Development of Novel Solutions for Robotic 3D Ceramic Paste Printing

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UWE Bristol University of the West of England

C F P R Centre For Print Research

UKRI Research England

Presentation Content

Collection of Research Aspects

Research overview
Context – Why paste 3D Printing ?

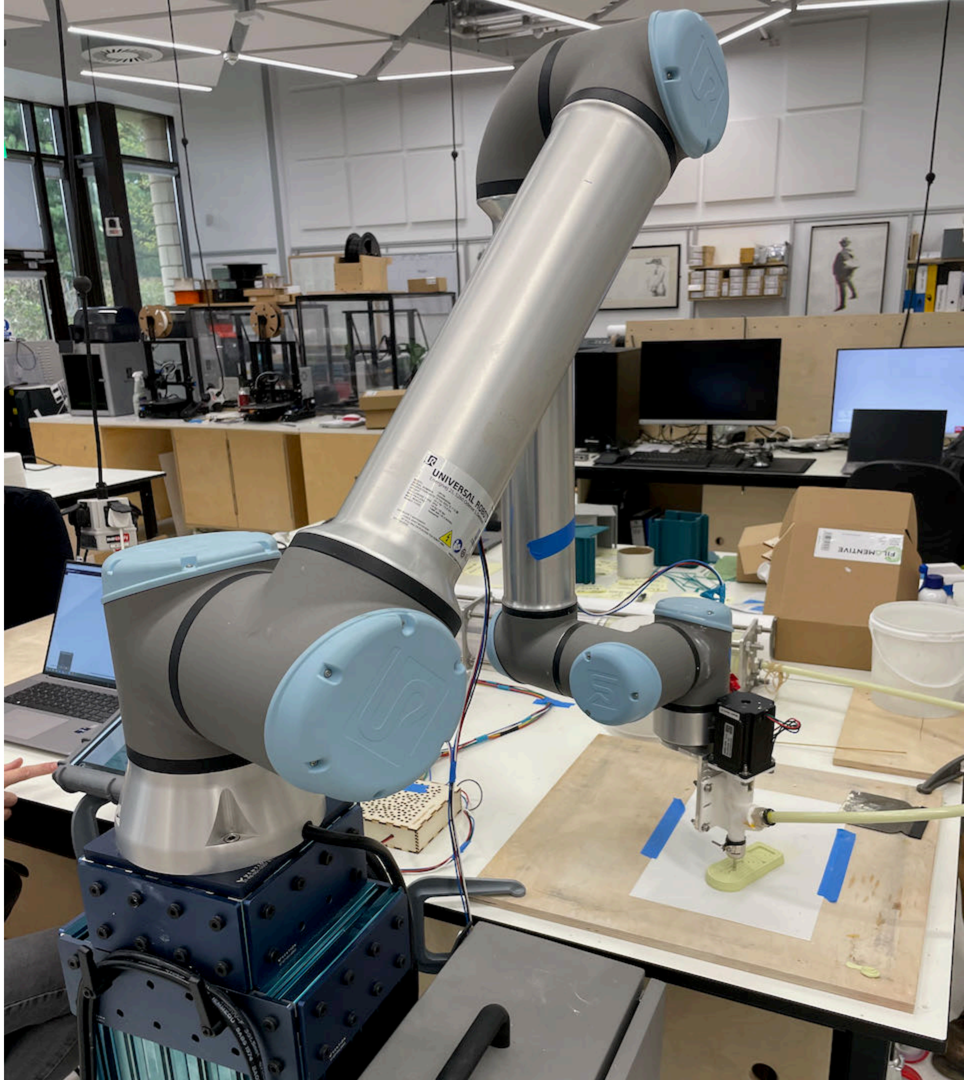
Hydraulic system experiments
Early experiment – Feedback Loop System

Auger design
Key aspects of paste printing research

Hardware system Iterations
Print housing development and mechanical delivery system

Print System: robotic Integration
Overview - challenges – current solution

Conclusion/discussion
Key research challenges still remaining



Context

Why Research into Ceramic 3D Paste Printing?

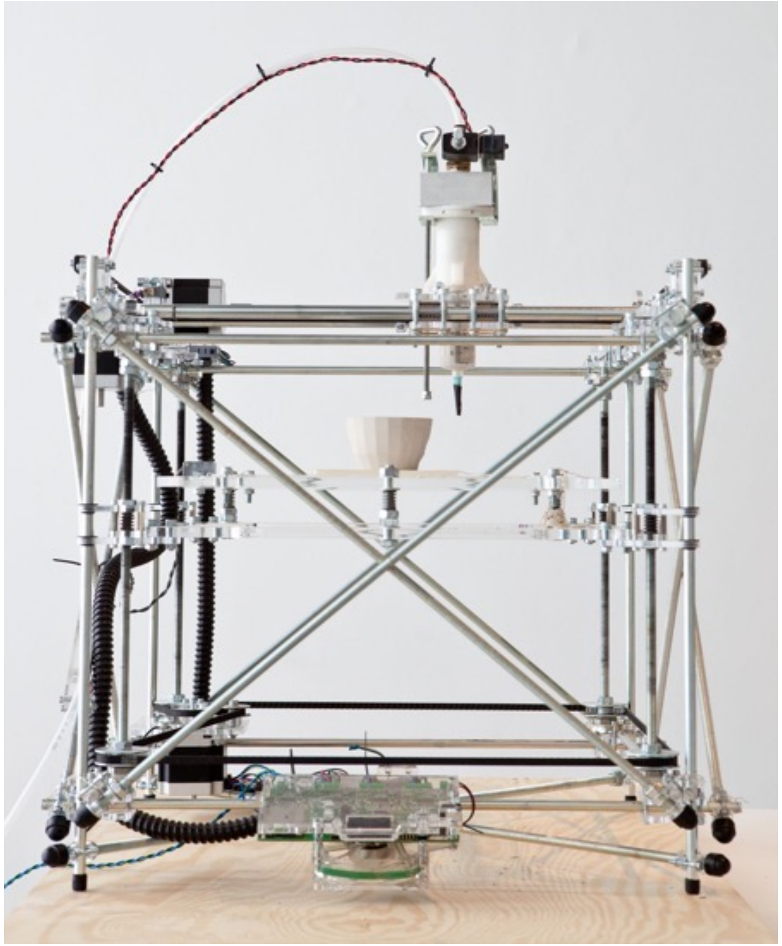
under researched - under utilised (industry)
creative practitioner development - little industry adoption

non proprietary = very low cost
open source ethos, practitioner led development

scalable
can be miniaturised - can be maximised

flexible
wide range of ceramic pastes and composites can be used

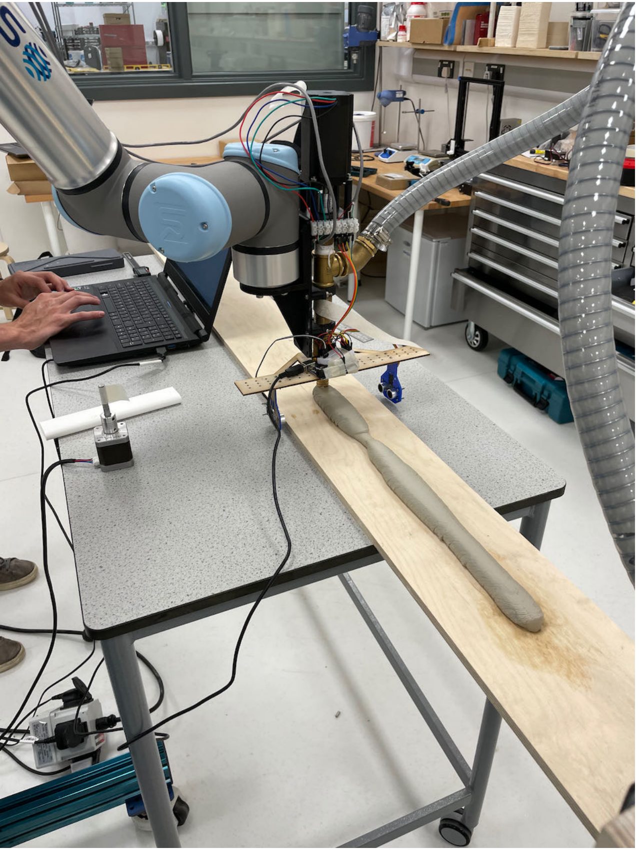
key research opportunities still remaining:
resolution / surface fidelity
Robotic arm integration still holds many underexplored possibilities
Possibilities for hybrid manufacturing: additive and subtractive

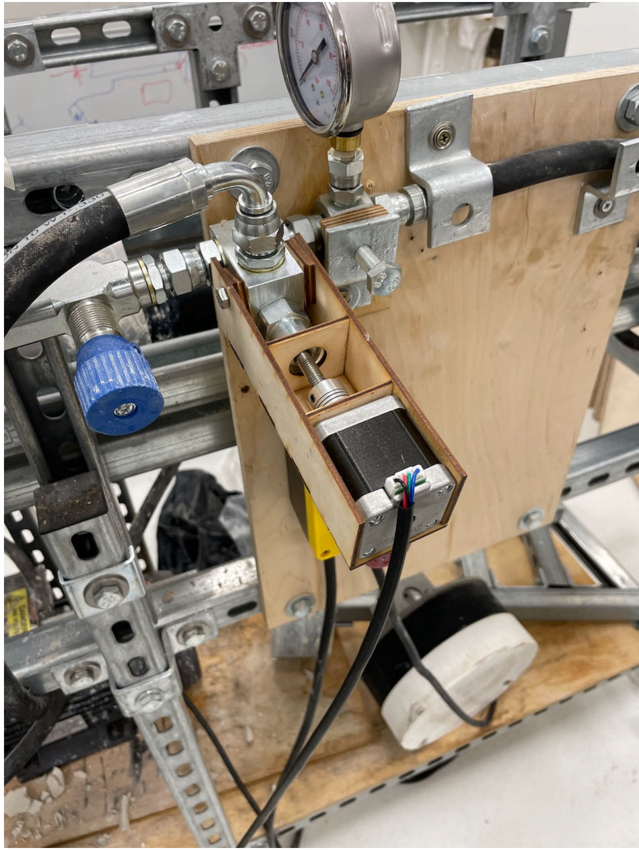


Studio Unfold 2009

Paste delivery : hydraulic system

Paste supply pressure control through sensor feedback loop

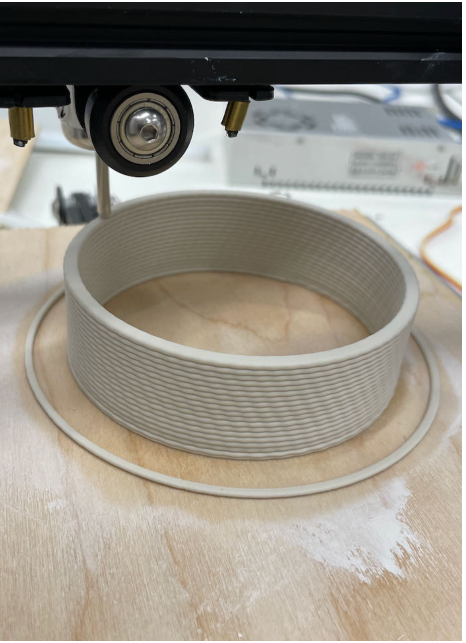


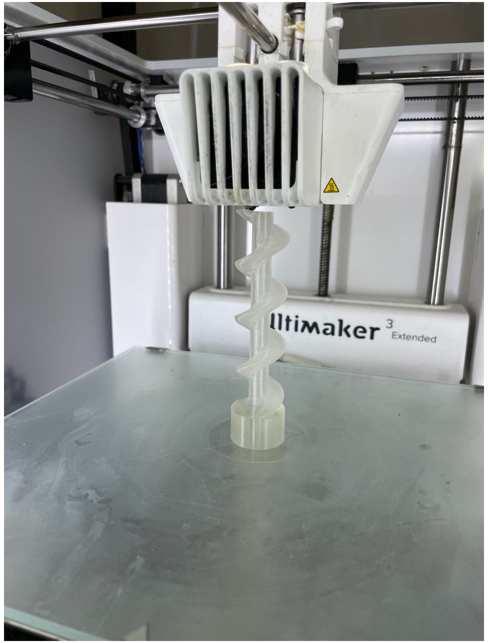


Large scale ceramic 3D print head development

Auger Design

Significance and early approaches





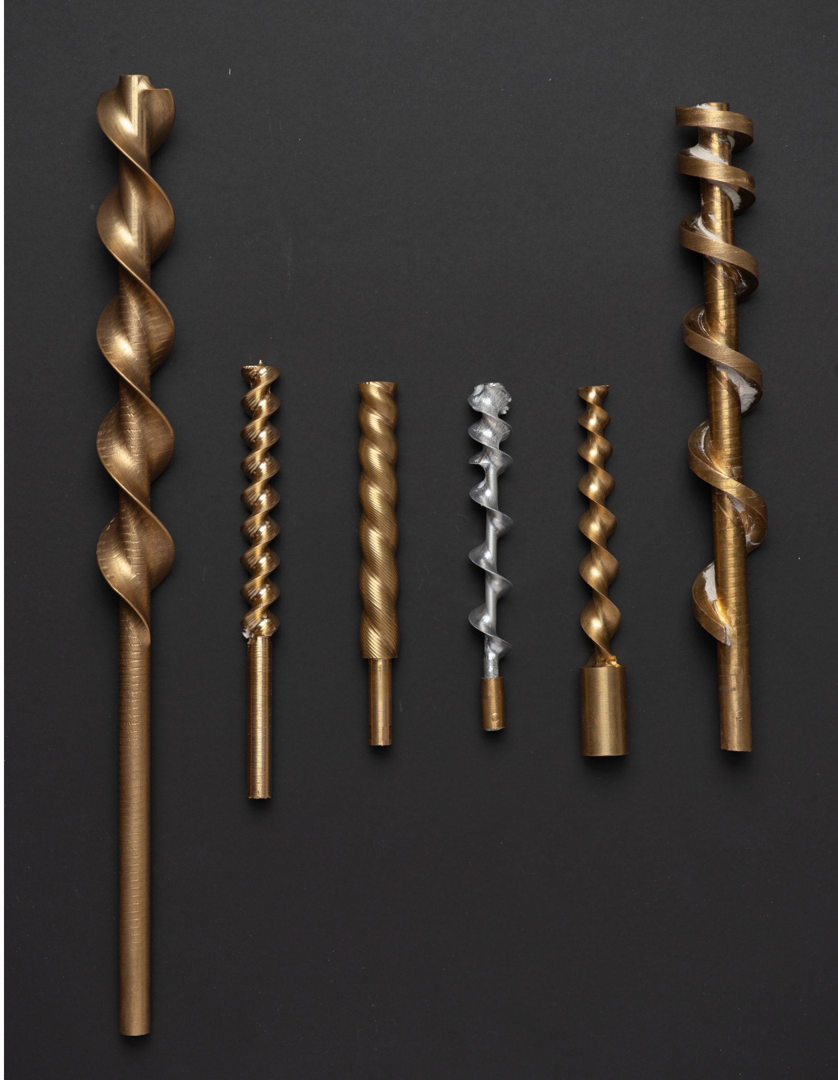
Auger Design

Toolmaking for 3D paste printing

To help optimise the process of creating these augers, we wrote a custom Numerical Control (NC) (g-code) program.

We can then input our variables, and it creates an auger to specification.

Through mathematical functions we can control the shape of the cross section, the number of helixes, the pitch at the start and end of the auger, the dimensions, and the resolution

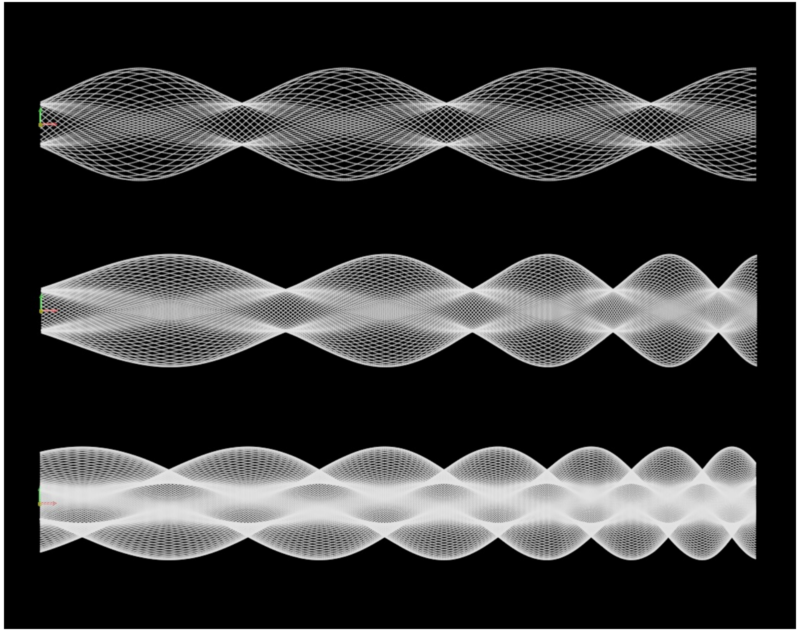


Auger Design

G Code Scripting

The main variables in auger design are the:

- Cross-sectional shape
- Pitch (which can vary from one end to the other)
- Number of helixes
- Diameter



Initiate machine

```
O01001 (Auger designing prototype):
:
(set datum at centre of the end of stock, set in A rotary axis):
G90 G40 G21 G17 G80:
M06 T1:
H1 M3 S12000:
G00 X-10 Y0 A0:
:
:
```

User defined variables

```
(Adjustable values):
#101=5.5 (Outer Radius of auger):
#102=70.0 (Flute Length):
#103=40.0 (Pitch at end of datum):
#104=40.0 (pitch at datum):
#105=2.0 (Number of helixes must be whole numbers):
#106=4.0 (Diameter of ball endmill):
#107=2 (Inner Radius of auger):
#109=5 (x movement increment):
#131=350 (Feed rate)
#124 = 50.000 (Radial Resolution):
#112=3 (spikeyness):
:
:
```

Driven variables

```
(Driven Values - Do not change):
#133=-1 (Multiplier dependant of whether the pitch increases or decreases):
IF[[#104-#103]LT0]#133=1:
#110=#103/#109 (initial pitch per increment move):
#111=#133*[ABS[[#104-#103]/[#102/#109]]](Change in pitch per incremental x movement):
#120=#102/#109: (Create number of moves):
#122=[#104]+#111(save for absolute angles):
#123=0.000 (x coordinates):
#100=3.142 (pi):
#127=#124 (Reset for Radial Resolution):
#125=360/[#124] (Incremental radial ):
#126=#101-#107 (height of flights):
#128=[[180*#105]/#127] (increments for z calculations):
#129=0.000 (z calculation):
#130=0 (A start positions):
#132= 0(hold for anglular increments):
#113 = 0 (hold for cos valeu):
:
:
```

Pause to check

```
M01 (Check variables in machine):
:
:
M11:
:
:
```

Loop to define cross section

```
WHILE[#124GT0]DO1:
:
G90:
G00 Z[20+#101] F300:
X0 A#132:
G00 Z[0.5+#101] F300:
X0 F300:
#114=#112
#113=COS[#129]:
WHILE[#114GT0]DO3:
#113=[#113 * COS[#129]]:
#114=#114-1:
END3:
Z[[ABS[#126*#113]]+#107] F300 (Creates the cross-sectional shape):
X0:
:
:
```

Loop to define helix

```
WHILE[#120GT0]DO2 (move in helix around A axis):
:
G90:
#122=#122+#111:
#123=#123+#109:
#132=#132+[[#109*360]/[#122]]:

G01 X[#123] A[#132] F[#131]:
#120=#120-1:
:
END2:
:
:
#123=0.000:
#122=#111+#104 (Reset pitch increment):
#120=#102/#109 (reset number of moves):
#124 = #124-1: (increment loop):
#130=#130+#125 (Increment A move):
#132=#130
#129=#129+#128 (Increment for Z height calulations):
:
END1:
:
:
```

End

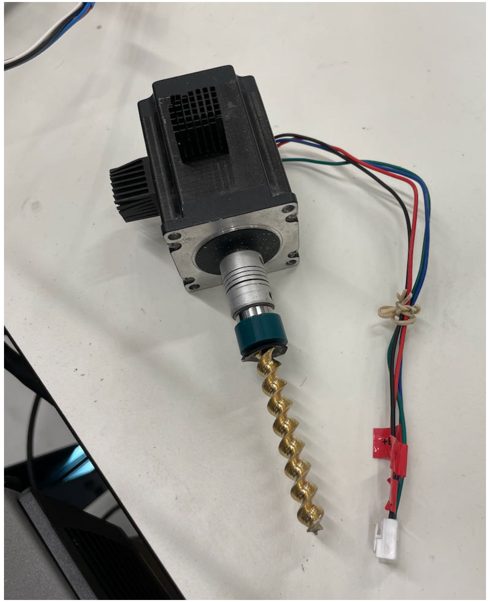
```
G00 Z20 F300:
G28 Z0:
M10:
M30:
```

A u g e r M a n u f a c t u r i n g

G C o d e S c r i p t i n g

Scrip imbedded on interface of 4-axis HAAS milling machine.

- Cross-sectional shape
- Pitch
- Number of helixes
- Diameter



mechanical – digital paste supply approach

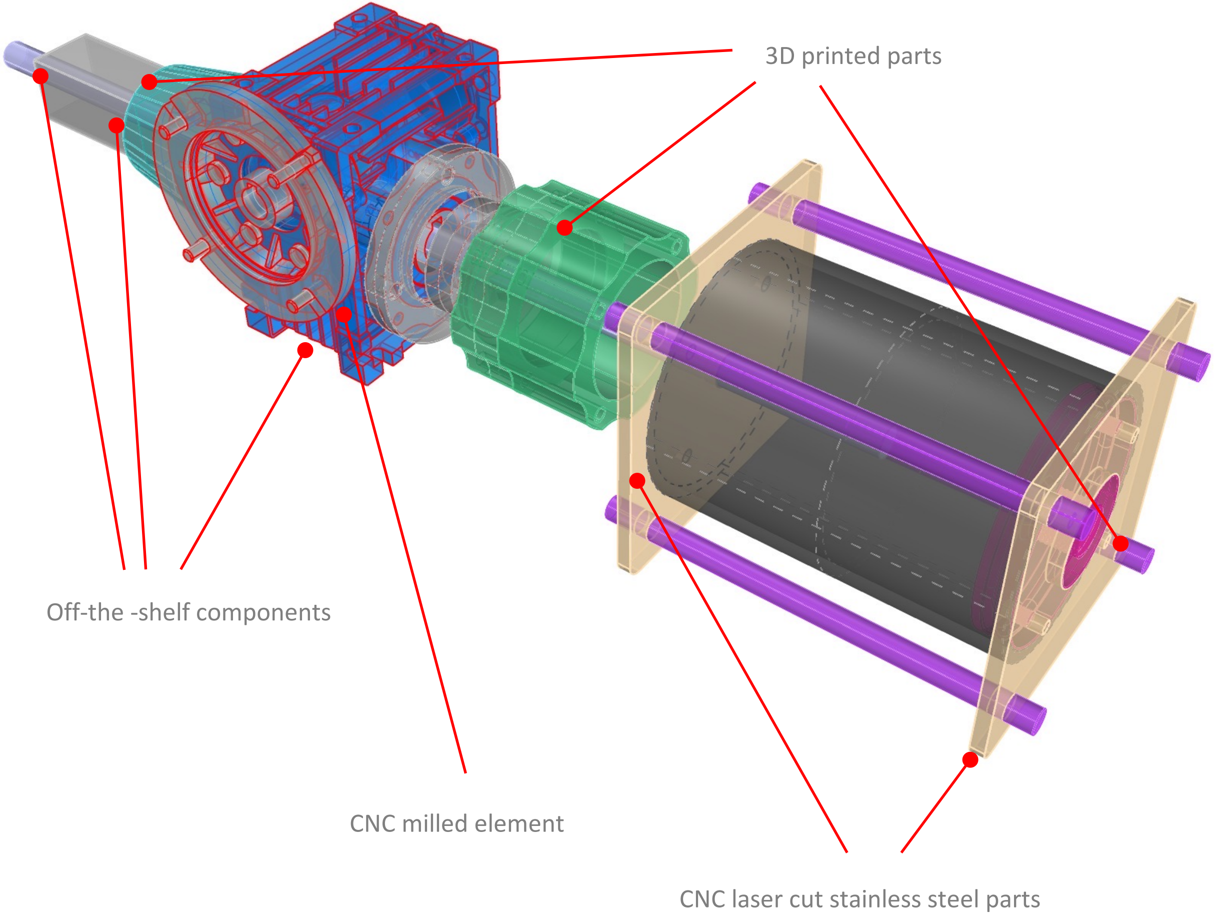
Hardware
Paste container

Components

A Nema 23, 34 or 42 is attached to a NMRV 30, 40 or 50 gearbox which provides high torque to push considerable amount of clay in the pipe.

Leadscrew is moved linearly which pushes the piston forward to deliver the paste to housing through a small pipe connected by BSP connectors.

There are two metal plate attached to pipe which prevents loads of pressure created by gearbox to break the pipe.



Hardware
For paste delivery

Case study

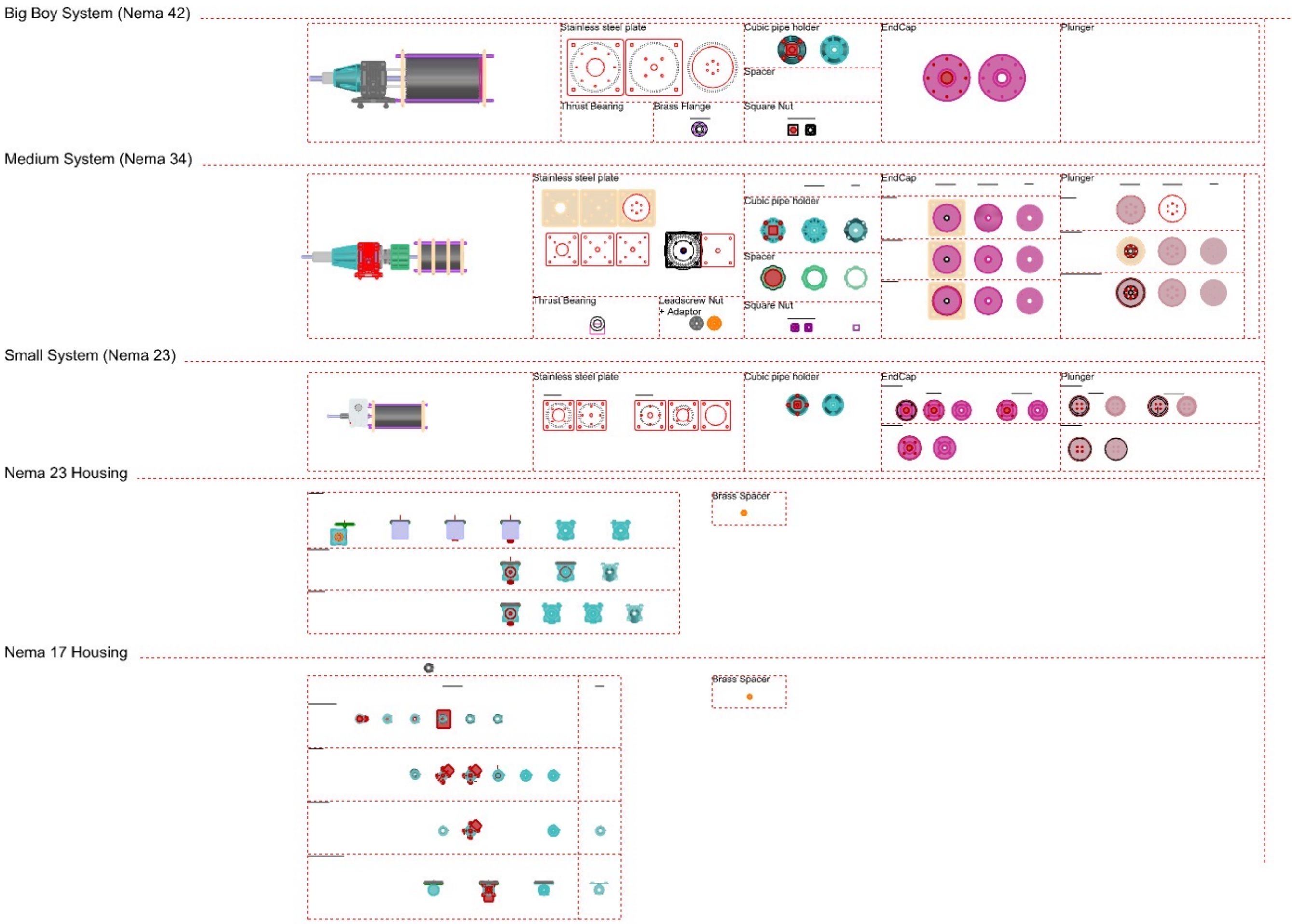
The early design stage started by case studies from available delivery systems in the market including Wasp clay printer and Bryan Cera extrusion solution.

Case confirmation

Available systems were built and tested to confirm the efficiency and reliability. This resulted in hardware failure such as components breaking, speed failure. So, the system had to be altered to fill the gap.

Result

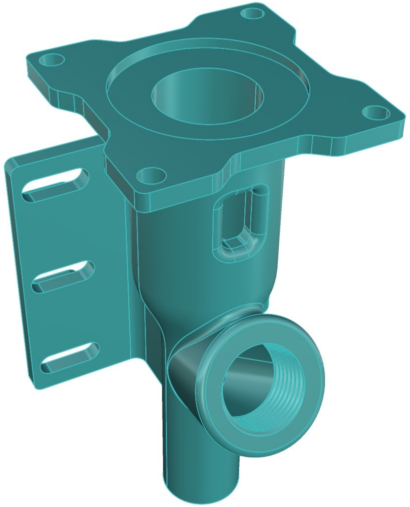
Small, Medium and big scale system were developed for different purposes.



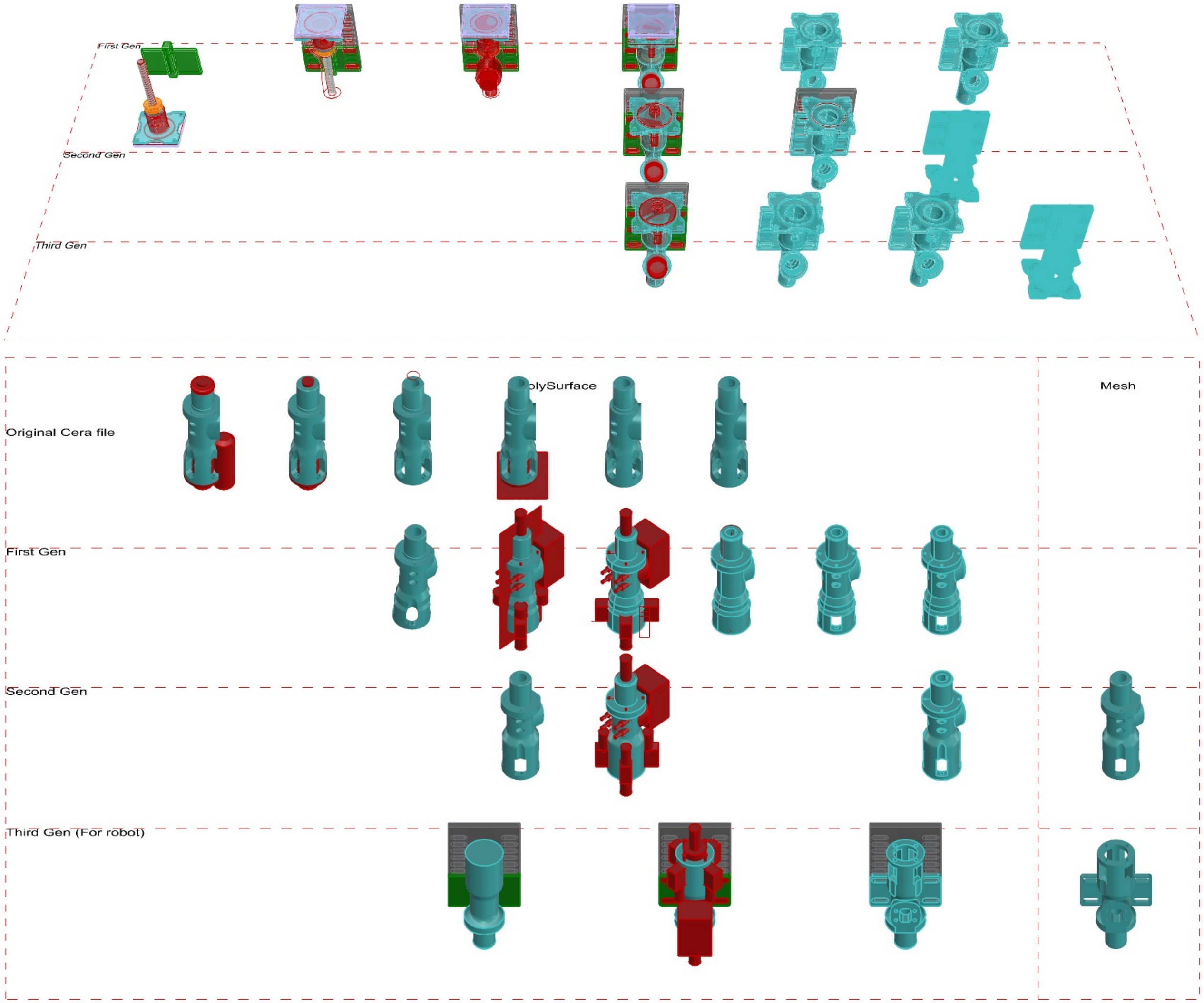
Hardware
Housing

Design iteration through empirical testing

Paste has proven to show inconsistency when it is about to get extruded. Too many tests were done to achieve the optimum model which is cheap, fully functioning and prevents leaking when printing with small nozzles.



low cost 3D Printed



Print System

Robotic Arm Integration

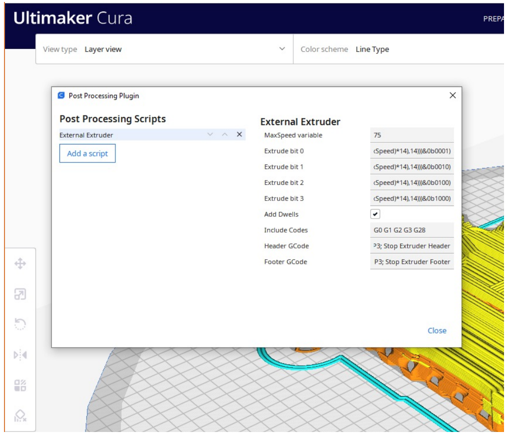
Integrating paste extrusion system with a Universal Robots UR10e robotic arm.

- Custom slicer and toolpath generation for robotic arm
- Control sequence for external extruder interface
- Workflow

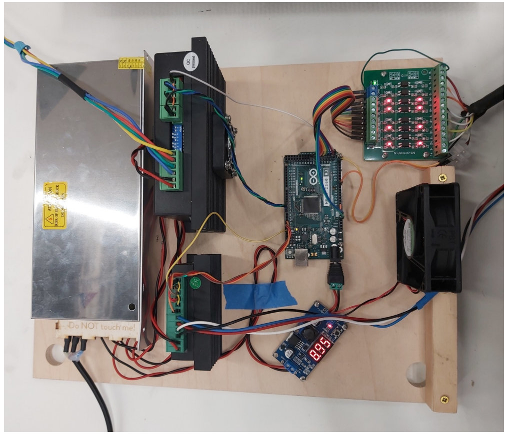
Print System

Custom Slicer

Bespoke plugin created for Ultimaker Cura that adds functionality to the machine code (GCode) to synchronise the extruder with the robot movements during the print.



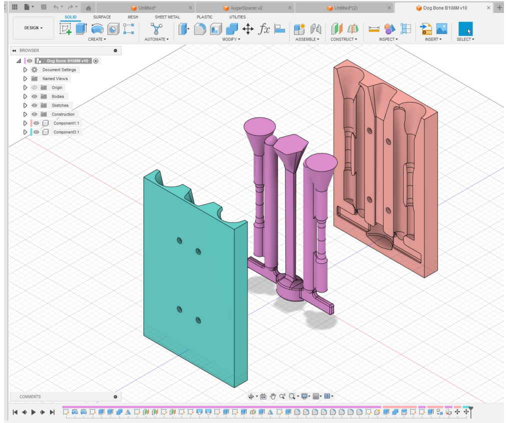
Plugin available within Cura, parameters can be adjusted here depending on setup.



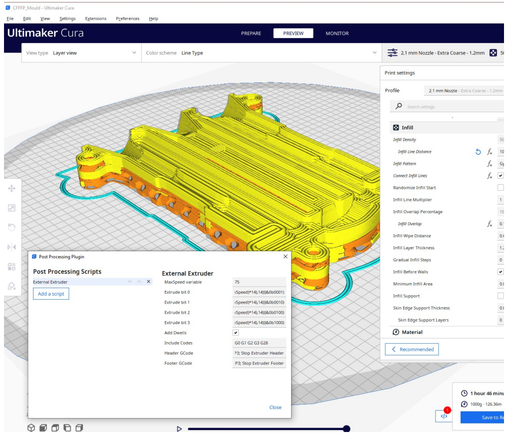
Arduino based system reads commands from the robot and moves the motors at the desired speed to extrude the paste.

Print System

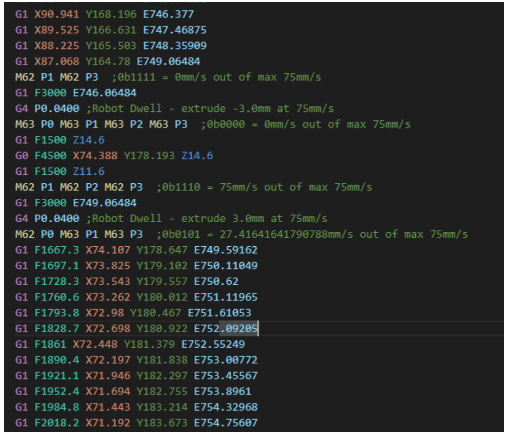
Workflow (part 1)



Design the mould in CAD software.



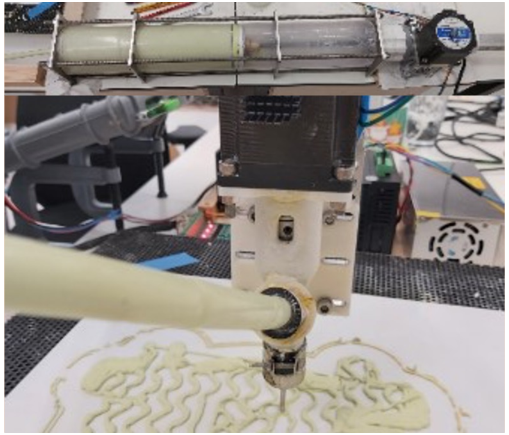
Bring the 3D model into Cura, enable the robot plugin, decide on settings for the print, and generate GCode.



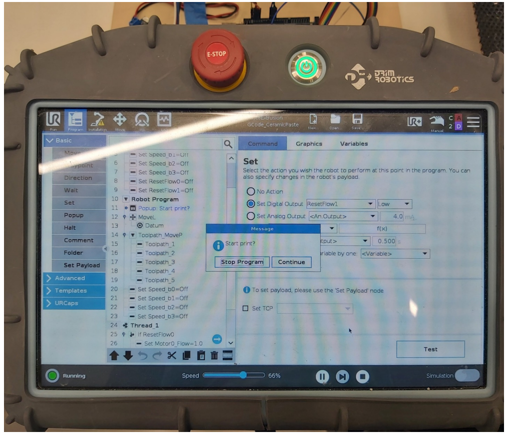
Upload the GCode to the robot with a USB stick.

Print System

Workflow (part 2)



Load the paste material. Prime the paste so it fills the extrusion system all the way to the print head.



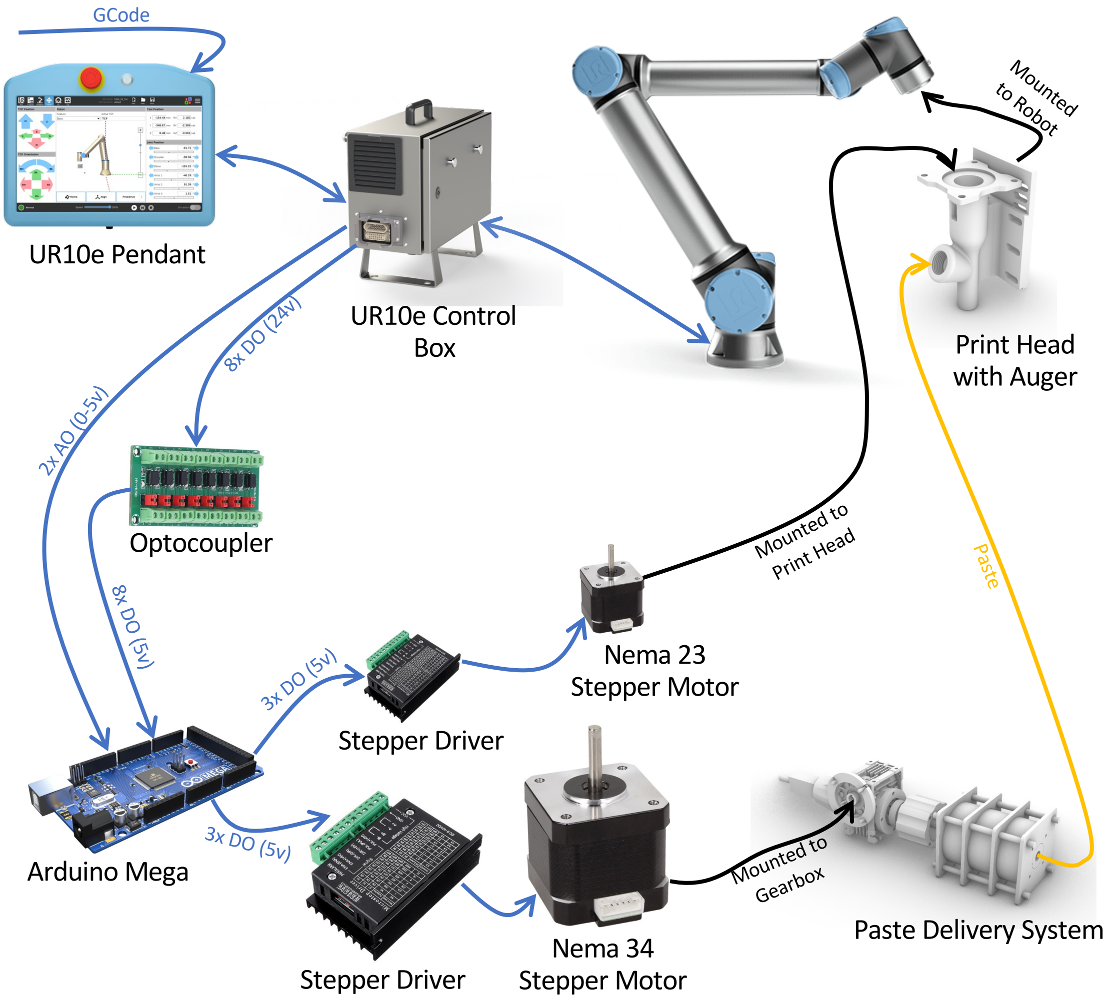
Set up the datum point for the robot and play the robot program. The robot will read the GCode and control the extrusion system.

Control the flow rates and print speed while printing with the robot's touchscreen interface.

Print System

Control Sequence

1. GCode uploaded on Pendant then program started
2. Control box moves robot according to GCode
3. Control box sends signal to Arduino with DO (through optocoupler) and AO
4. Arduino sets DO pins to control stepper drivers
5. Stepper drivers step motors at appropriate RPM
6. Material travels from delivery system to print head



Signal

Physical Connection

Material Flow

```
G1 X17.6 Y-135.873 E105.40636
G1 X20.445 Y-135.693 E106.38945
G1 X23.049 Y-135.423 E107.29228
G1 X25.848 Y-135.027 E108.26716
G1 X28.249 Y-134.602 E109.10804
G1 X30.755 Y-134.086 E109.99039
G1 X33.102 Y-133.539 E110.82147
G1 X37.212 Y-132.466 E112.28635
G1 X41.547 Y-131.22 E113.84184
G1 X45.739 Y-129.93 E115.3544
G1 X49.167 Y-128.824 E116.59659
G1 X49.929 Y-130.736 E117.30639
G1 X51.577 Y-133.846 E118.52019
G1 X53.544 Y-136.743 E119.72777
G1 X55.81 Y-139.415 E120.93598
G1 X58.365 Y-141.833 E122.14912
G1 X61.152 Y-143.955 E123.35713
G1 X64.162 Y-145.765 E124.56838
G1 X67.347 Y-147.238 E125.77854
G1 X70.67 Y-148.357 E126.98774
G1 X74.099 Y-149.111 E128.19851
G1 X77.584 Y-149.49 E129.40744
G1 X81.092 Y-149.49 E130.61721
G1 X84.58 Y-149.111 E131.82716
G1 X88.003 Y-148.358 E133.03584
G1 X91.333 Y-147.237 E134.24755
G1 X94.519 Y-145.762 E135.45831
G1 X97.52 Y-143.959 E136.66566
G1 X100.315 Y-141.83 E137.87732
G1 X102.864 Y-139.416 E139.08801
G1 X105.134 Y-136.744 E140.29711
G1 X107.105 Y-133.837 E141.50833
G1 X108.747 Y-130.74 E142.71719
G1 X110.044 Y-127.486 E143.92522
G1 X110.985 Y-124.098 E145.13784
G1 X111.213 Y-122.711 E145.62258
G1 X113.768 Y-122.278 E146.51626
G1 X117.044 Y-121.332 E147.69218
G1 X120.194 Y-120.03 E148.86763
G1 X123.177 Y-118.379 E150.0434
G1 X125.951 Y-116.411 E151.21633
G1 X128.498 Y-114.137 E152.39383
G1 X130.769 Y-111.596 E153.5691
G1 X132.744 Y-108.813 E154.74596
G1 X134.396 Y-105.824 E155.92371
G1 X135.701 Y-102.673 E157.09987
G1 X136.644 Y-99.399 E158.27485
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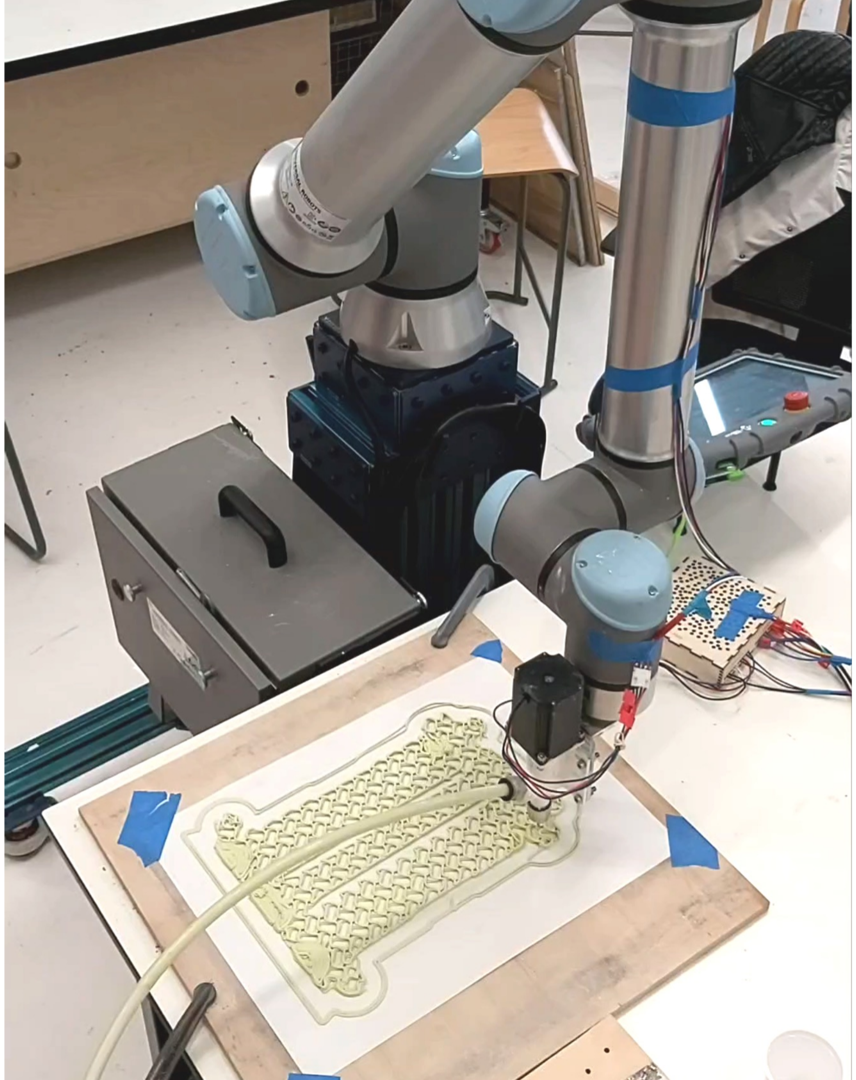


Conclusion/discussion

Research Opportunities and future plans

Resolution
Smoothing and hybrid manufacturing approaches

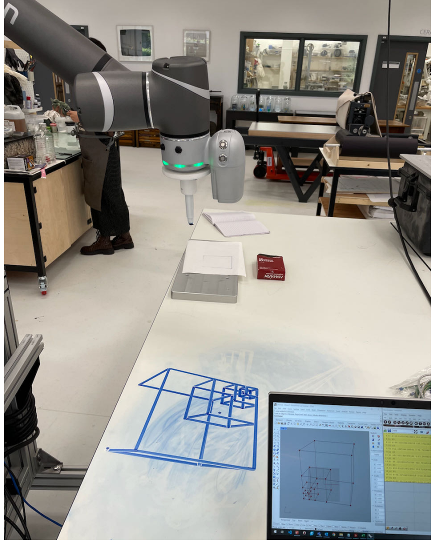
Novel material/pastes
Ceramic shell paste for direct metal casting

Industry applications
Novel and appropriate use for technology

Robots: Scale
Collaborative robots are growing!

Robots: Ai / Machine vision
Cobots integrated with vision enabling feedback loop

Open source approach
Github and Hardware X



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