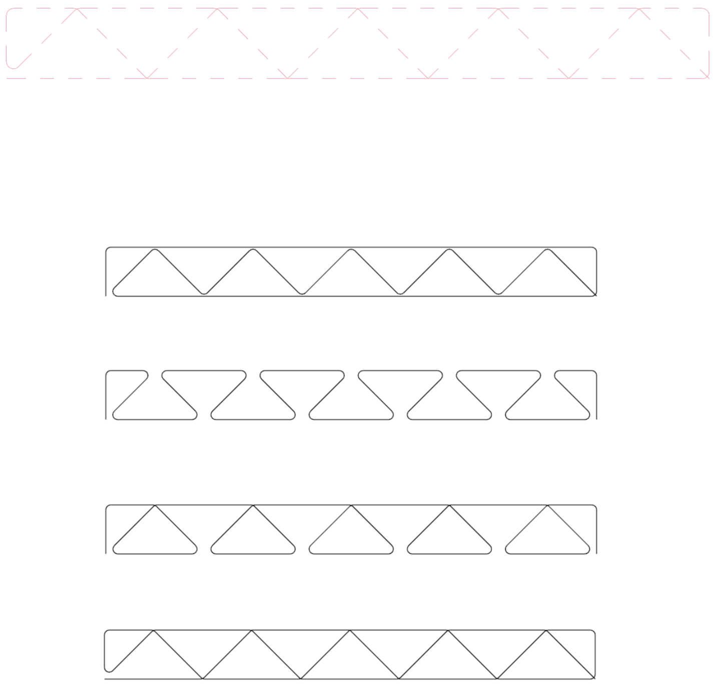
# 03/ Main take aways

The placement of concrete through the programming of print paths represents a new way of controlling the bulk density and load bearing capacity of this traditionally massive material.

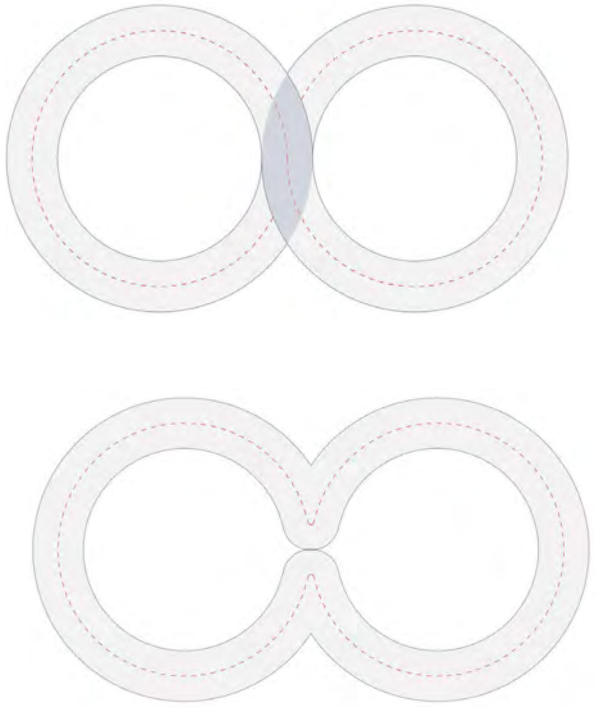
These findings form the basis of future research looking at:

- how to design print paths to achieve maximum structural performance

# 03/ Ongoing explorations

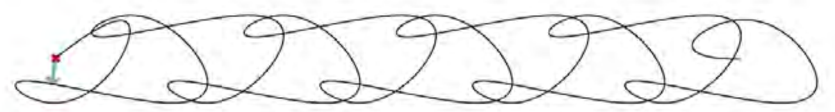


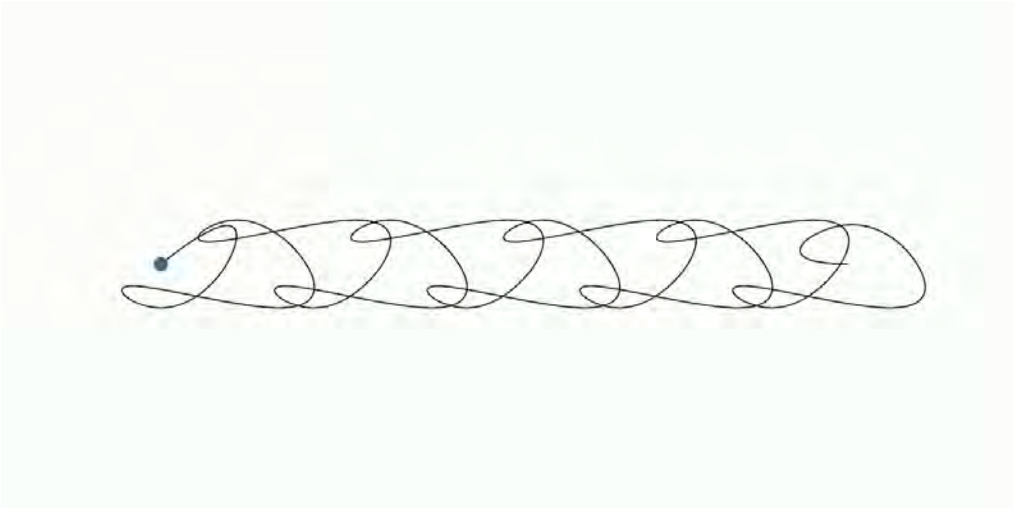
Print patterns and buildability in 3DCP

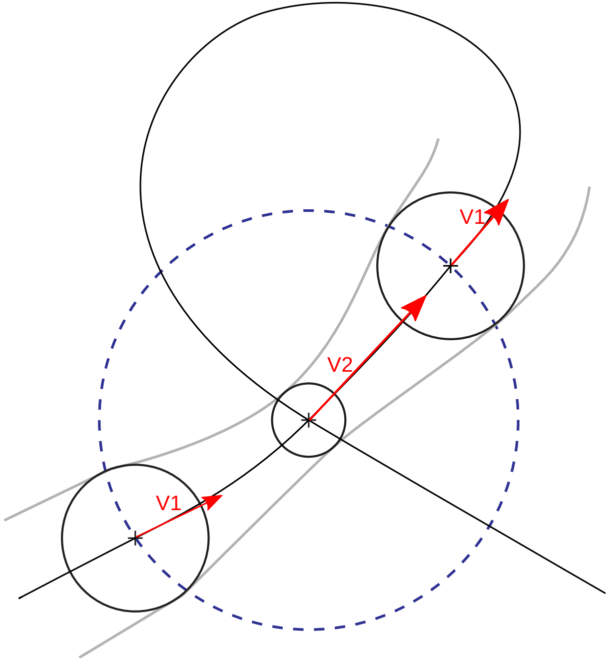


Crossing print path comparison

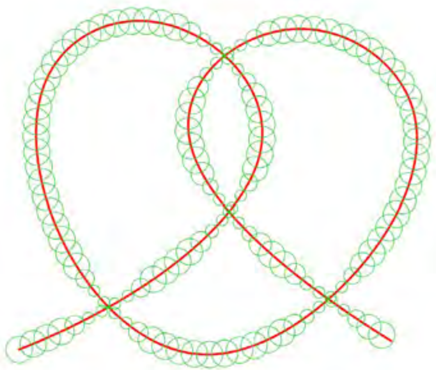
# 03/ Compensation method for intersecting print paths in 3DCP

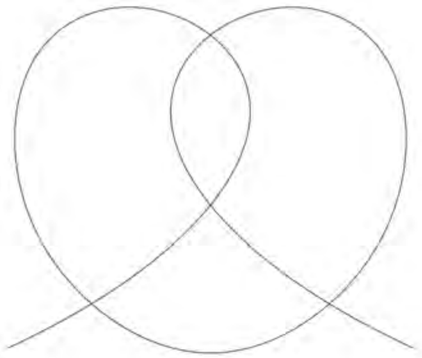






# 03/ Compensation method for intersecting print paths in 3DCP

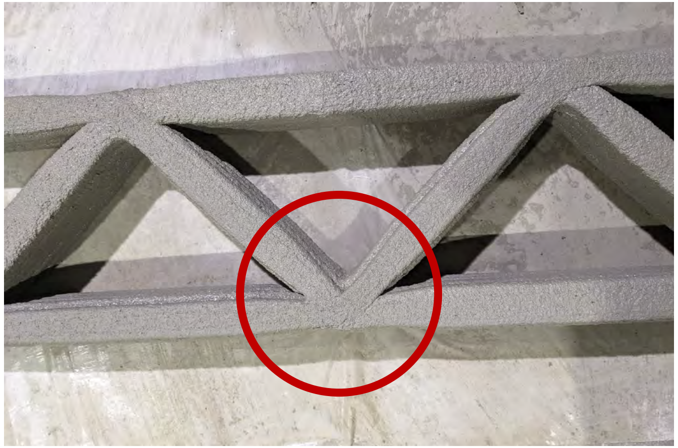


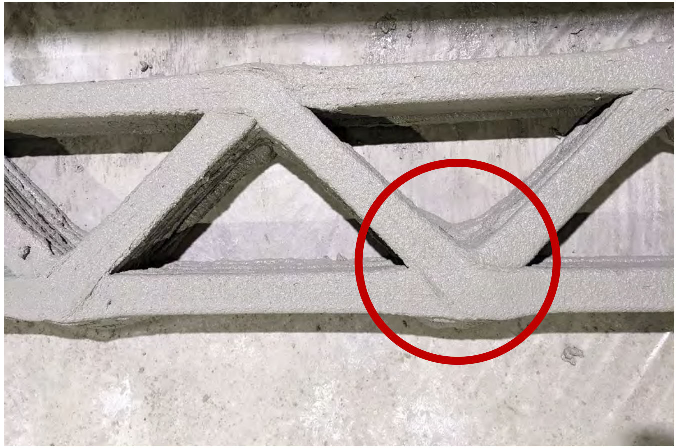


*Compensation*

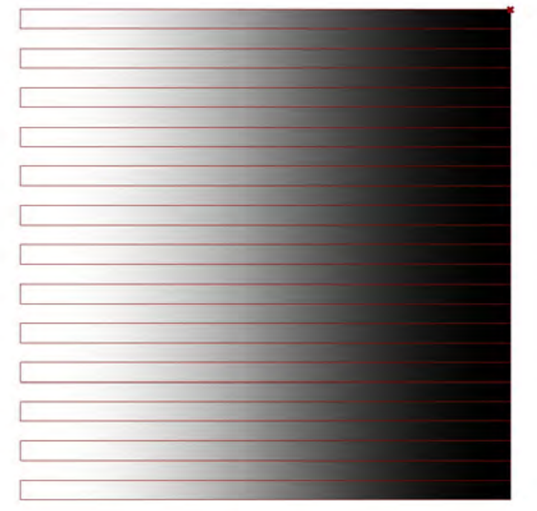
*No compensation*

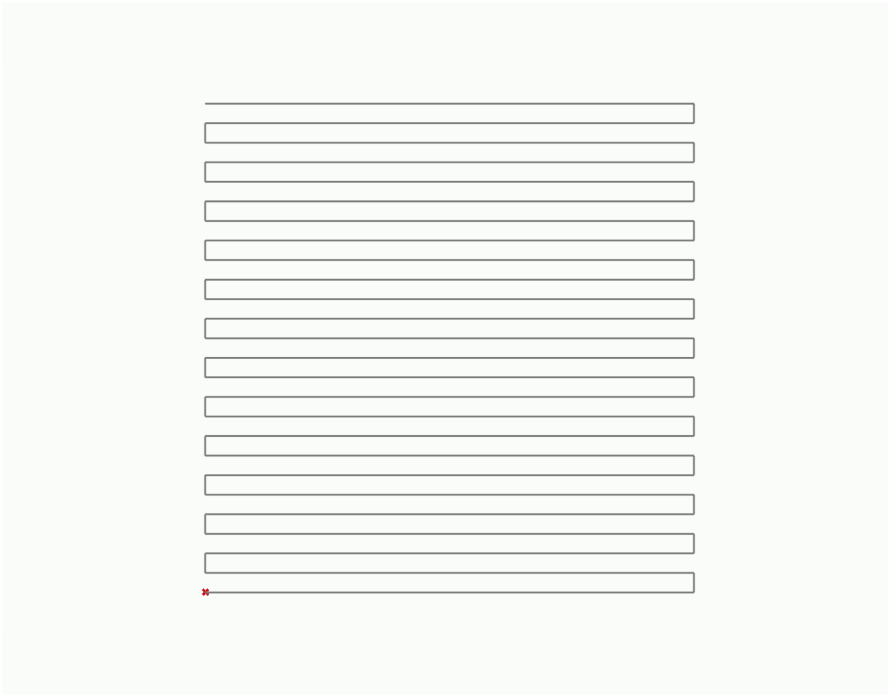
# 03/ Compensation method for intersecting print paths in 3DCP





# 03/ Variable flow method in 3DCP





# 02/ Main take aways

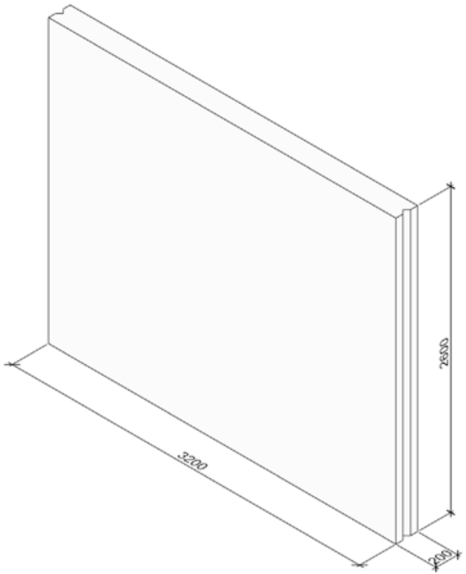
The placement of concrete through the programming of print paths represents a new way of controlling the bulk density and load bearing capacity of this traditionally massive material.

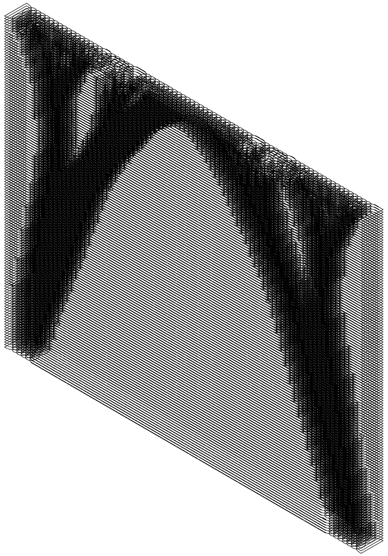
These findings form the basis of future research looking at:

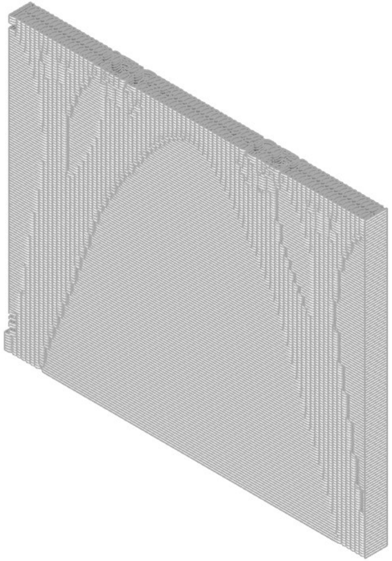
- how to design print paths to achieve maximum structural performance

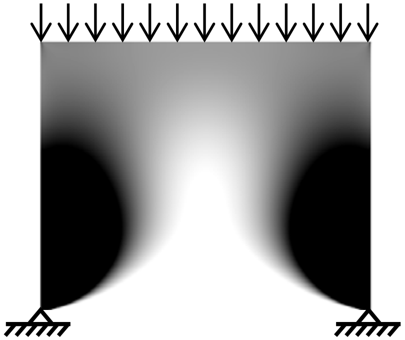
- how to vary printing patterns according to local load bearing criteria to optimize the amount of material used in 3D printed concrete structures

# 03/ Research objectives







Optimisation by:

- Geometry of print path
- Density of print paths
- Varying material flow of print path

01/ Background

02/ Aims and objectives

03/ Current research

04/ Discussion

# Thank you for listening!

This project has received support from Hesselmanska Foundation, the Development Fund of the Swedish Construction Industry (SBUF) and the strategic innovation program Smart Built Environment (2020-00257), which is part of the strategic innovation areas initiative funded by Vinnova – the Swedish Innovation Agency, Formas – a Swedish Research Council for Sustainable Development and the Swedish Energy Agency.