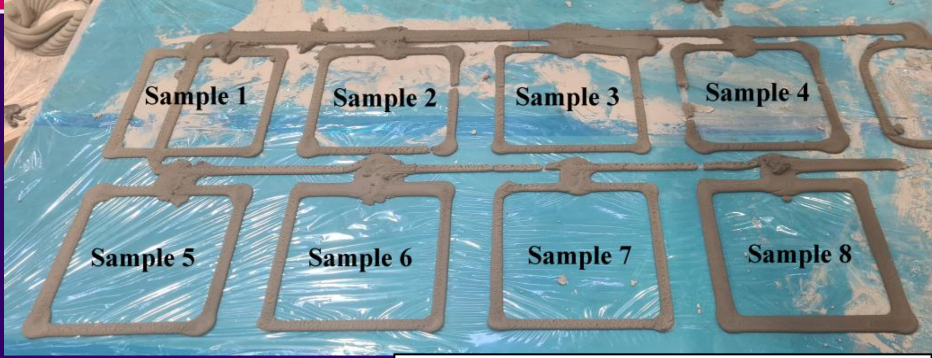

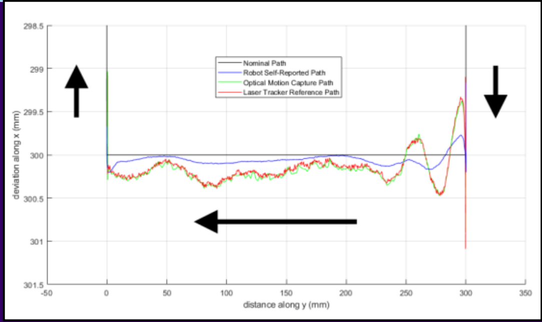

Measurement and control of serial manipulator robots for 3D Concrete Printing

3D Metrology Conference – 18-09-25

Connor Gill

Laura Justham, Niels Lohse, Adam Haynes (MTC), James Dobrzanski, Richard Buswell, Peter Kinnell

Loughborough University

3DMC 3D METROLOGY CONFERENCE

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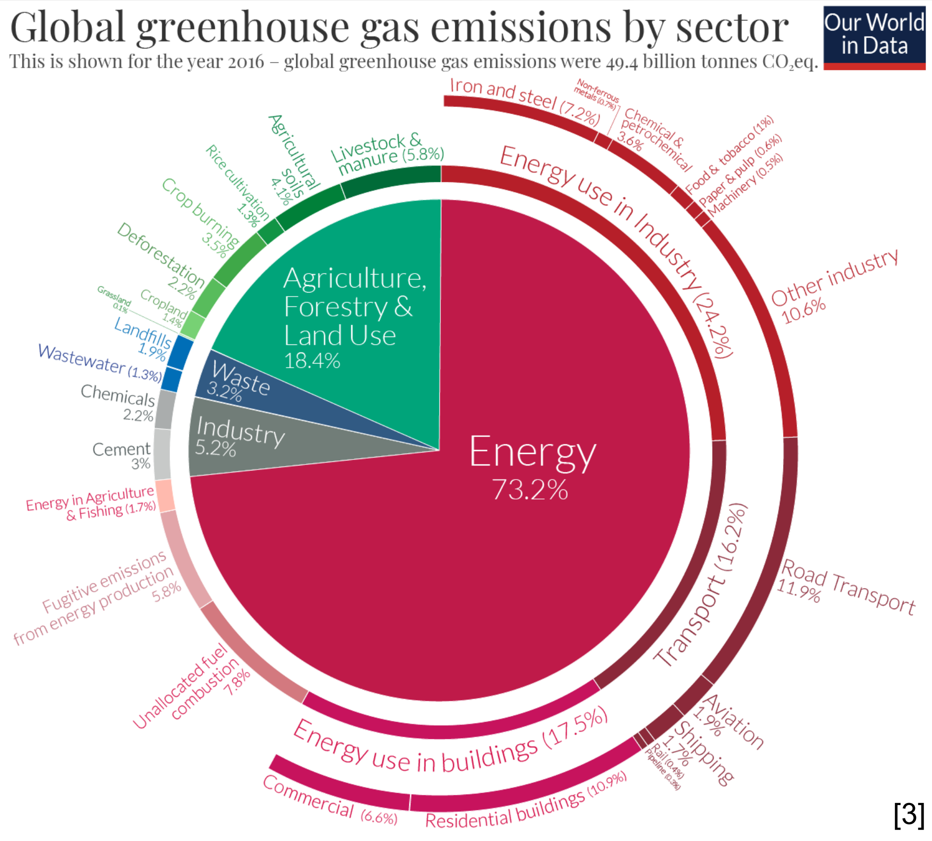
Intelligent Automation

Why 3D Concrete Printing?

- Cement productions accounts for around 8% of global CO2 emissions [1]
- Concrete is the second most used material in the world (behind water) [2]

[4]



[3]

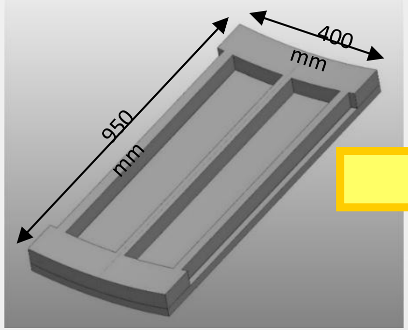
[1] Lehne J, Preston F. Making concrete change. Innovation in Low-carbon Cement and Concrete. 2018.
[2] Hendrik Van Oss G. Mineral Commodity Summaries. Prepared for the US Geological Survey. 2007.
[3] Hannah Ritchie, Max Roser and Pablo Rosado (2020) - "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-greenhouse-gas-emissions' [Online Resource].
[4] https://www.archdaily.com/979145/3d-printing-with-low-carbon-concrete-reducing-co2-emissions-and-material-waste

Why 3D Concrete Printing?

[1]

[1] https://www.construx.eu/en/precast-moulds/stair-moulds/

3D Concrete Printing Process



"Hybrid" process

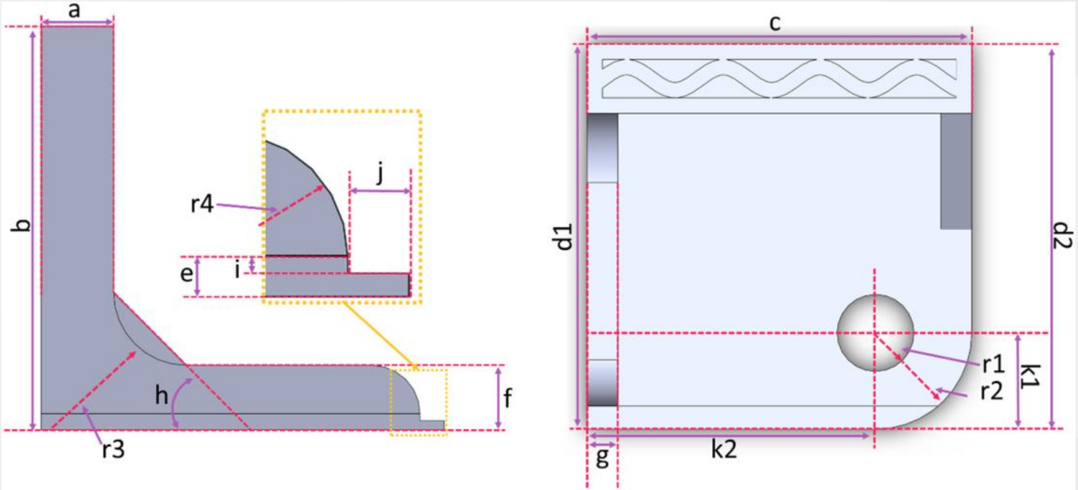
CAD

Print

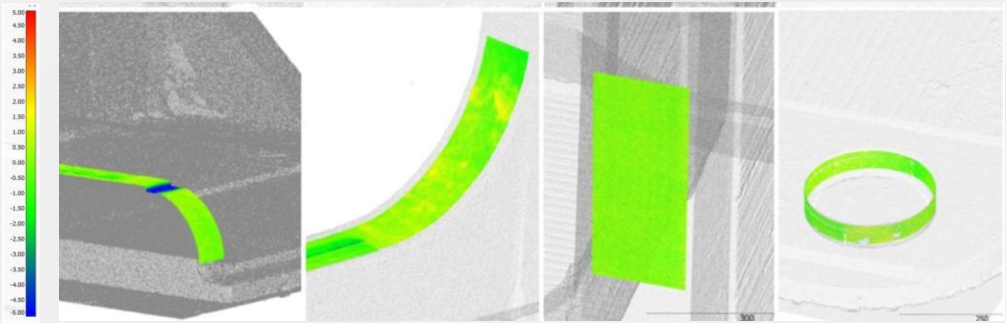
Post-Process

Final Part

Standardised test part



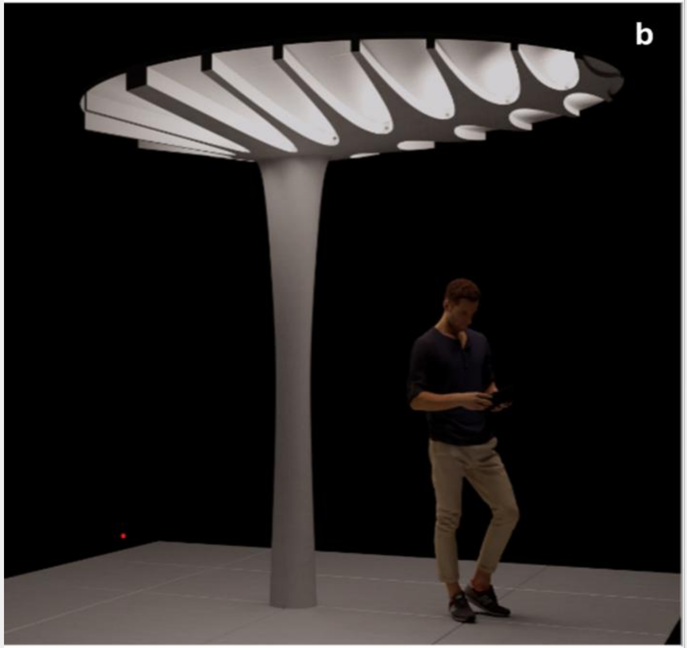
[1] Buswell R, Xu J, De Becker D, Dobrzanski J, Provis J, Kolawole JT, Kinnell P. Geometric quality assurance for 3D concrete printing and hybrid construction manufacturing using a standardised test part for benchmarking capability. Cement and Concrete Research. 2022 Jun 1;156:106773.



	Description	Target (mm)	H-3DCP Stdev. surface (mm)	3DCP Error mean (mm)	3DCP Error max (mm)	H-3DCP Stdev. surface (mm)	H-3DCP Error mean (mm)	H-3DCP Error max (mm)
A	Wall thickness	180	1.06	3	9	0.16	3	4
B	Wall height	1000	0.35	3	8	0.23	1	10
C	Wall length	1000	2.65	6	22	0.21	-4	-2
D1	Panel length	1000	1.06	1	14	0.3	9	11
D2	Panel length	1000	1.25	10	12	0.41	9	11
E	Panel thickness	40	0.35	1	6	0.23	-2	-1
F	Rib height	160	0.35	0	2	0.23	1	1
G	Rib width	80	0.84	2	8	0.2	0	1
I	Rebate depth	17	0.58	5	4	0.23	-3	-3
J	Rebate width	60	0.87	-3	-3	0.36	0	0
K1	Hole position	250	1.76	-3	2	0.3	-3	-2
K2	Hole position	250	0.87	3	5	0.36	1	2
M	Hole diameter	200	3.23	-40	-30	0.48	1	2

[1] Buswell R, Xu J, De Becker D, Dobrzanski J, Provis J, Kolawole JT, Kinnell P. Geometric quality assurance for 3D concrete printing and hybrid construction manufacturing using a standardised test part for benchmarking capability. Cement and Concrete Research. 2022 Jun 1;156:106773.

The Canopy



[1] Dobrzanski J, Xu J, Bartek R, De Becker D, Kinnell P, Kolawole J, Konstantatou M, Maddock R, Isa MN, Sehlstedt V, Buswell R. From digital crafting to digital manufacturing: automated production using hybrid 3D concrete printing. Journal of Building Engineering. 2025 Apr 19:112640.

The Canopy - Process





The Canopy - Process

Common Failure Modes

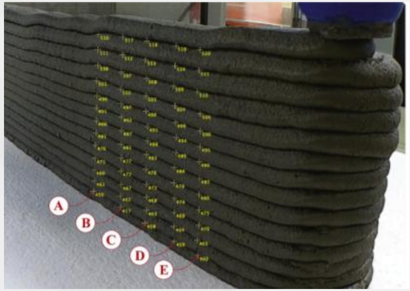
Voiding (underfilling)

[1]

Tearing

[2]

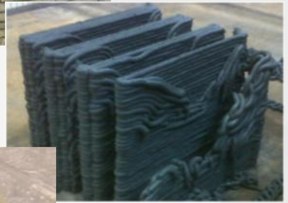
Layer Inconsistency



[1]

And more…

[3]

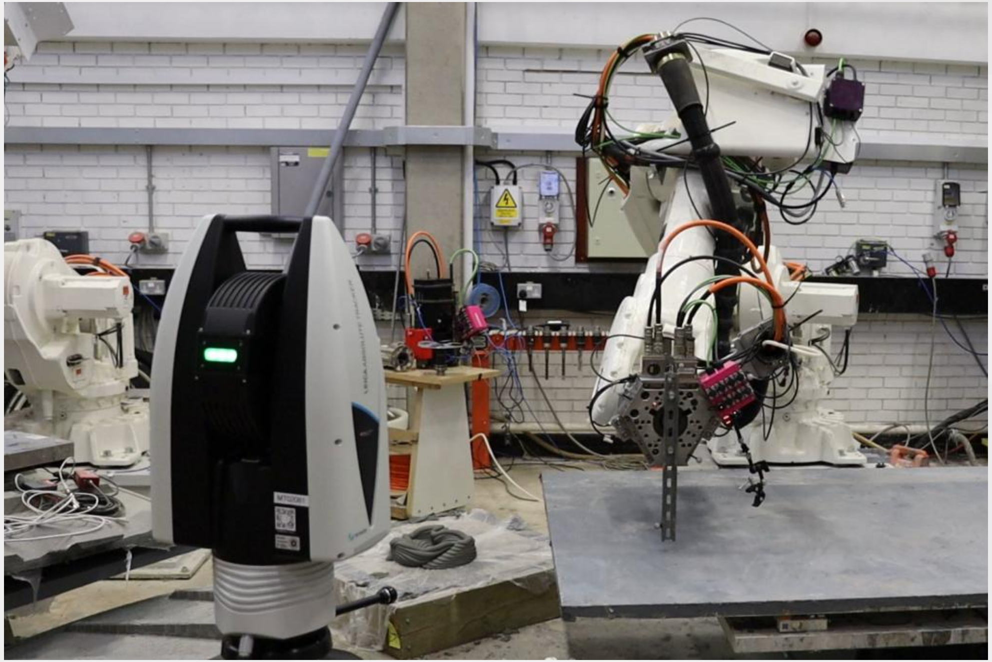


[1]

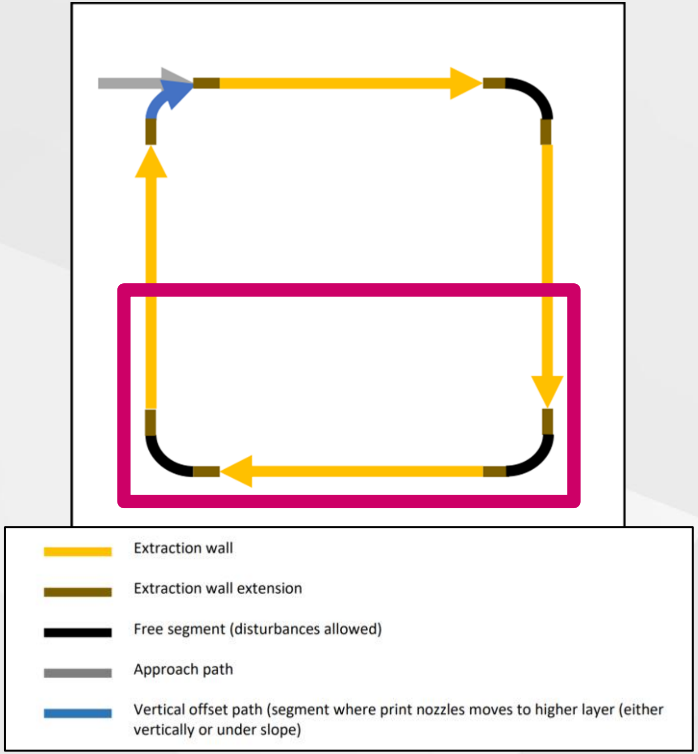
[4]

[1] Buswell RA, De Silva WL, Jones SZ, Dirrenberger J. 3D printing using concrete extrusion: A roadmap for research. Cement and Concrete Research. 2018 Oct 1;112:37-49
[2] Senthilnathan S, Raphael B. Using Computer Vision for Monitoring the Quality of 3D-Printed Concrete Structures. Sustainability. 2022 Nov 25;14(23):15682.
[3] De Schutter G, Lesage K, Mechtcherine V, Nerella VN, Habert G, Agusti-Juan I. Vision of 3D printing with concrete—Technical, economic and environmental potentials. Cement and Concrete Research. 2018 Oct 1;112:25-36.
[4] Suiker AS, Wolfs RJ, Lucas SM, Salet TA. Elastic buckling and plastic collapse during 3D concrete printing. Cement and Concrete Research. 2020 Sep 1;135:106016.

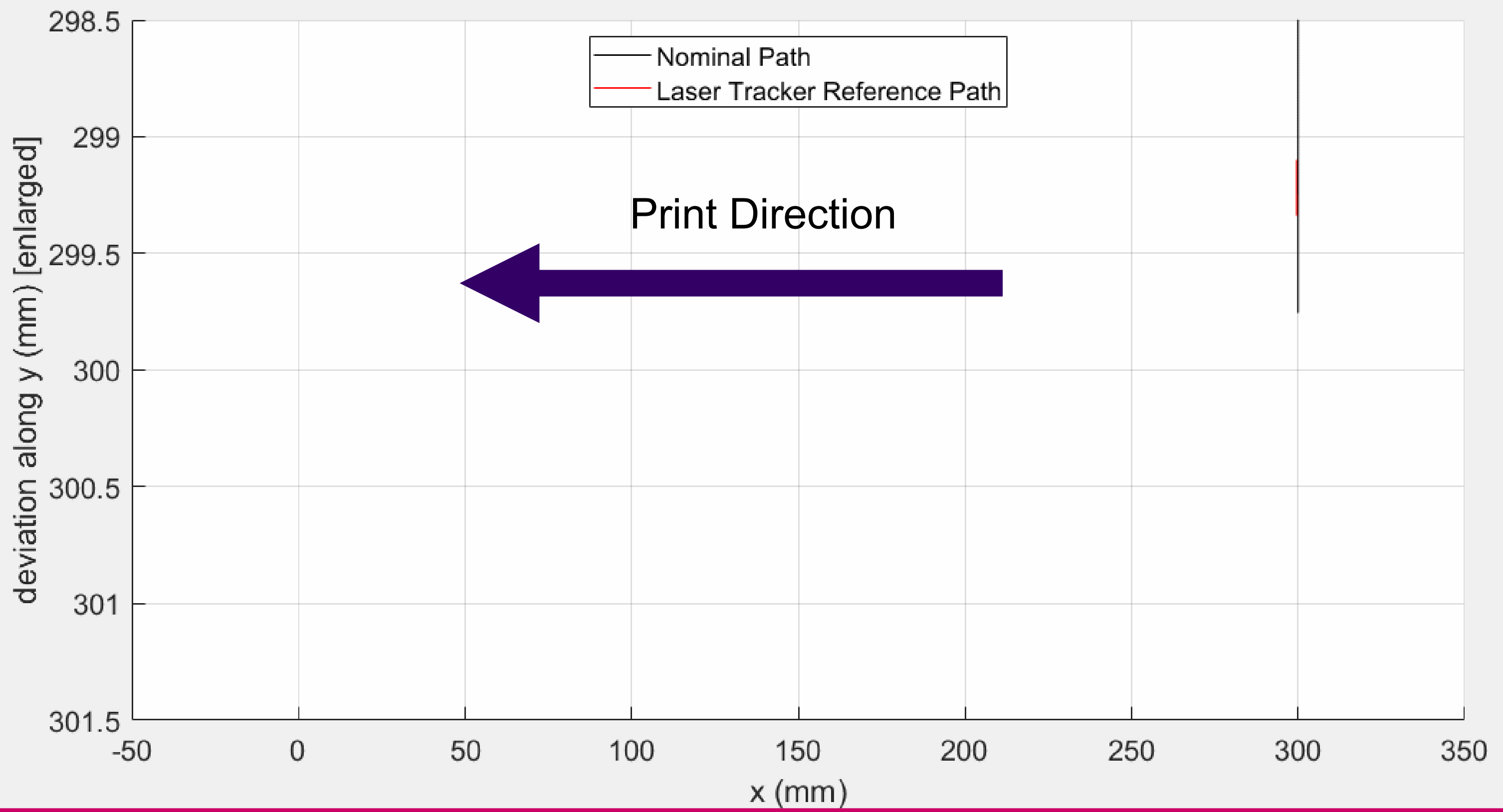
Measurement



RILEM TC 304-ADC ILS-mech Study Plan
doi:10.14459/2023mp1705940

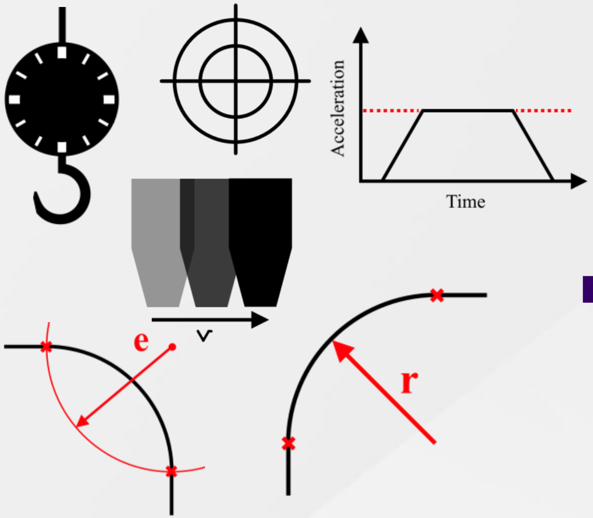


(Edge Length: 300 mm)


Nominal Path
Laser Tracker Reference Path
Print Direction
deviation along y (mm) [enlarged]
298.5
299
299.5
300
300.5
301
301.5
-50
0
50
100
150
200
250
300
350
x (mm)

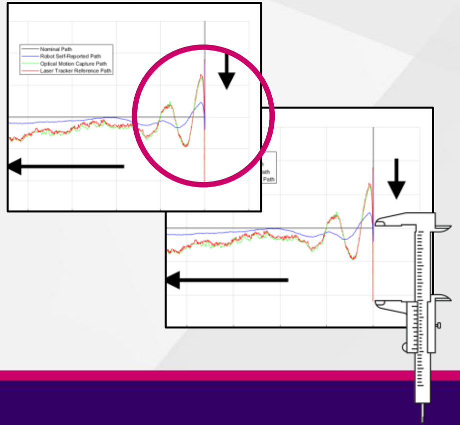
Methodology

Range of parameters are defined to test over

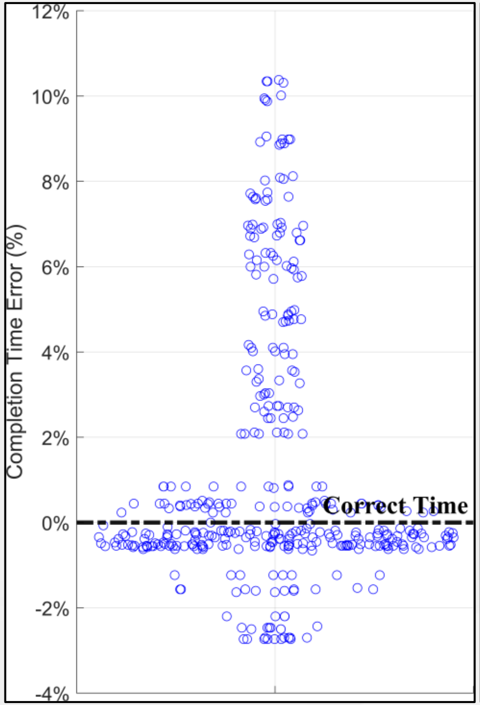


Full Factor analysis conducted resulting in 1575 samples

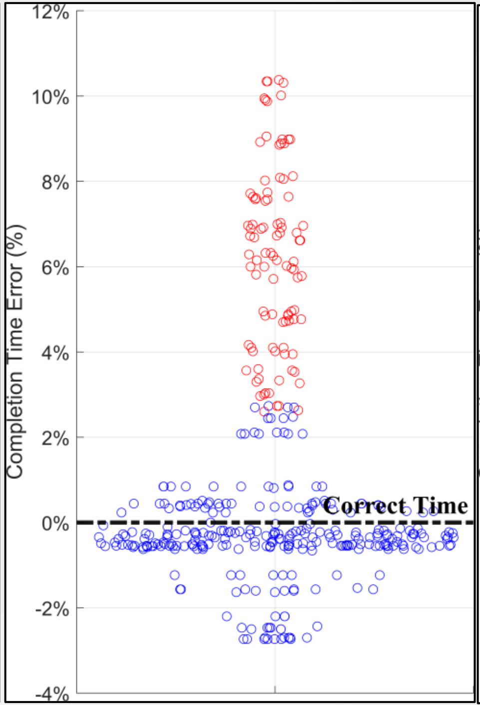
Analysed with several key characteristics



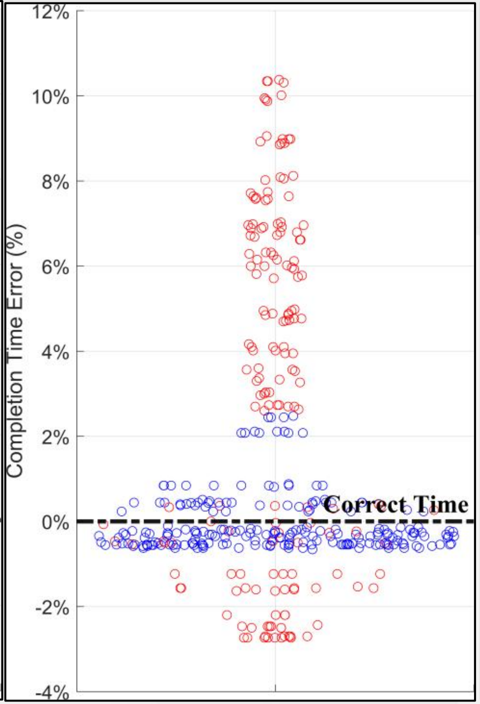
All data collected



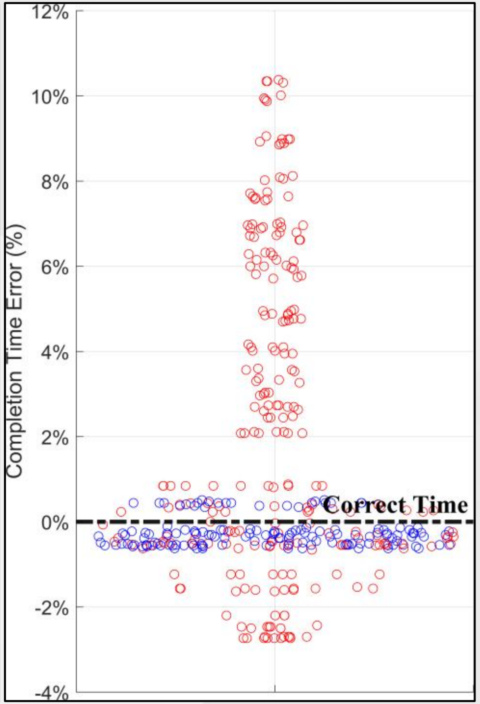
Only those with Corner movements



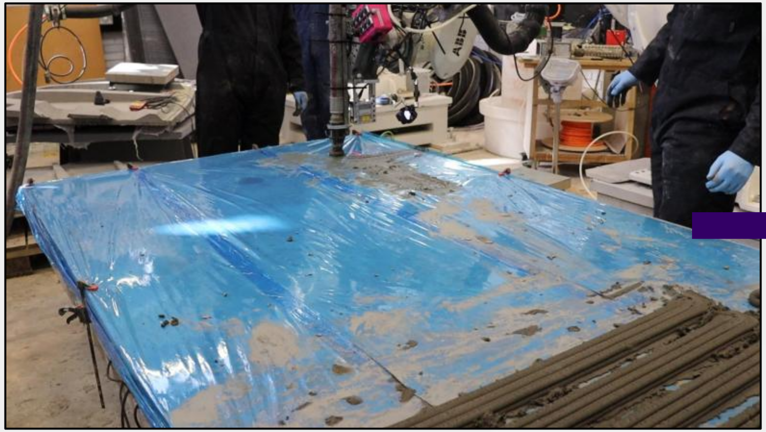
Non-‘fine’ ‘zone’ parameter

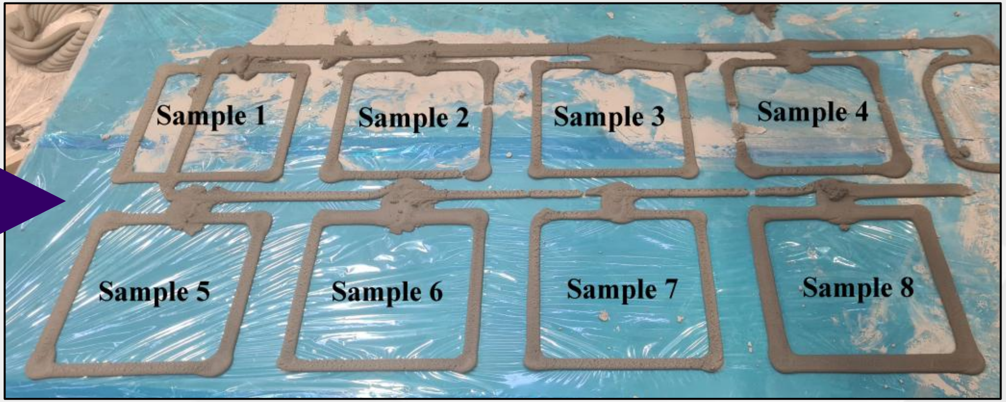


High acceleration limit

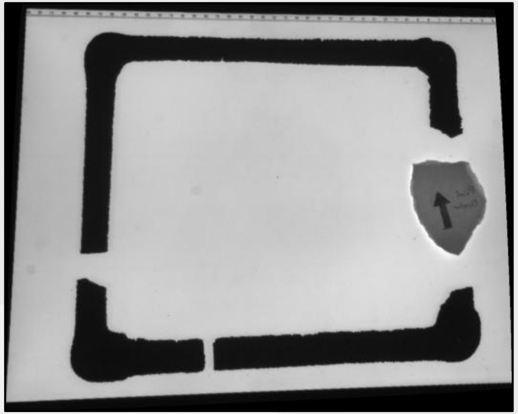


Printed Samples





Sample Imaging



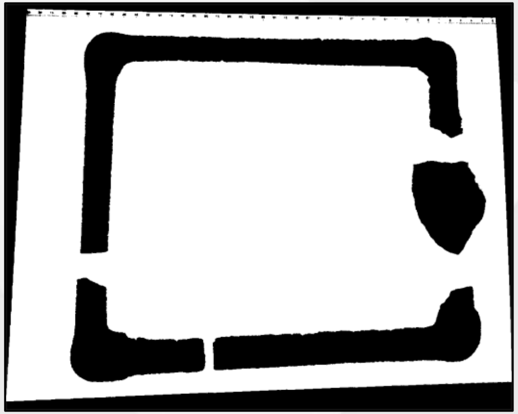
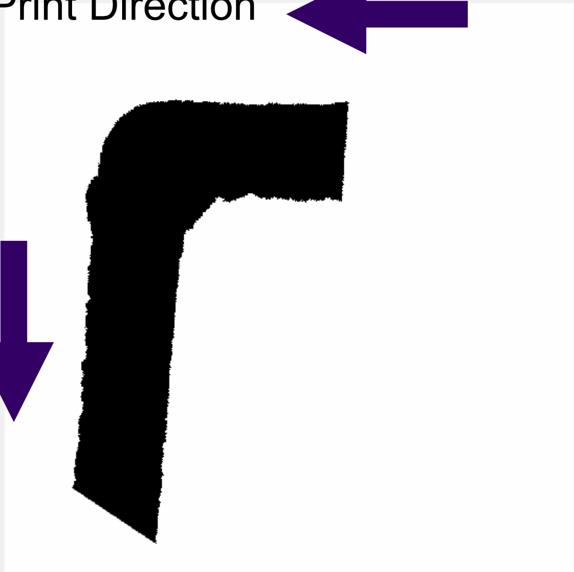
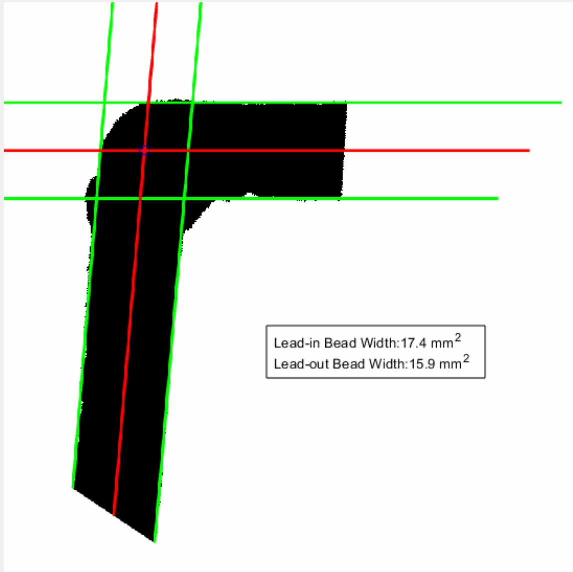


Image Analysis

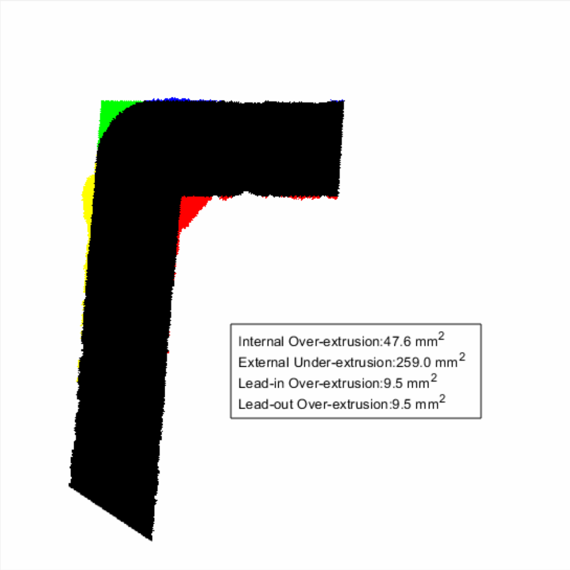
Print Direction



Thresholded



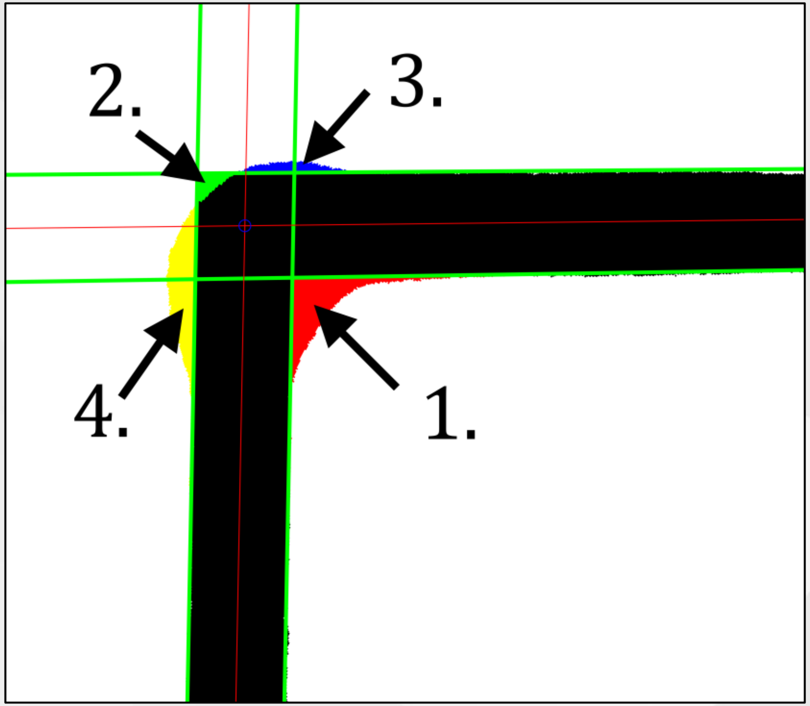
Edge Detection



Regions Highlighted

Extrusion Zones

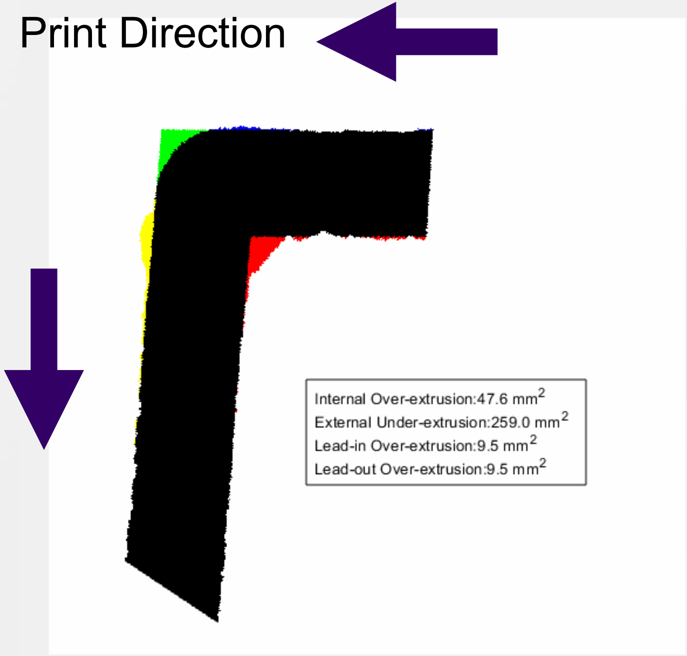
1. Internal Over-extrusion
2. External Under-extrusion
3. Lead-in Over-extrusion
4. Lead-out Over-extrusion

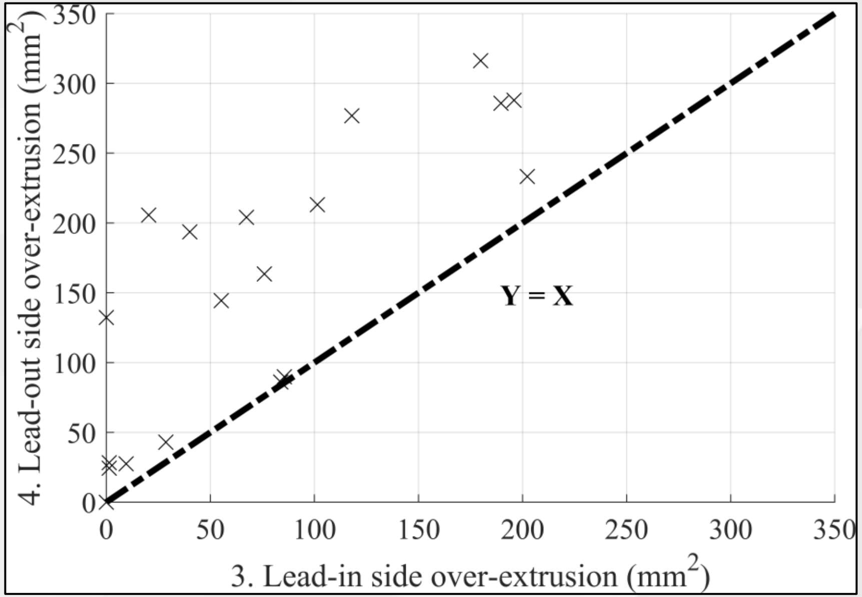


Total Over-extrusion = 1. + 3. + 4. – 2.

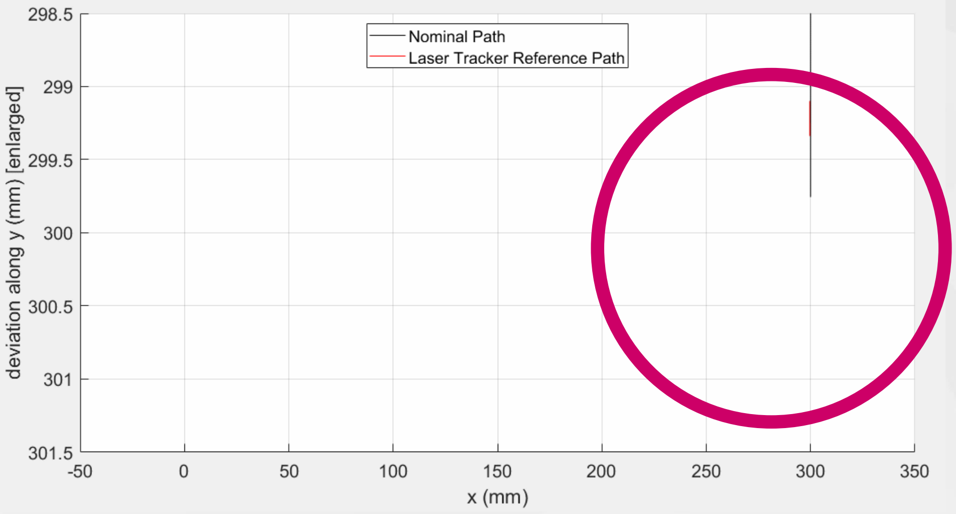
Lead-in vs Lead-out

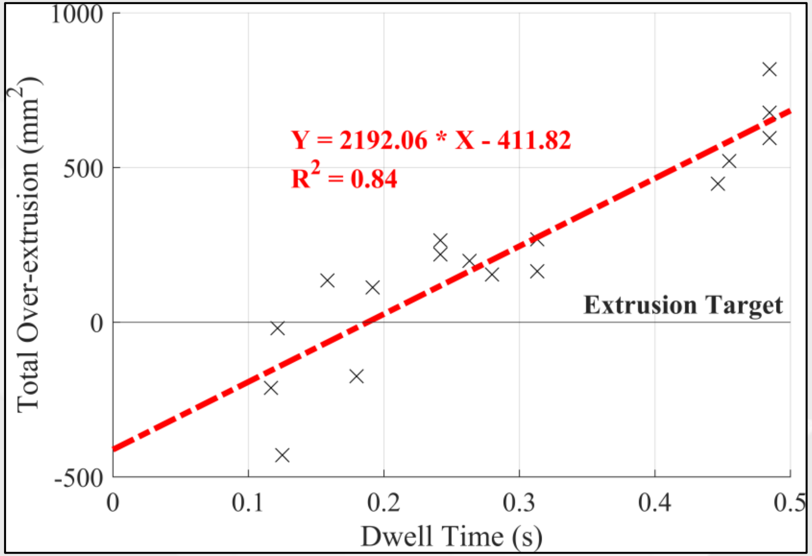
3. Lead-in Over-extrusion
4. Lead-out Over-extrusion

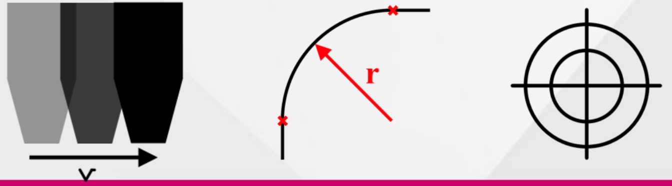




Dwell Time





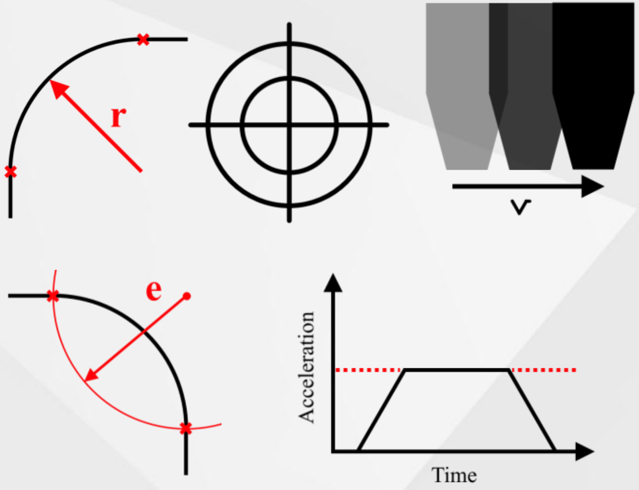


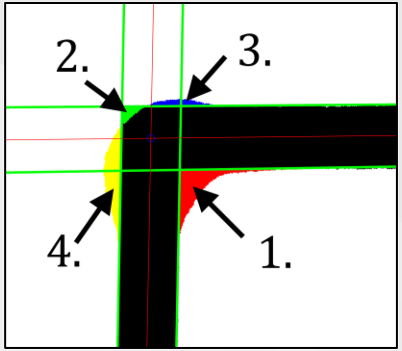
Range of Dwell Times is 0-1 s

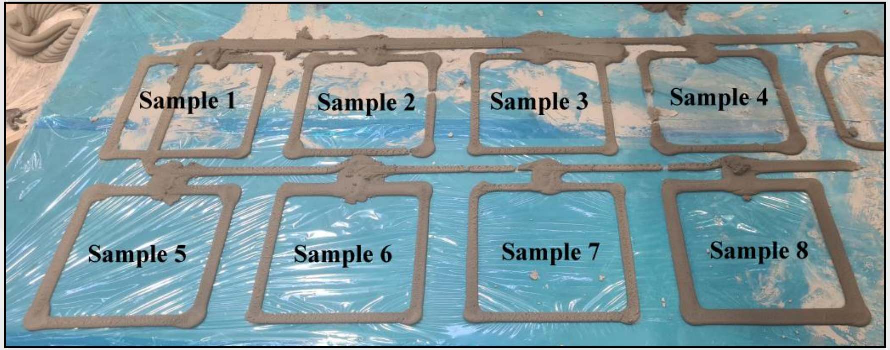
Conclusion

- The robot is not perfect, and it may need measuring!

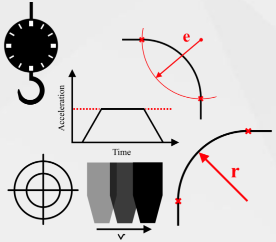
- Generally, for the best prints:
  - Have corner sections
  - Lower nozzle speed
  - Print closer to the base of the robot
  - High acceleration limits

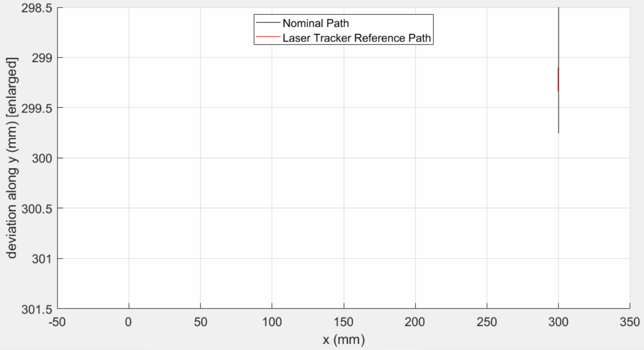






Any Questions?





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