Integration of Conductive Materials and SMD-Components into the FDM Printing Process for Direct Embedding of Electronic Circuits

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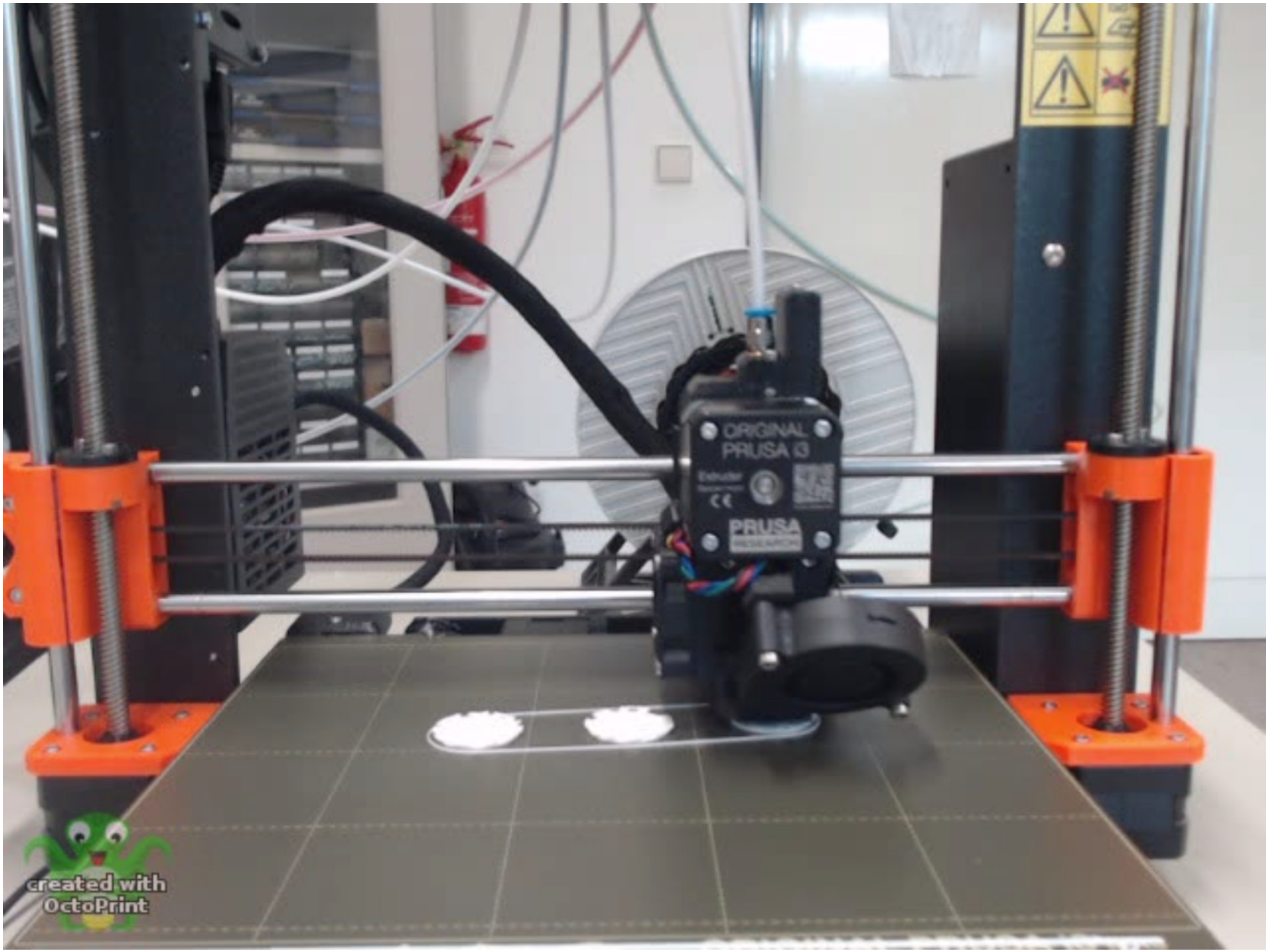
PhD Thesis Defense

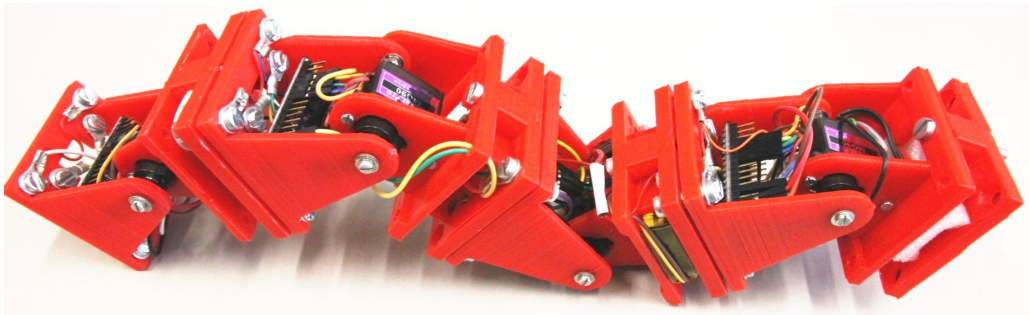
University of Hamburg
TAMS

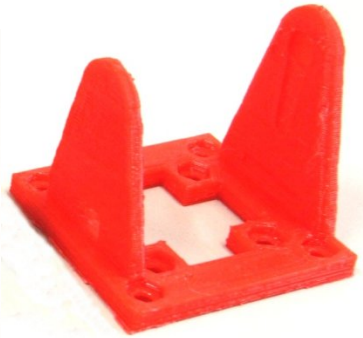
January 27, 2020

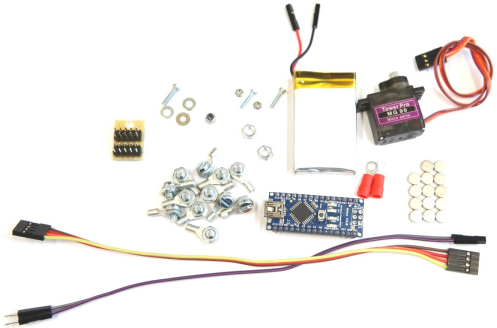
Fused Deposition Modeling (FDM)

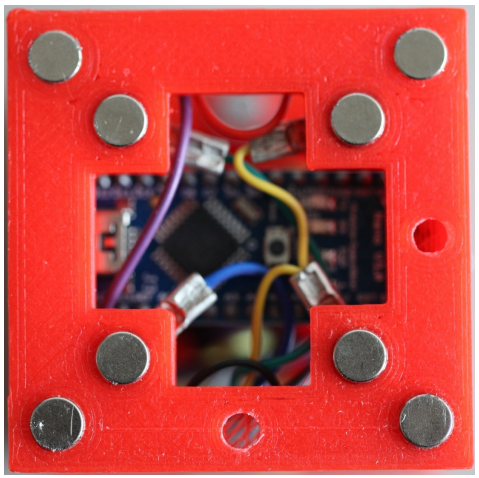


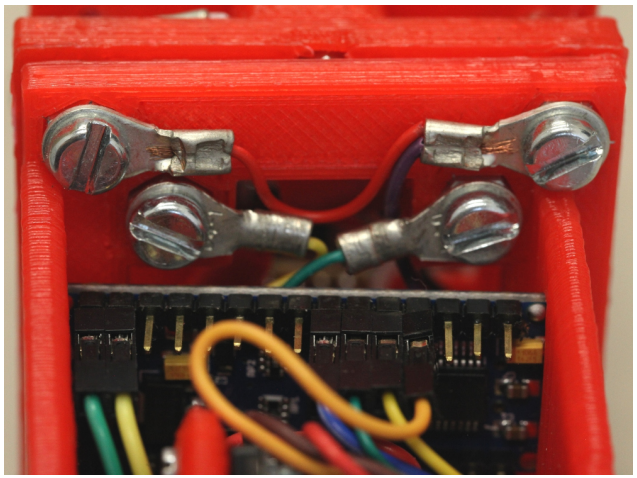
Motivation











Mission Statement

Full integration of electronic components and circuits into plastic objects in a single additive manufacturing process.

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Full integration of electronic components and circuits into plastic objects in a single additive manufacturing process.

+ Keep it low-cost!

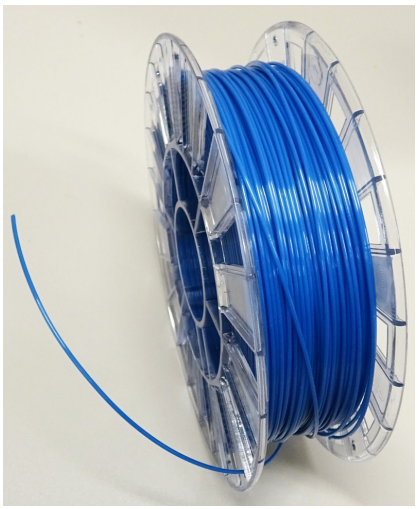
Challenges

1. Hardware / Materials
2. Design (CAD) and Routing Software
3. Machine Control and Calibration
4. Documentation and Inspection

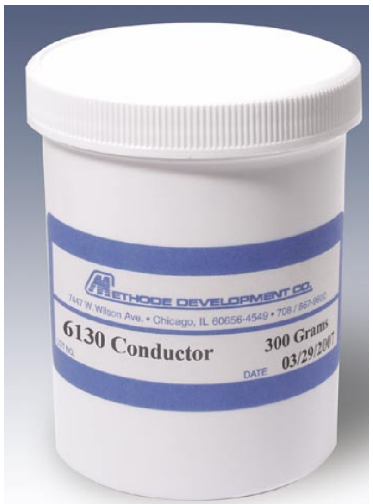
Hardware

[1]: Florens Wasserfall. Embedding of SMD populated circuits into FDM printed objects. In *Proceedings of the 26th International Solid Freeform Fabrication Symposium*, pages 180–189, 2015

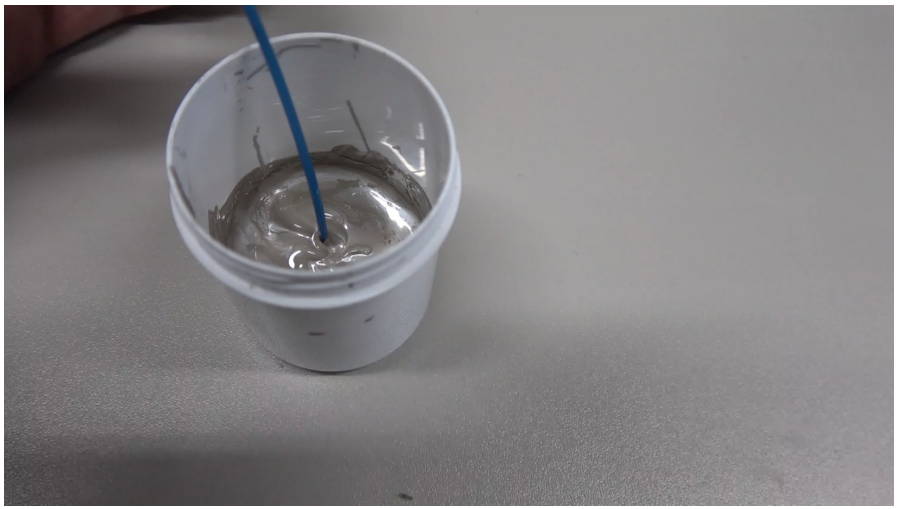
Materials



Filament

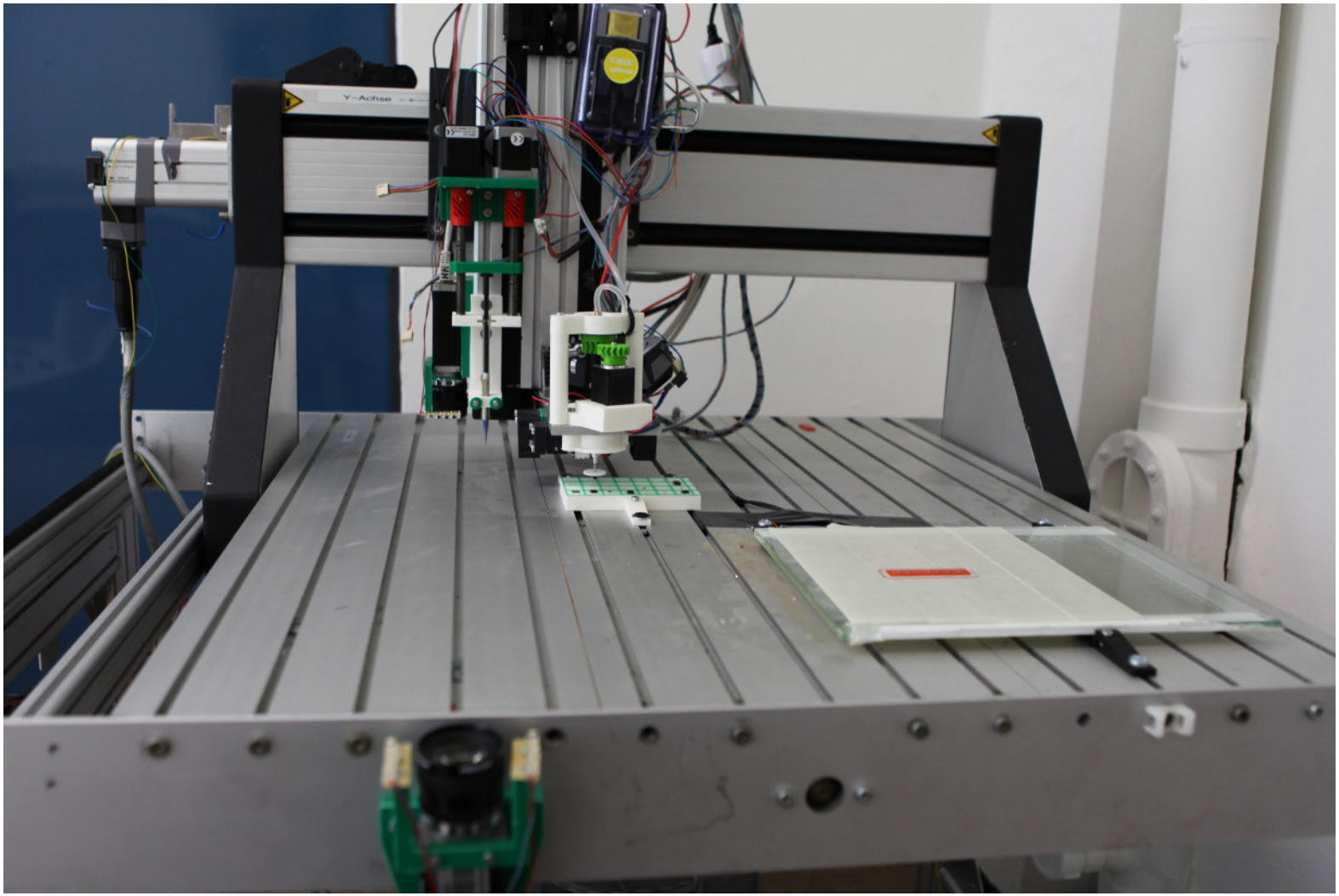


Silver Ink

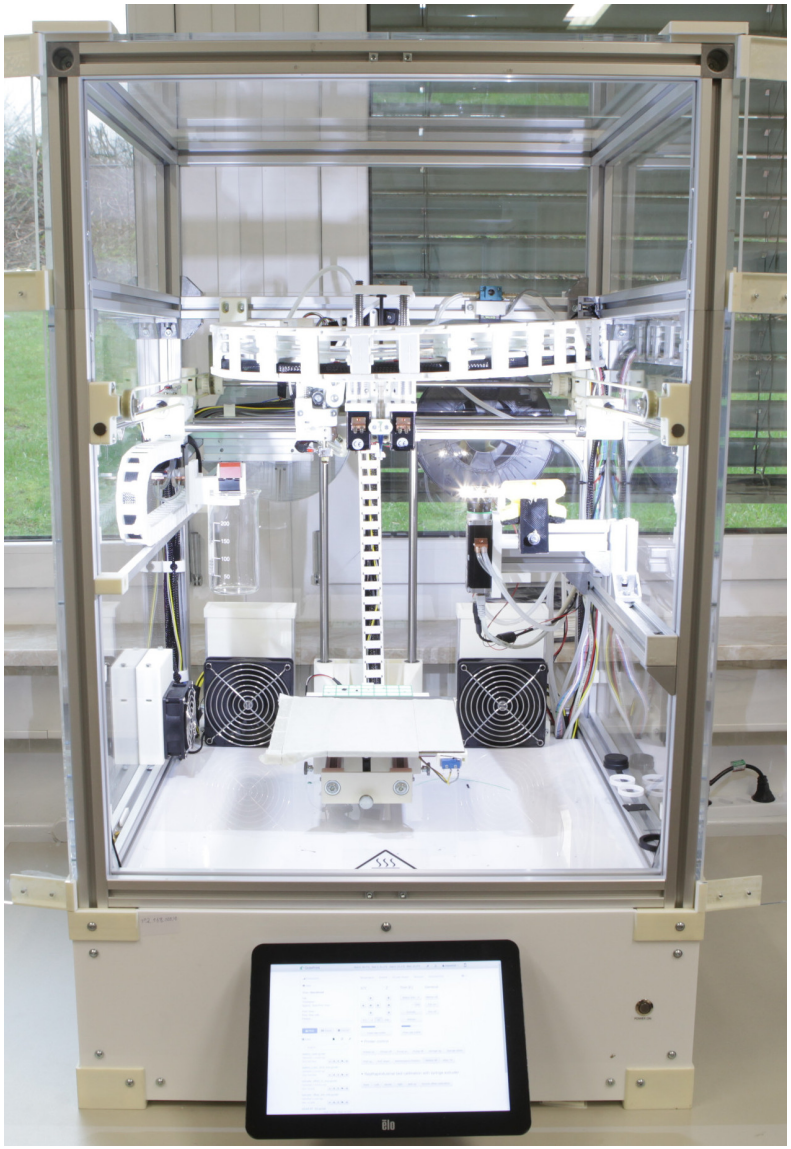


Ink Processing

Developing the Hardware



Developing the Hardware



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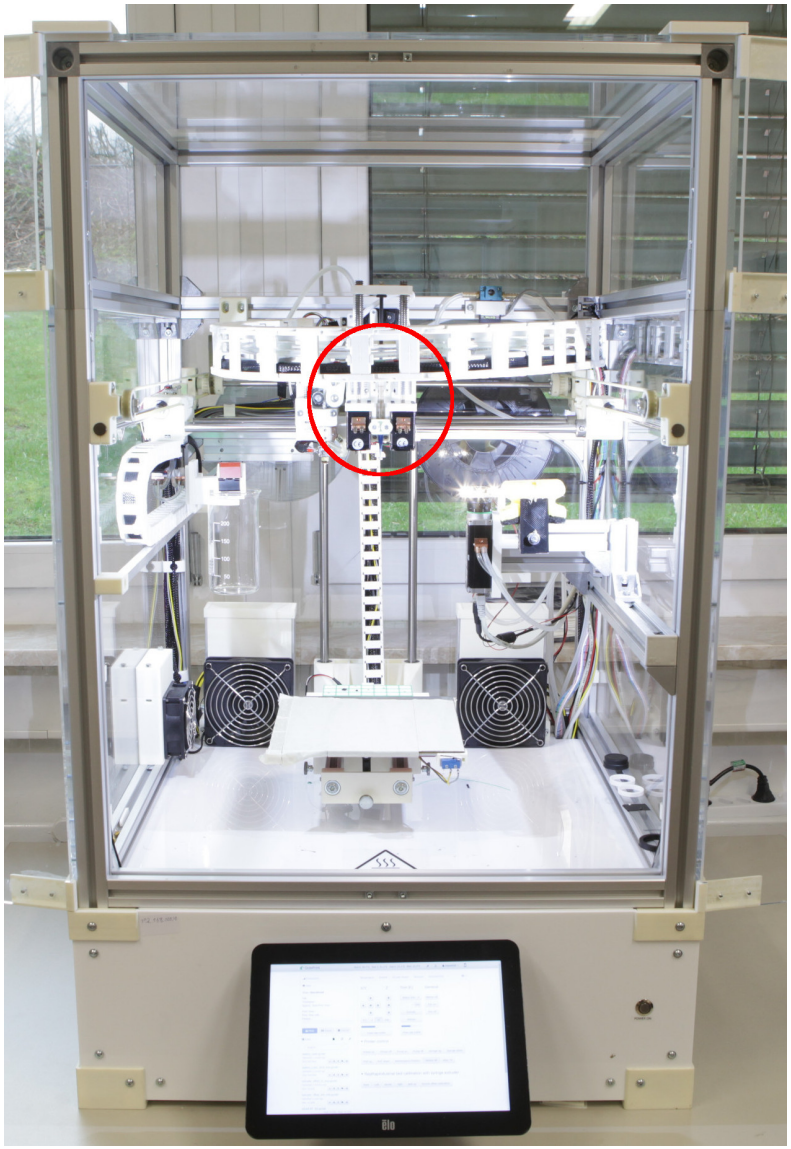
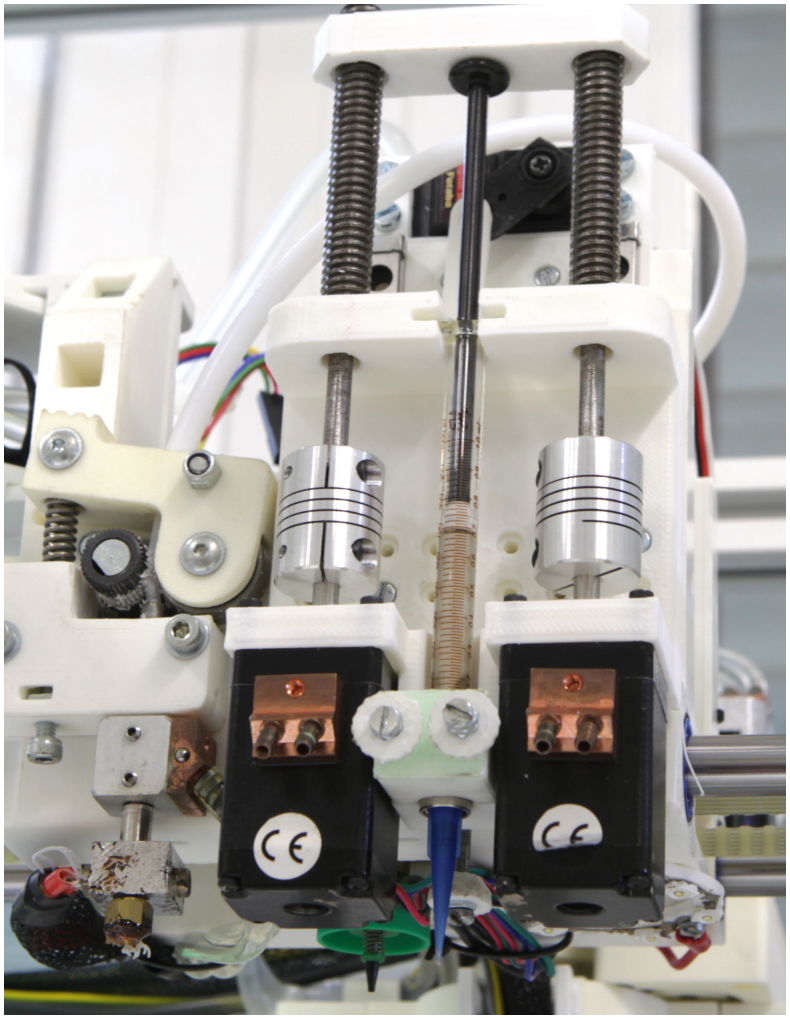
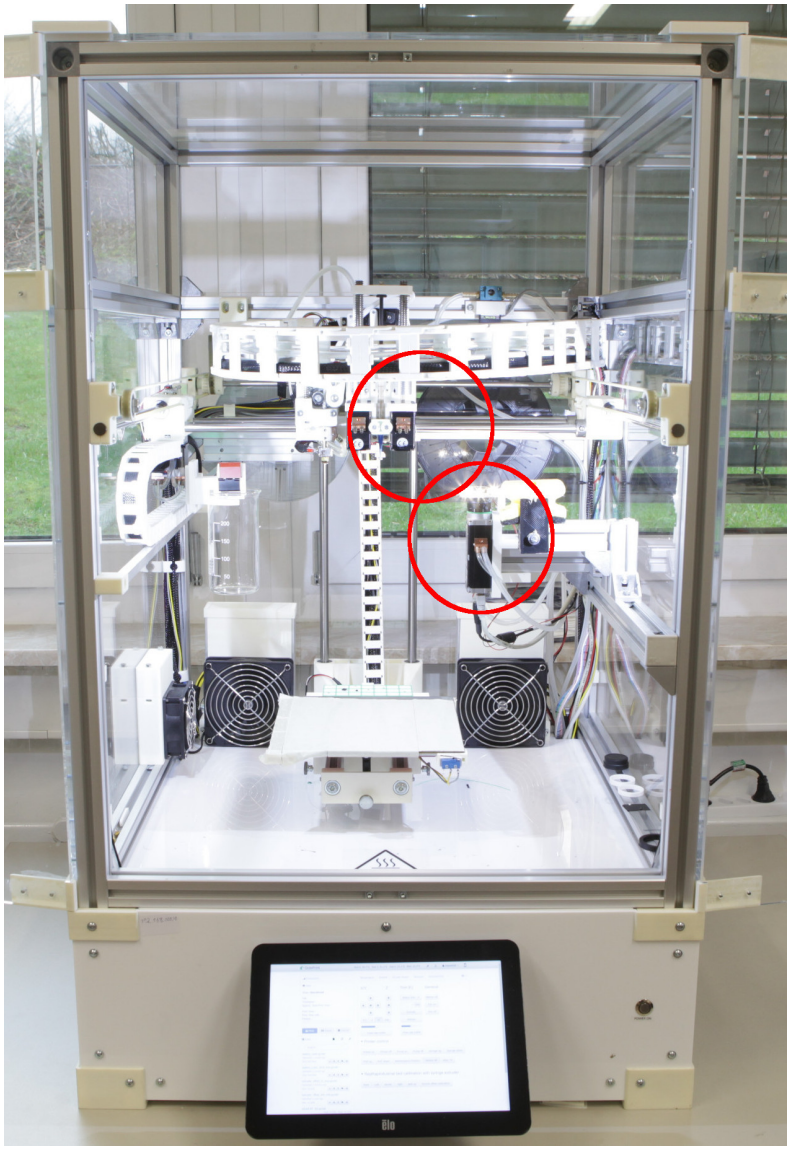
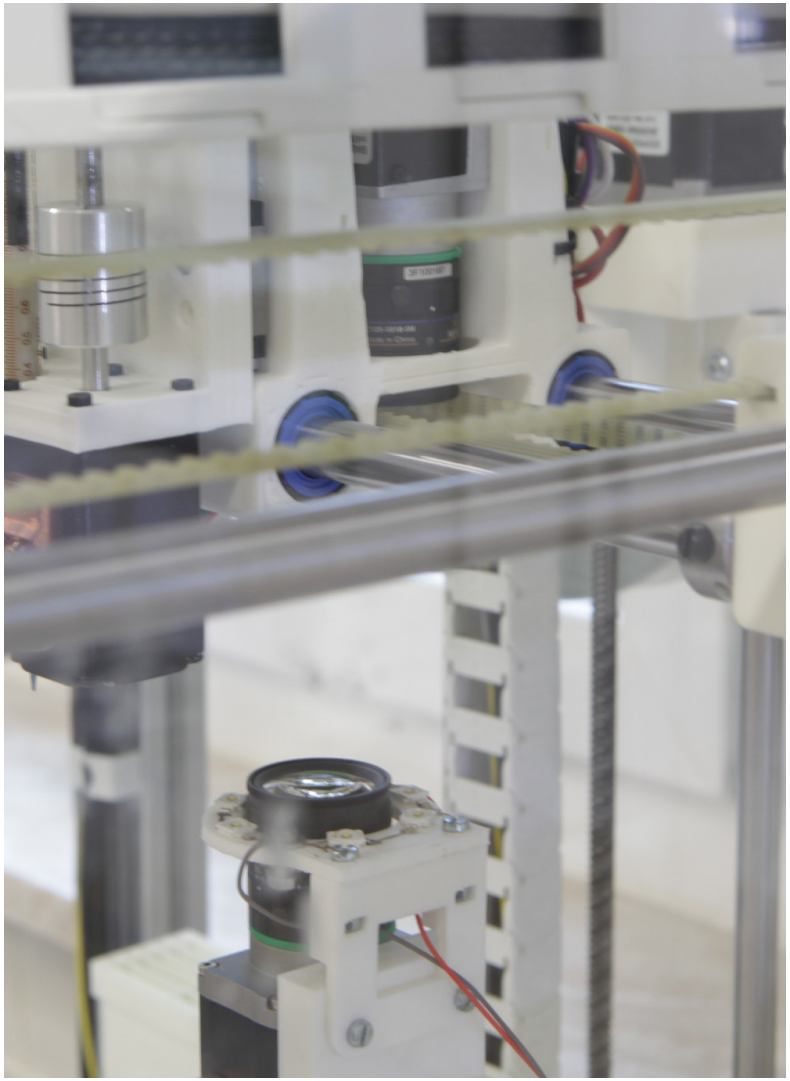




Conductive ink extruder

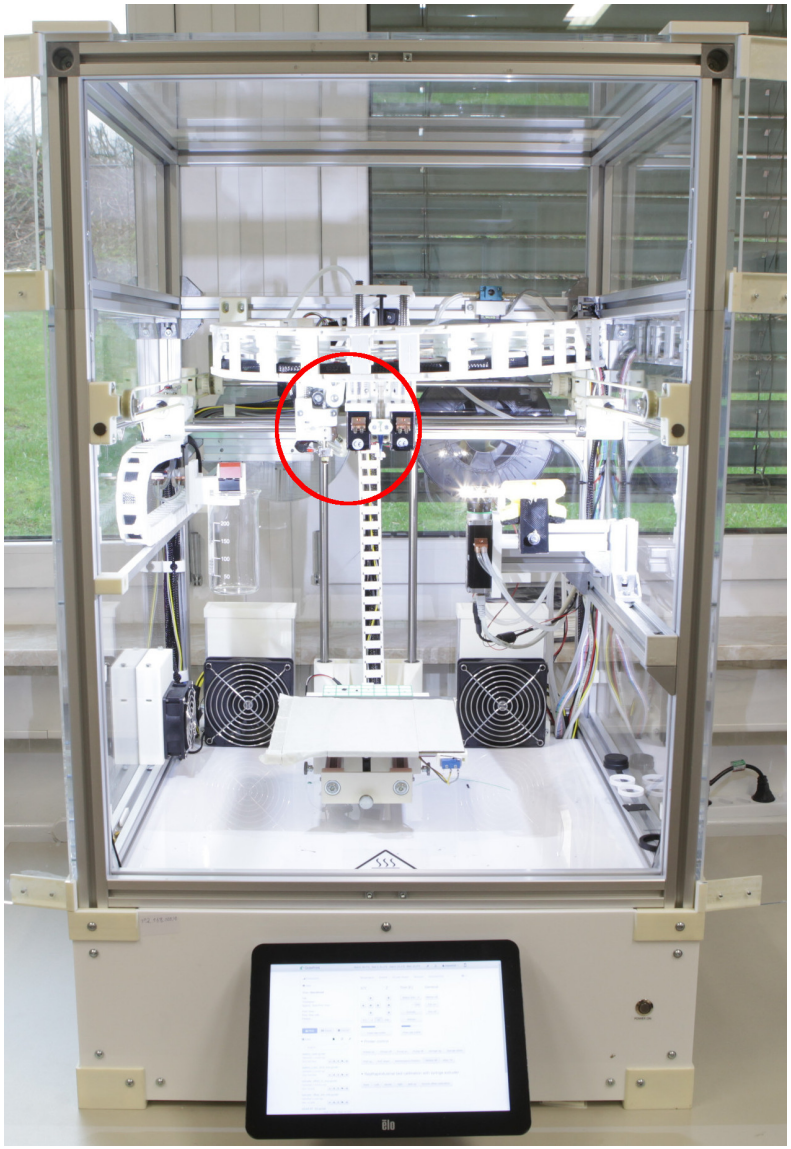
Developing the Hardware

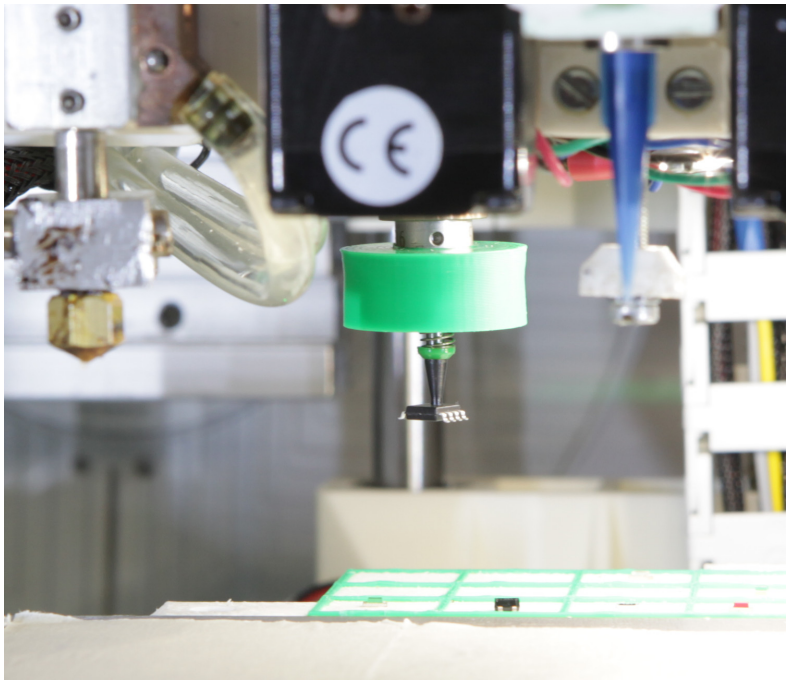




Cameras

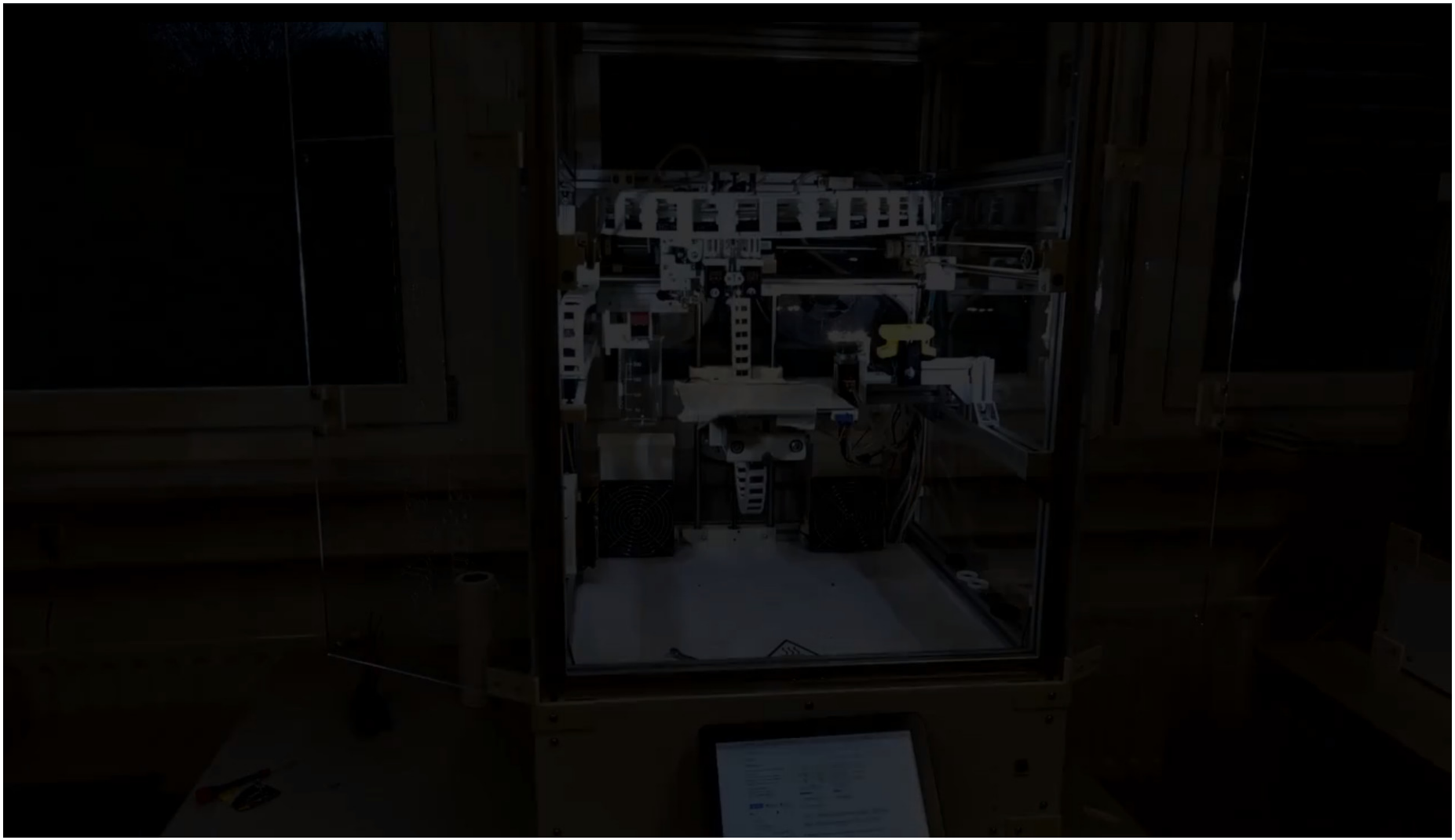
Developing the Hardware





Vacuum gripper

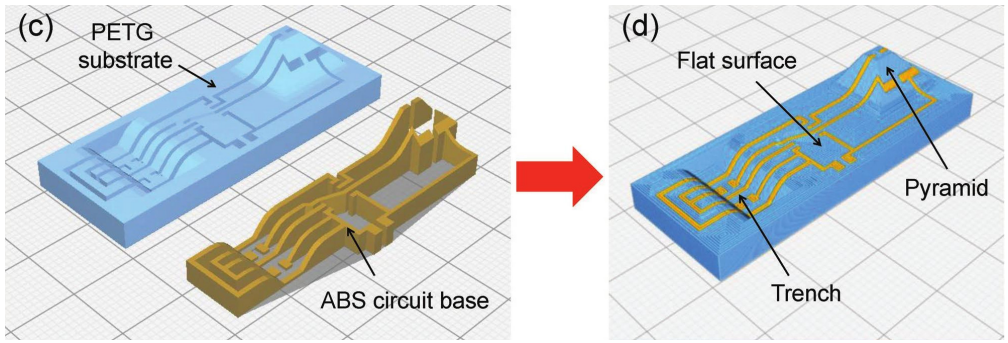
Developing the Hardware



Related Work

Current approaches

- Hand crafted CAD design
- Folding / mapping of PCB layouts
- Autodesk Project Wire
- Augmented CAM Processors
- Nextra / Target 3001!



[Ji Li et al. *Hybrid Additive Manufacturing Method for Selective Plating of Freeform Circuitry on 3D Printed Plastic Structure, 2019*]

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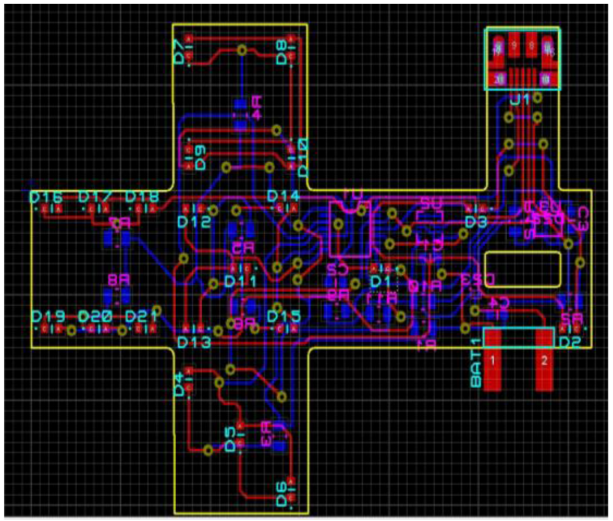

[MacDonald et al. *3D Printing for the Rapid Prototyping of Structural Electronics, 2014*]

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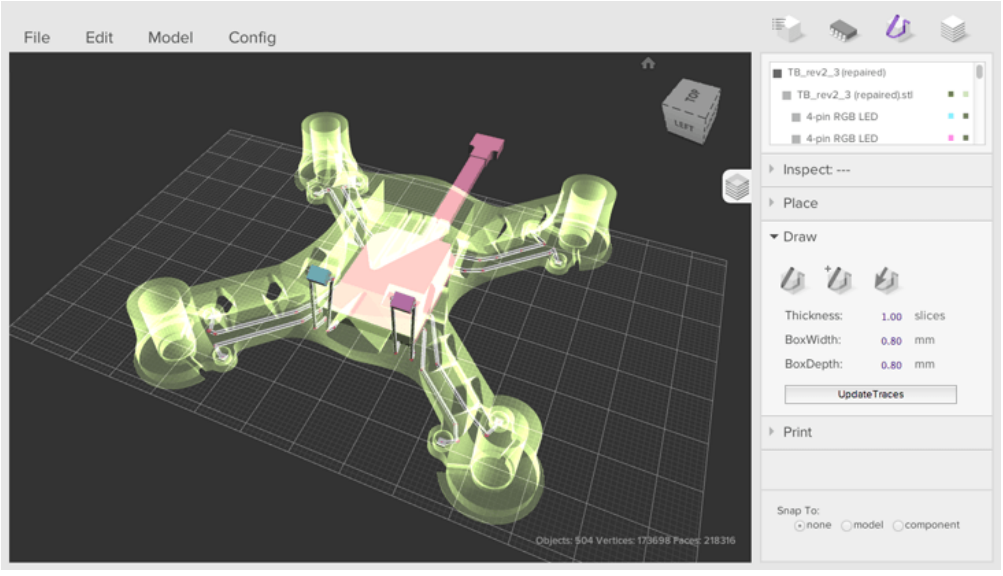

[Autodesk]

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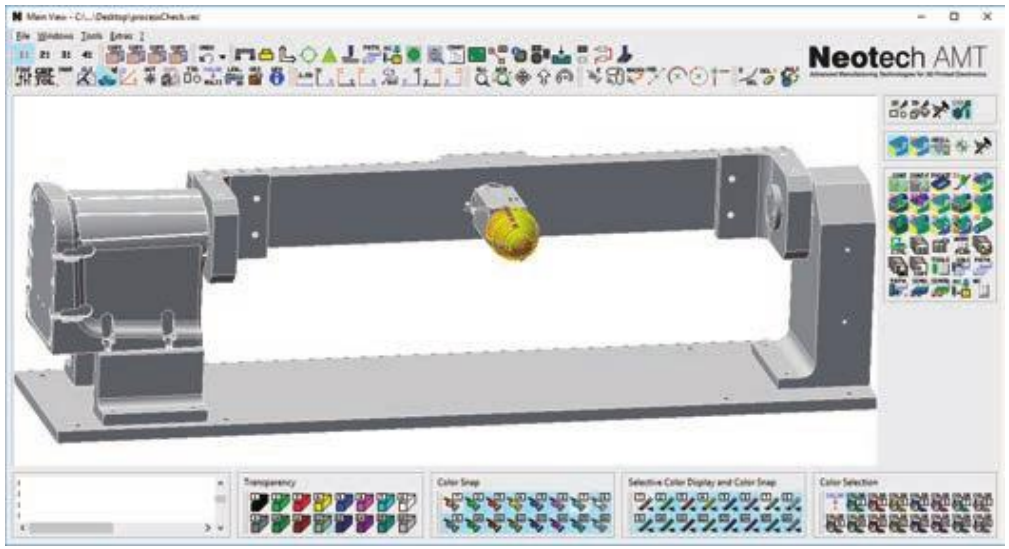

[Ankenbrand et al. *Mechatronic Integrated Devices, 2019*]

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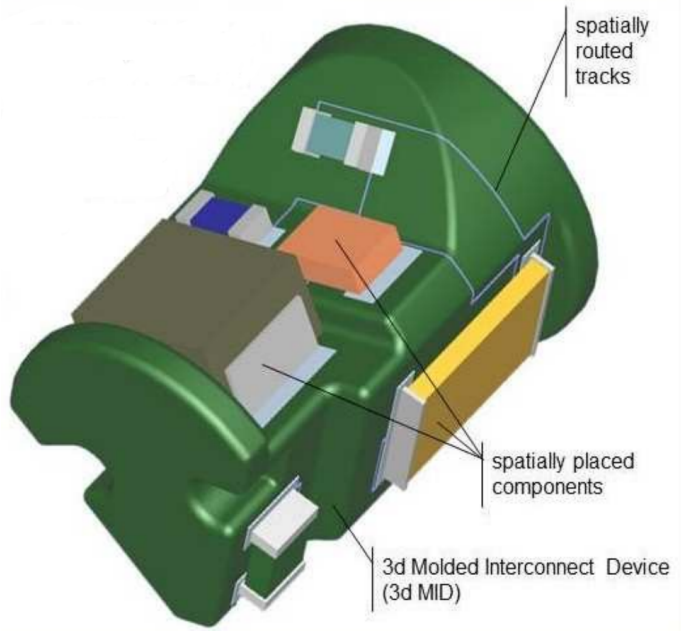
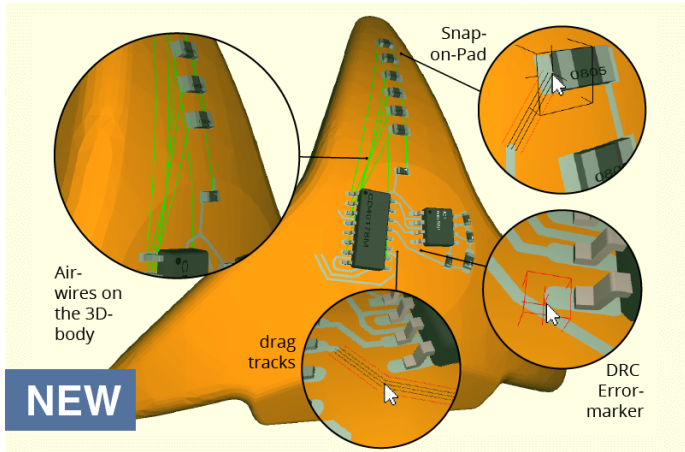




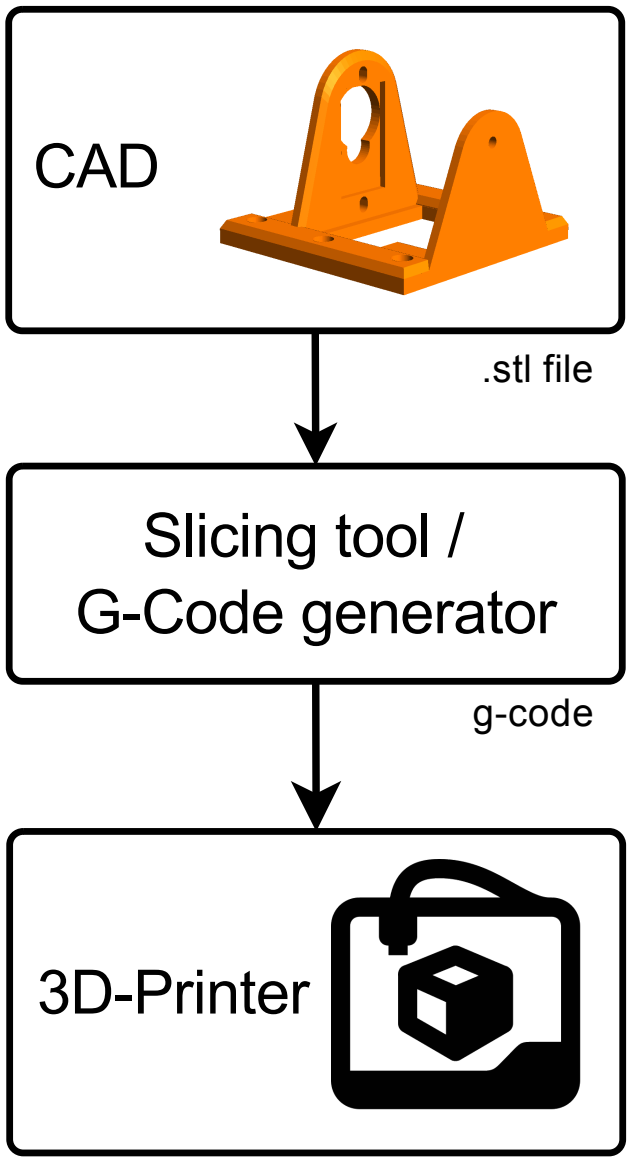
[Mecadtron / IB Friedrich website screenshots]

CAD / CAM Software

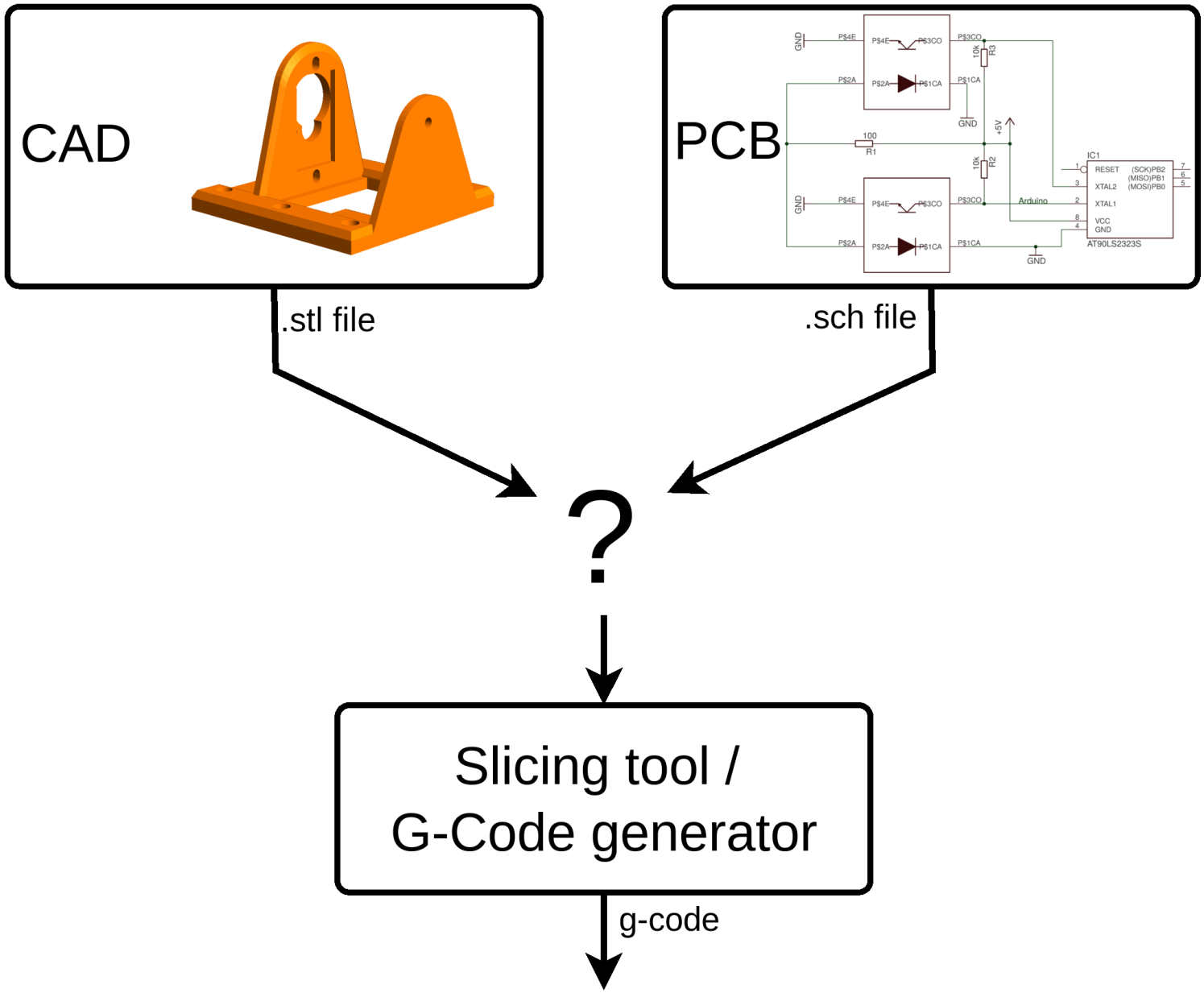
[2]: Florens Wasserfall, Daniel Ahlers, Norman Hendrich, and Jianwei Zhang.

3D-Printable Electronics - Integration of SMD Placement and Wiring into the Slicing Process for FDM Fabrication. In *Proceedings of the 27th International Solid Freeform Fabrication Symposium*, pages 1826–1837, Austin, 2016

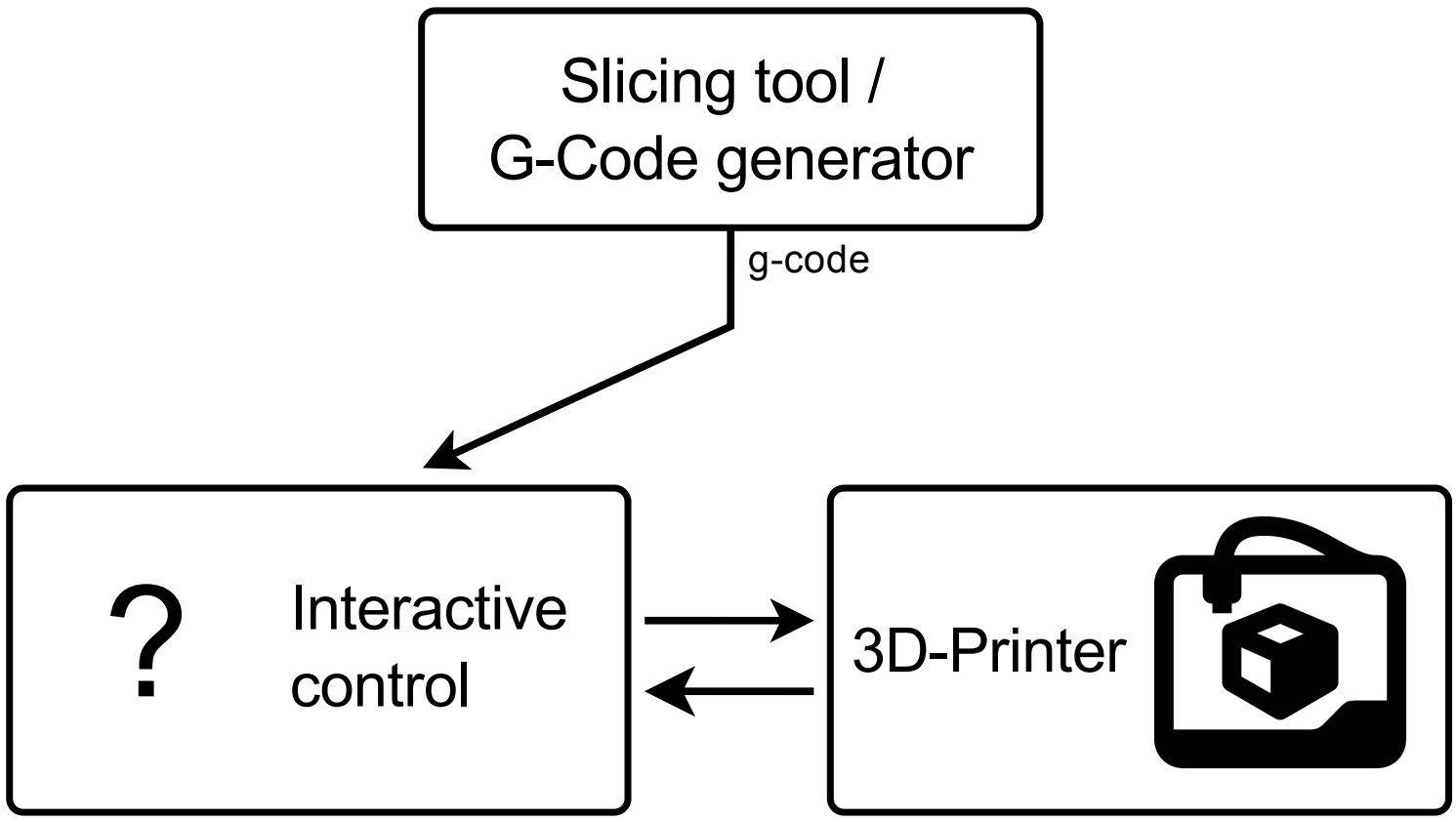
Software Tool-Chain



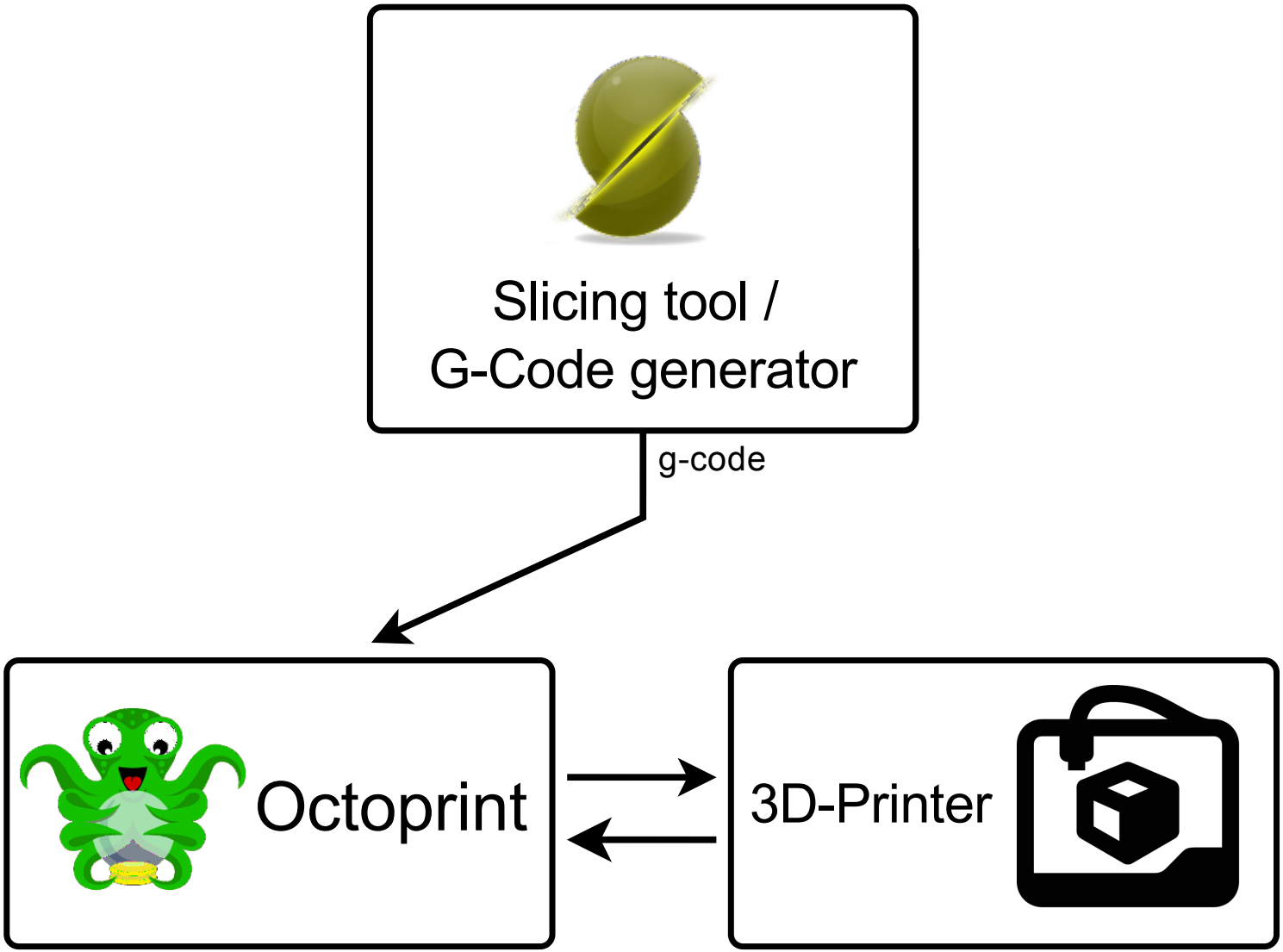
Software Tool-Chain



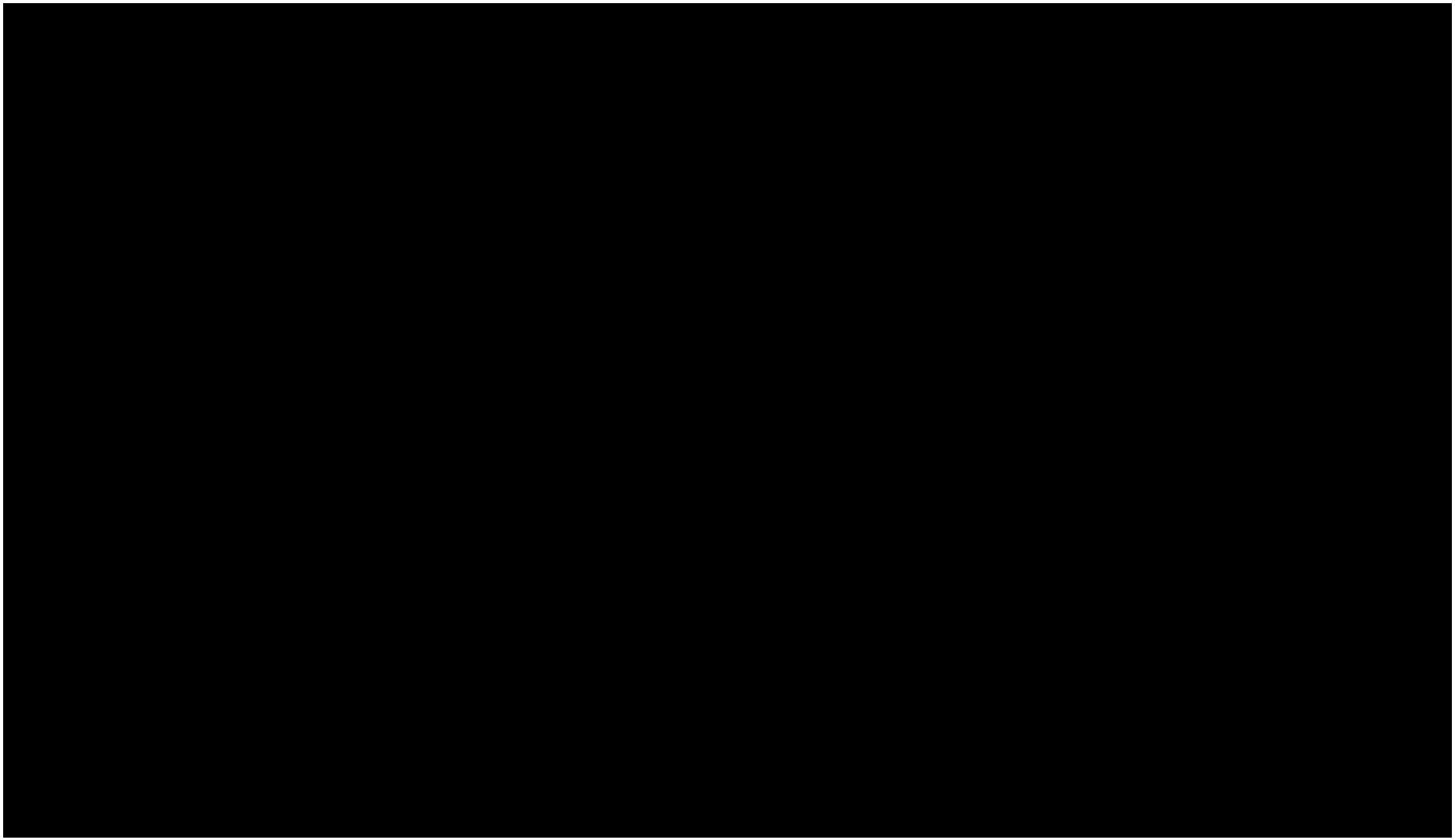
Software Tool-Chain



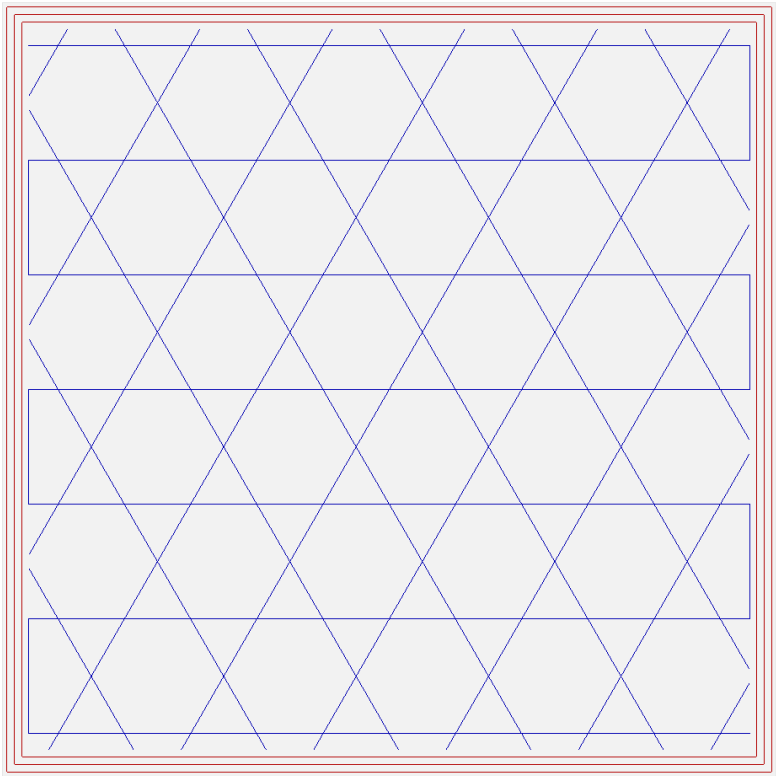
Software Tool-Chain

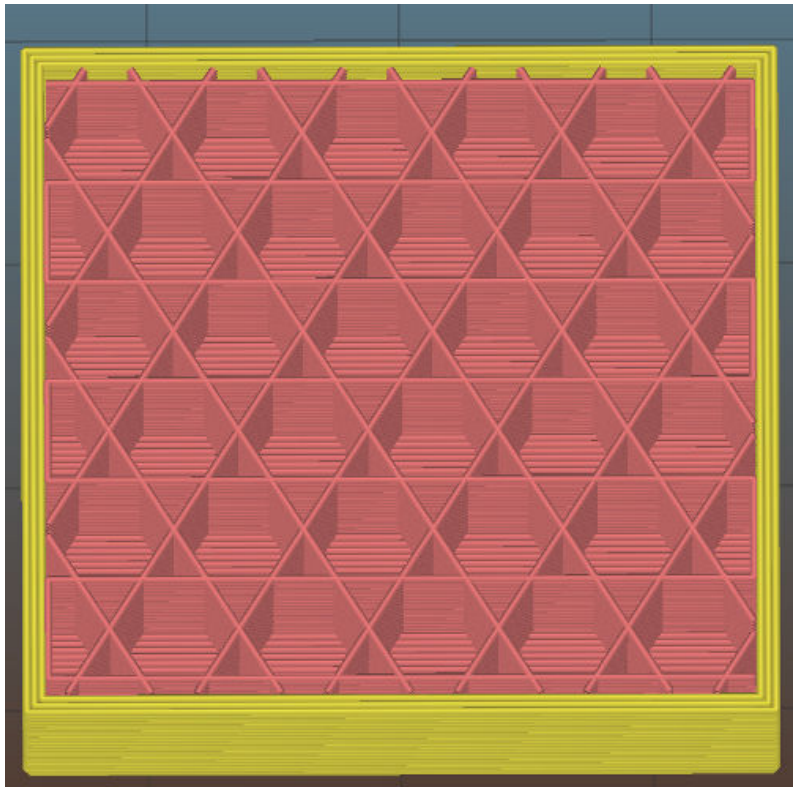


Software User Interface



Wire generation





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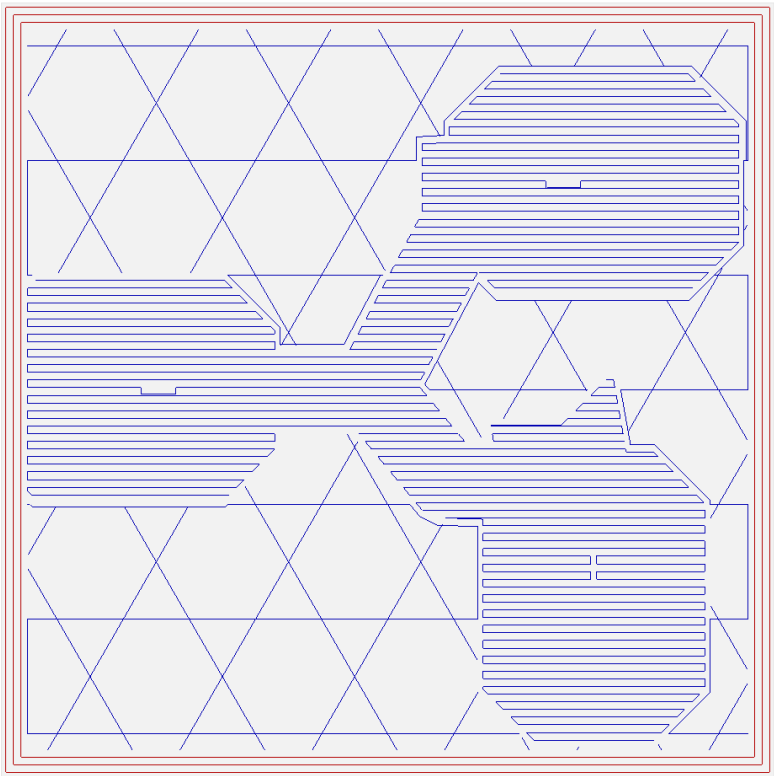
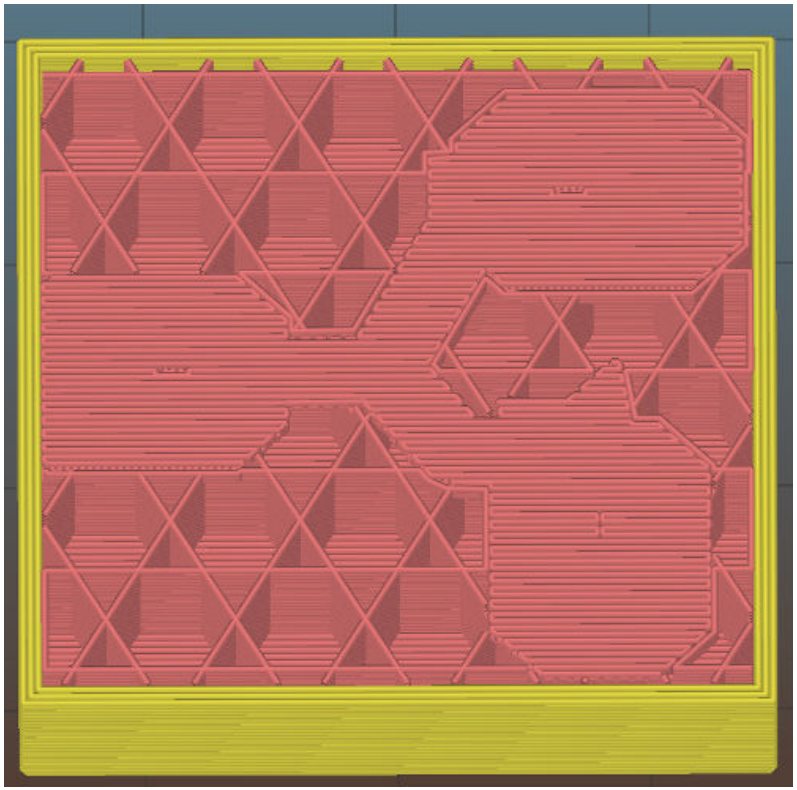
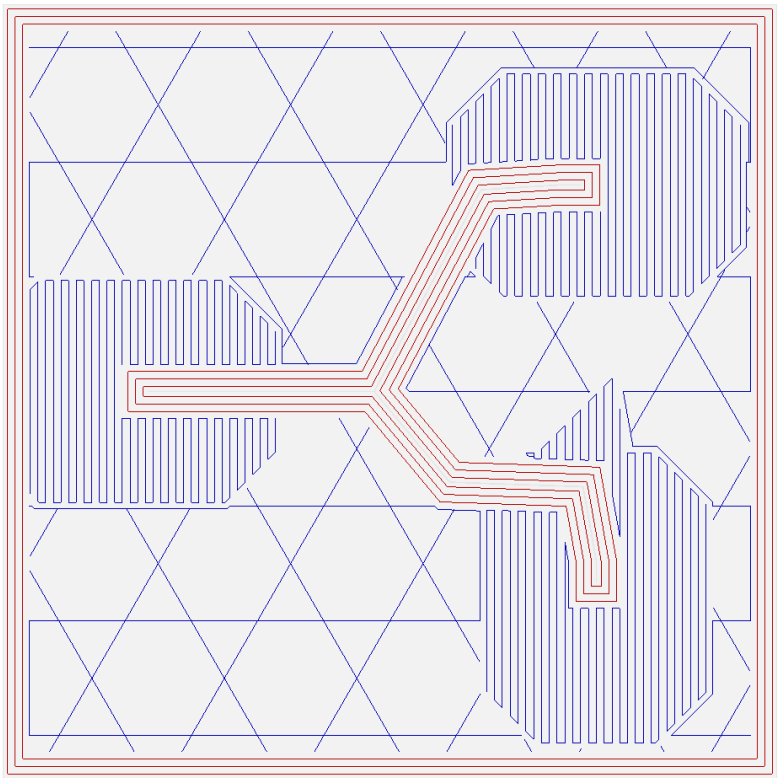
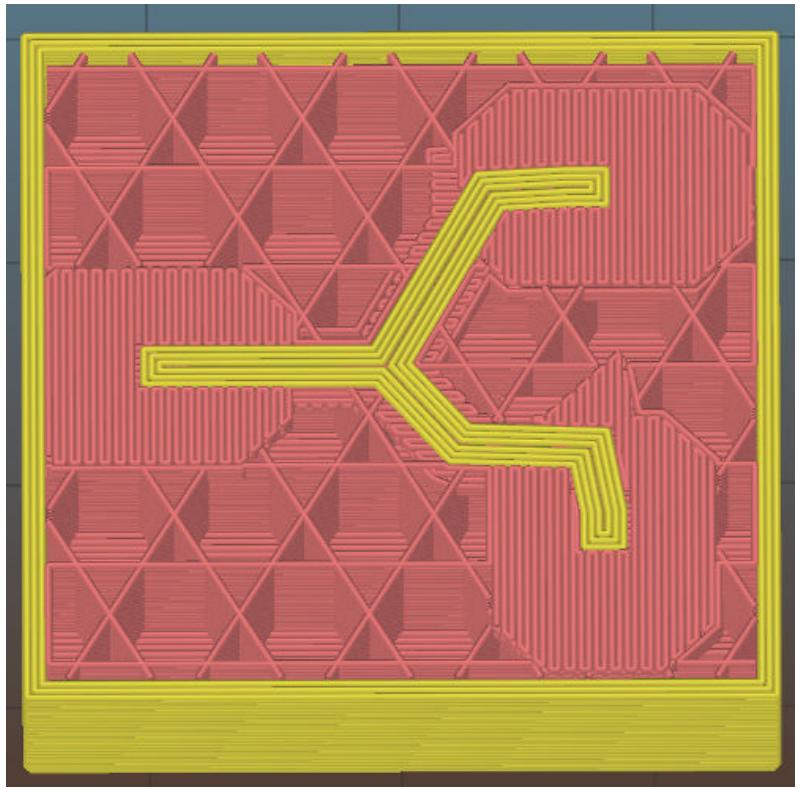




Wire generation





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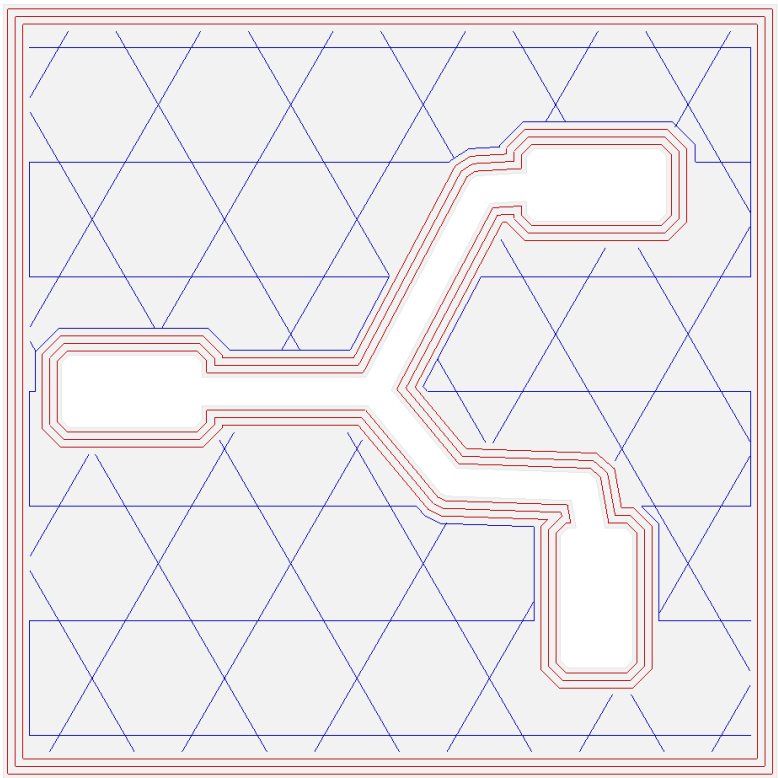
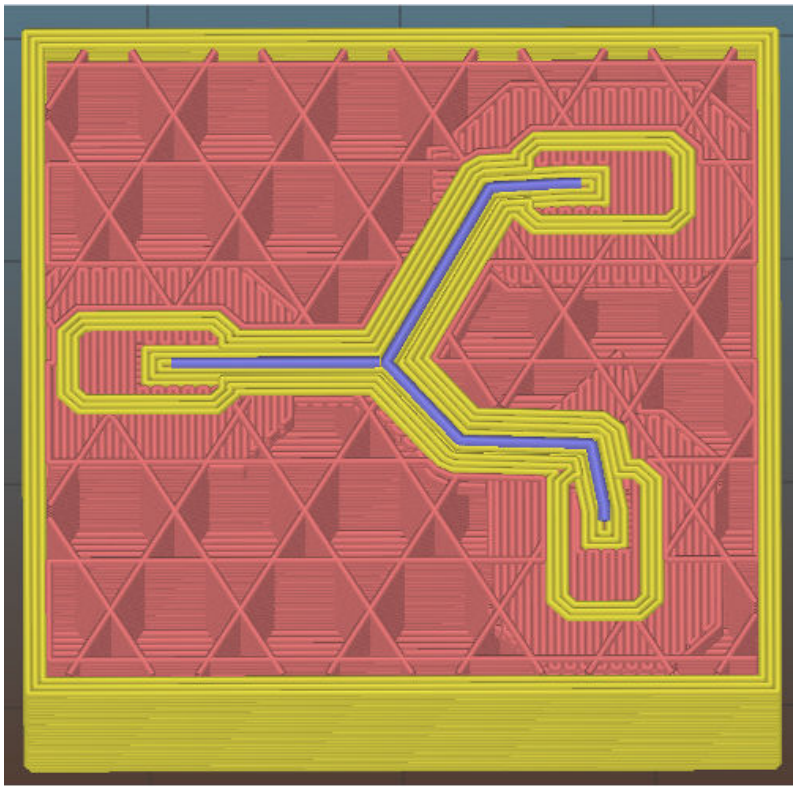
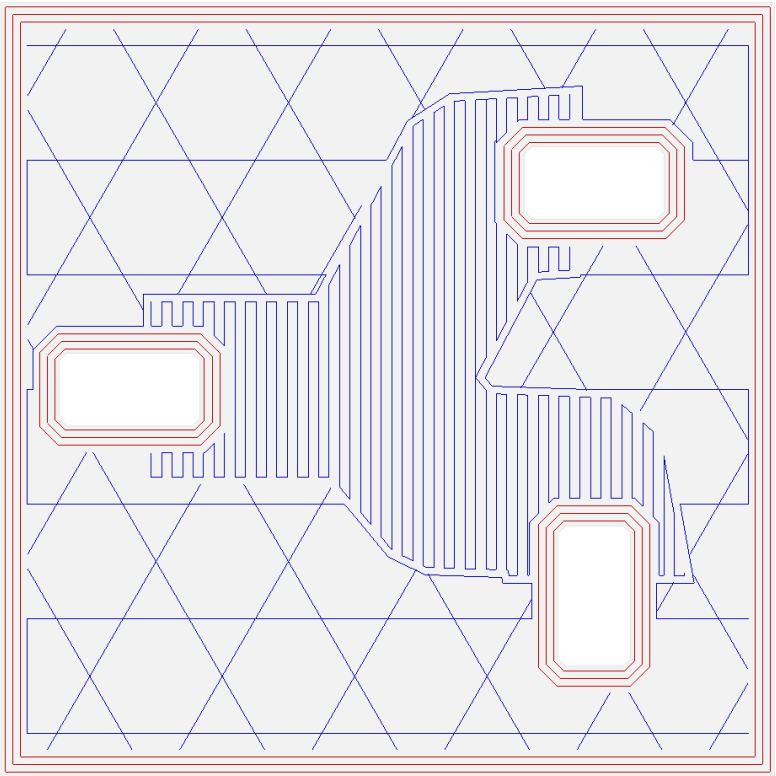
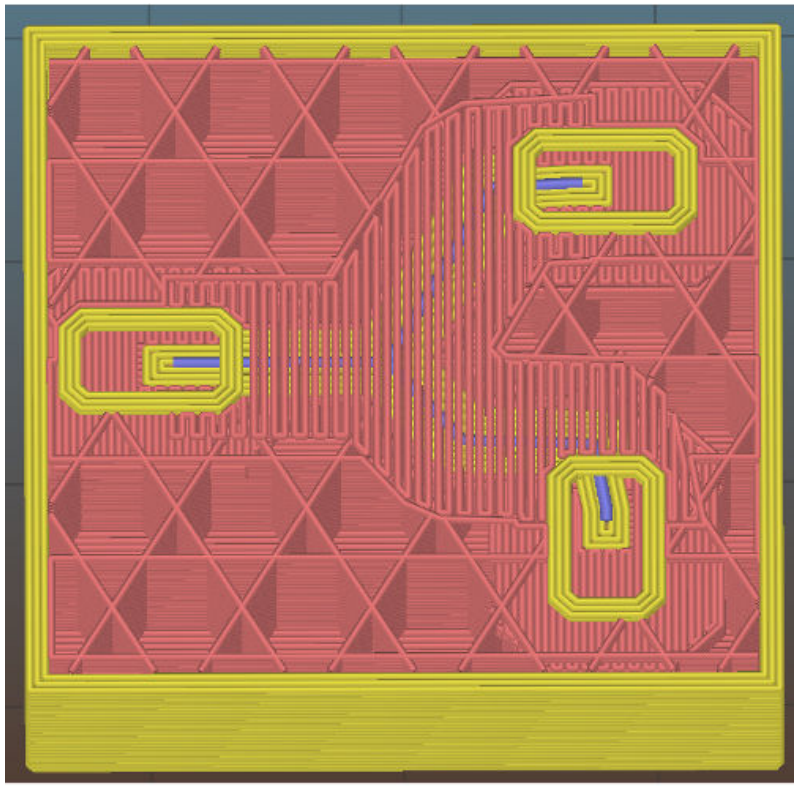




Wire generation





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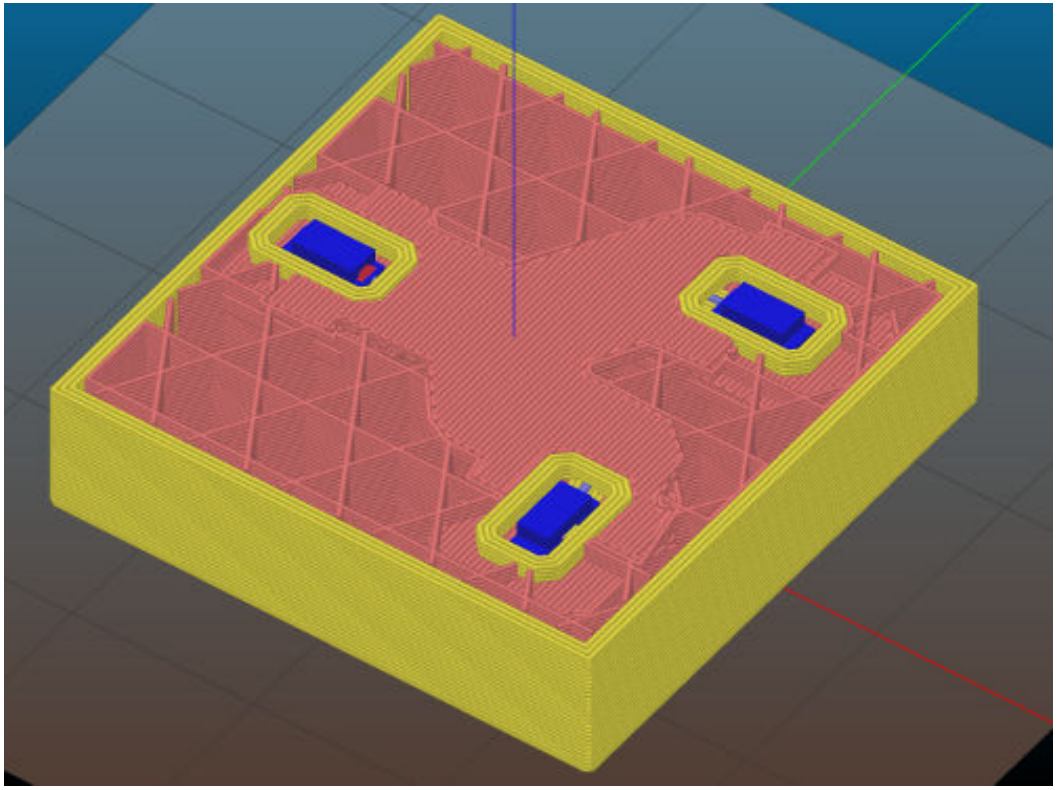

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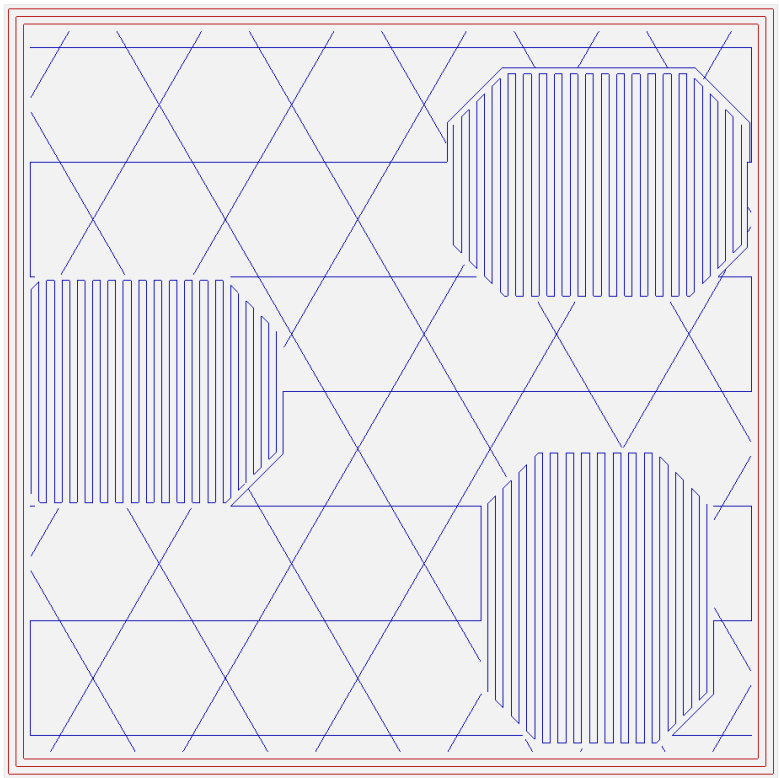
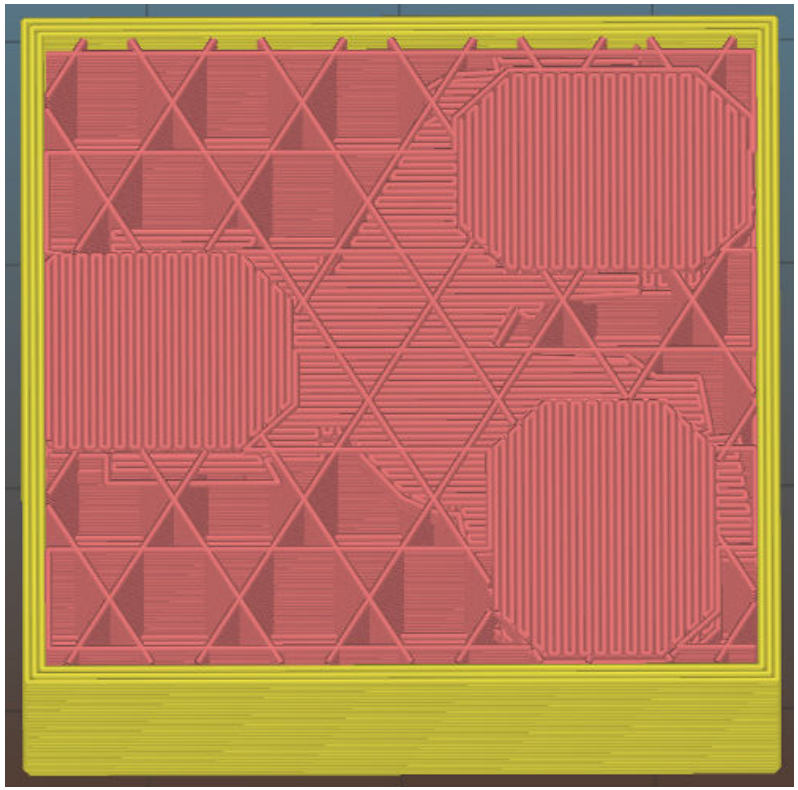
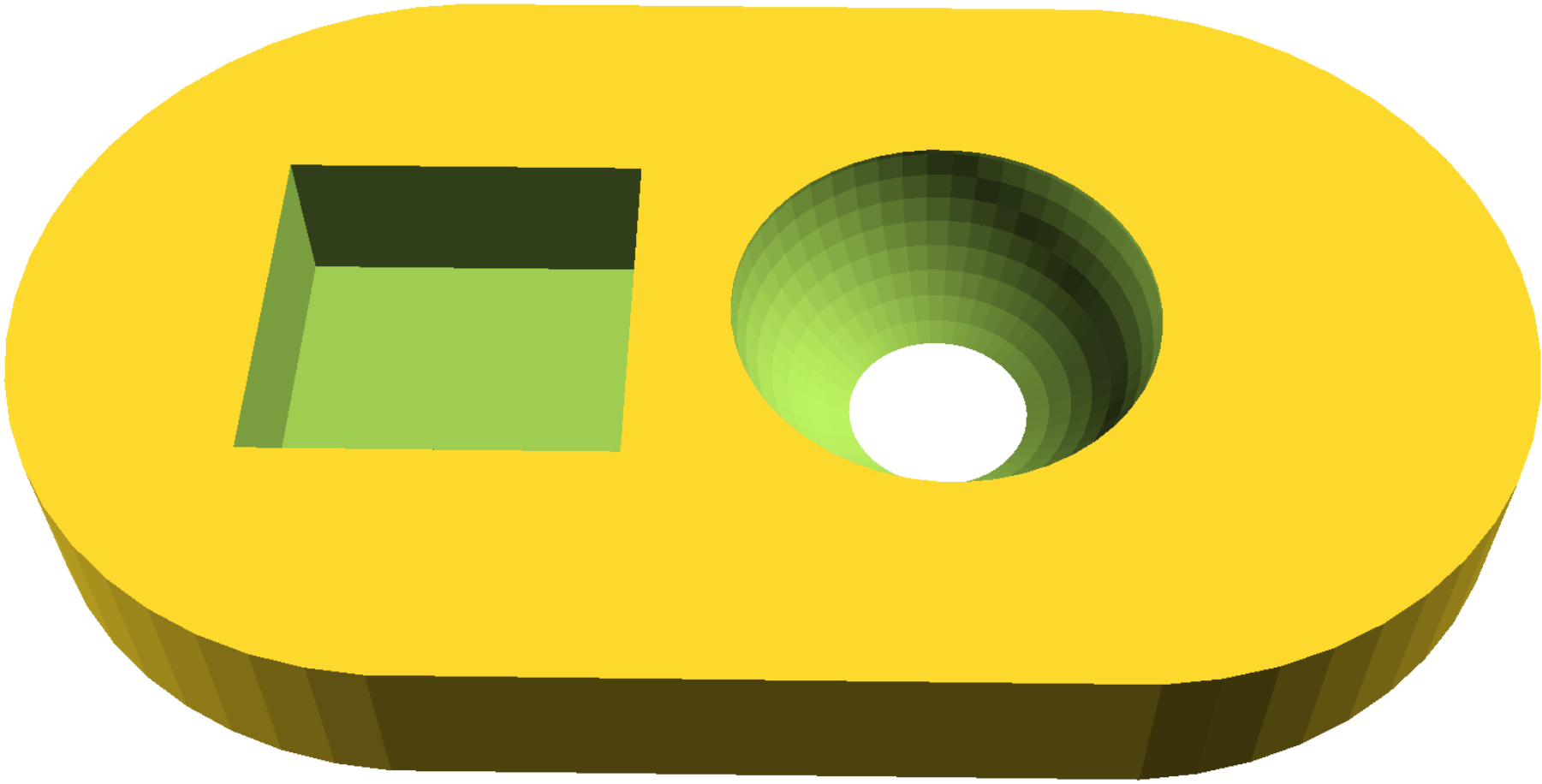




Routing

[3]: Florens Wasserfall. Topology-Aware Routing of Electric Wires in FDM-Printed Objects. In *Proceedings of the 29th International Solid Freeform Fabrication Symposium*, pages 1649–1659, Austin, 2018

Planar Routing



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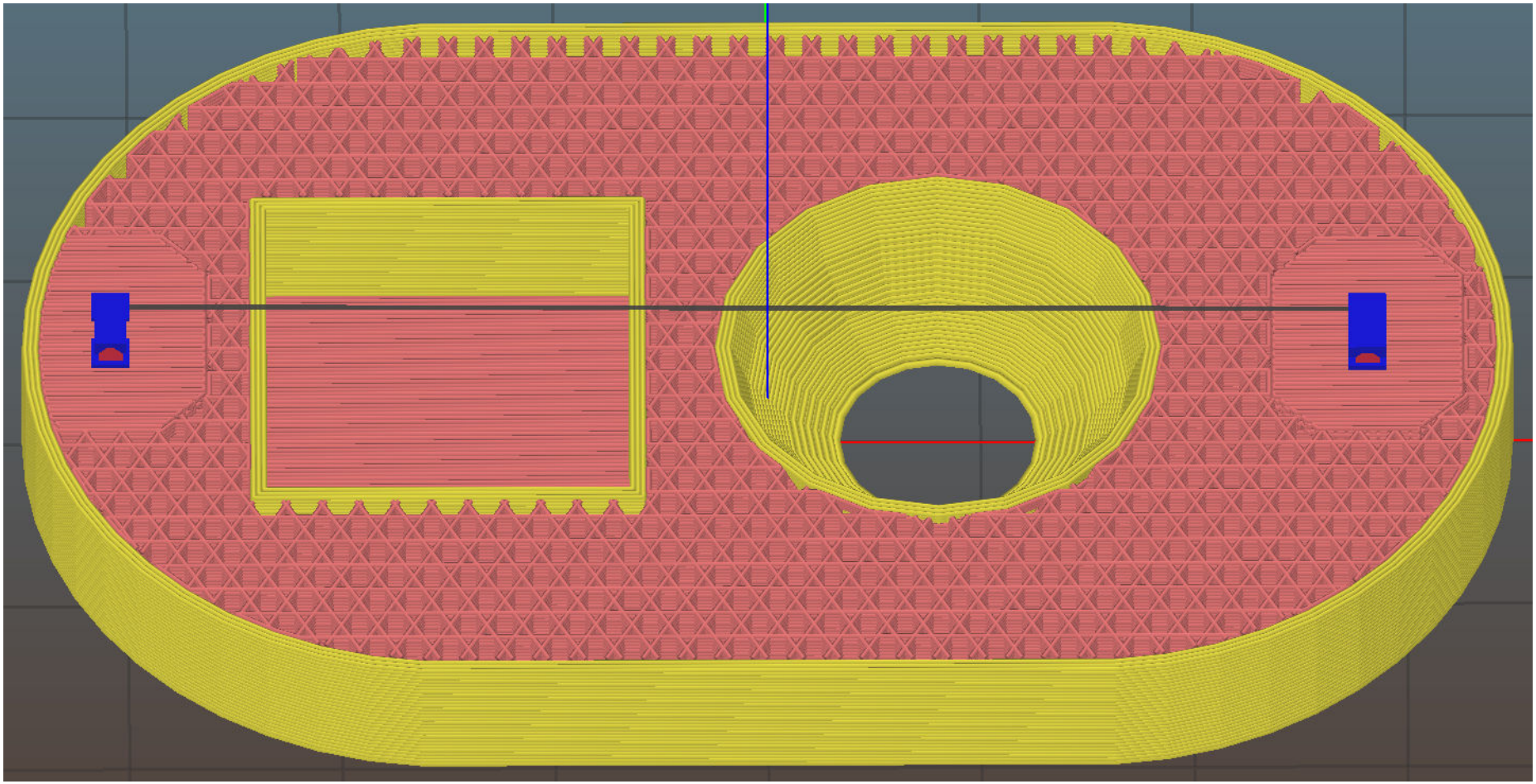

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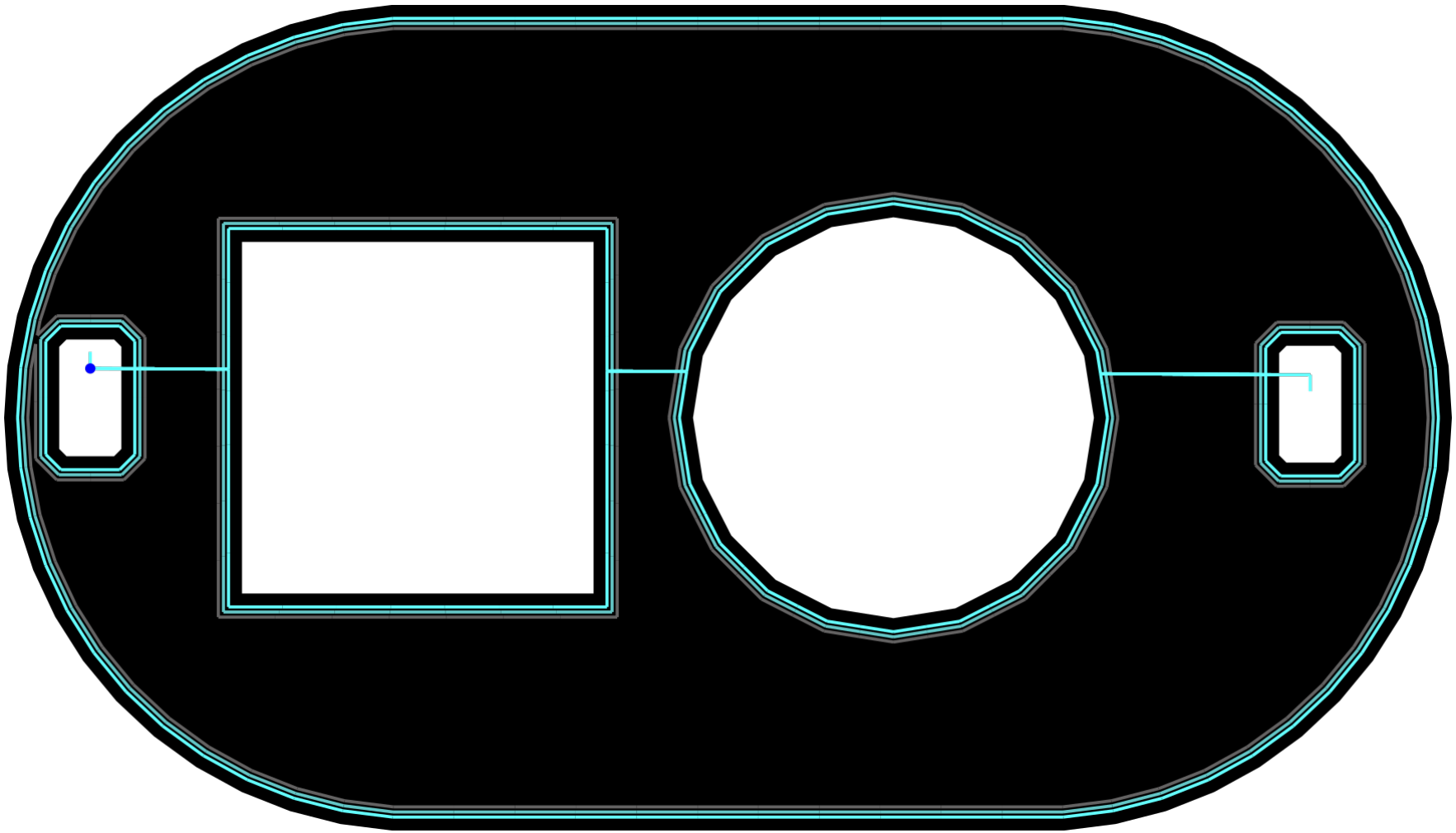

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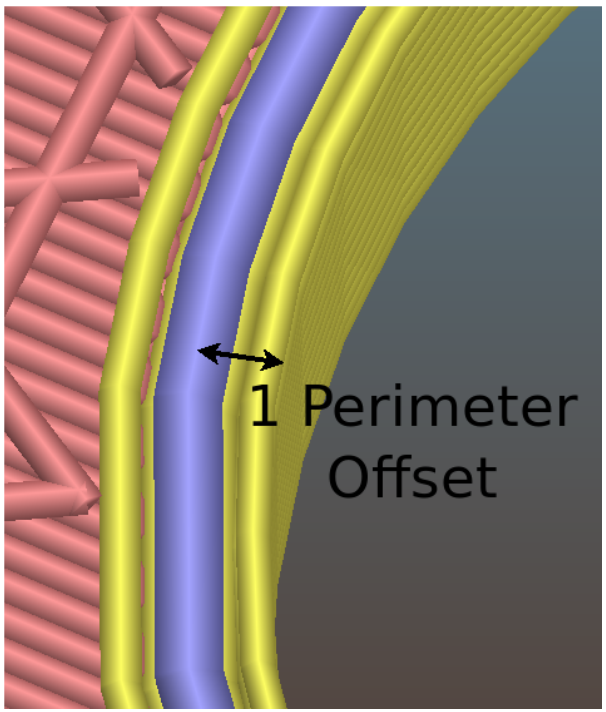

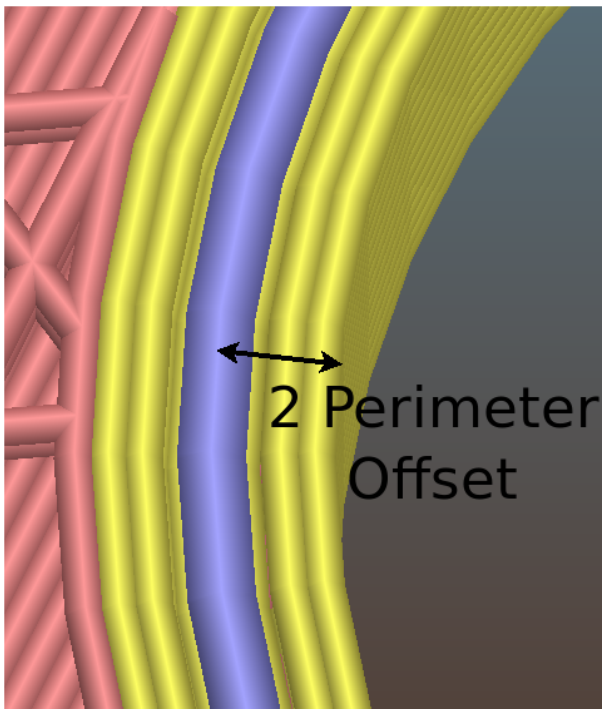

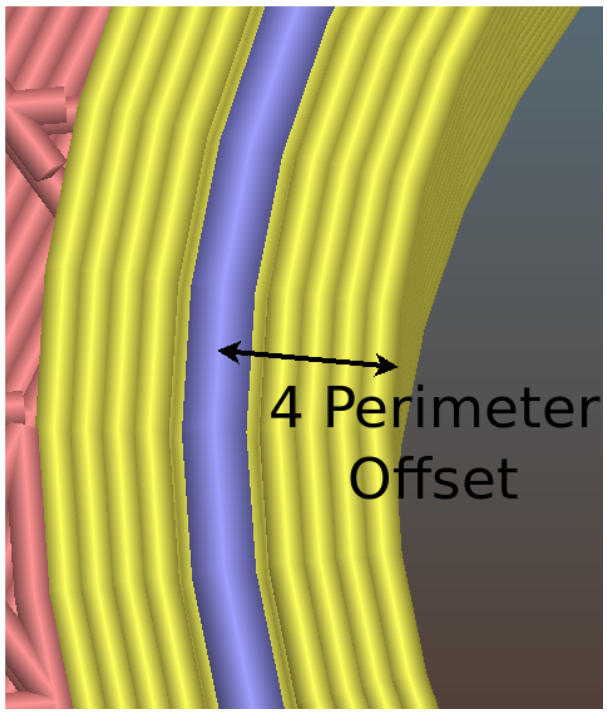

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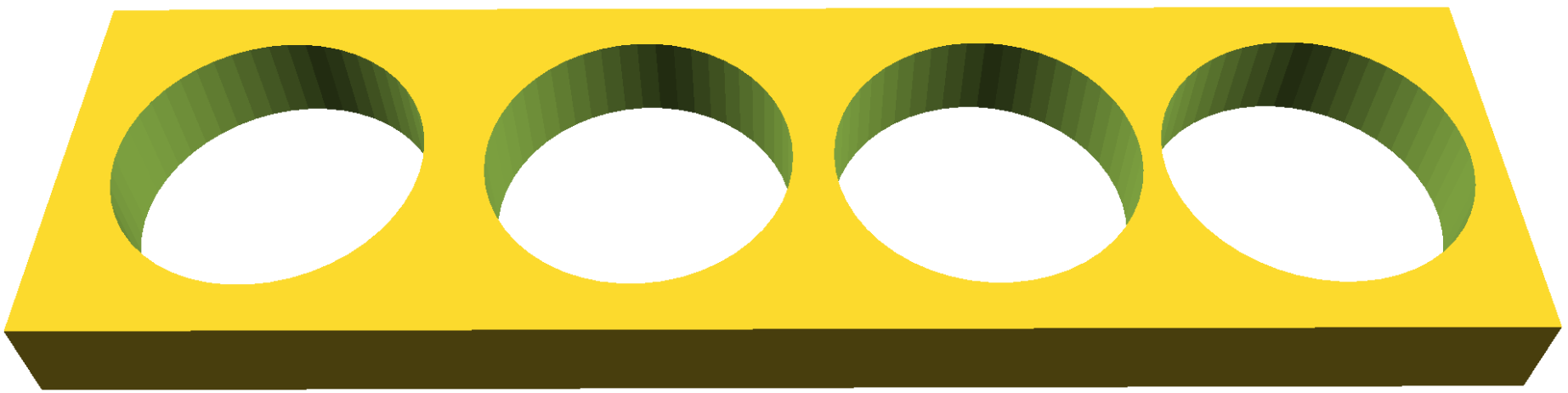

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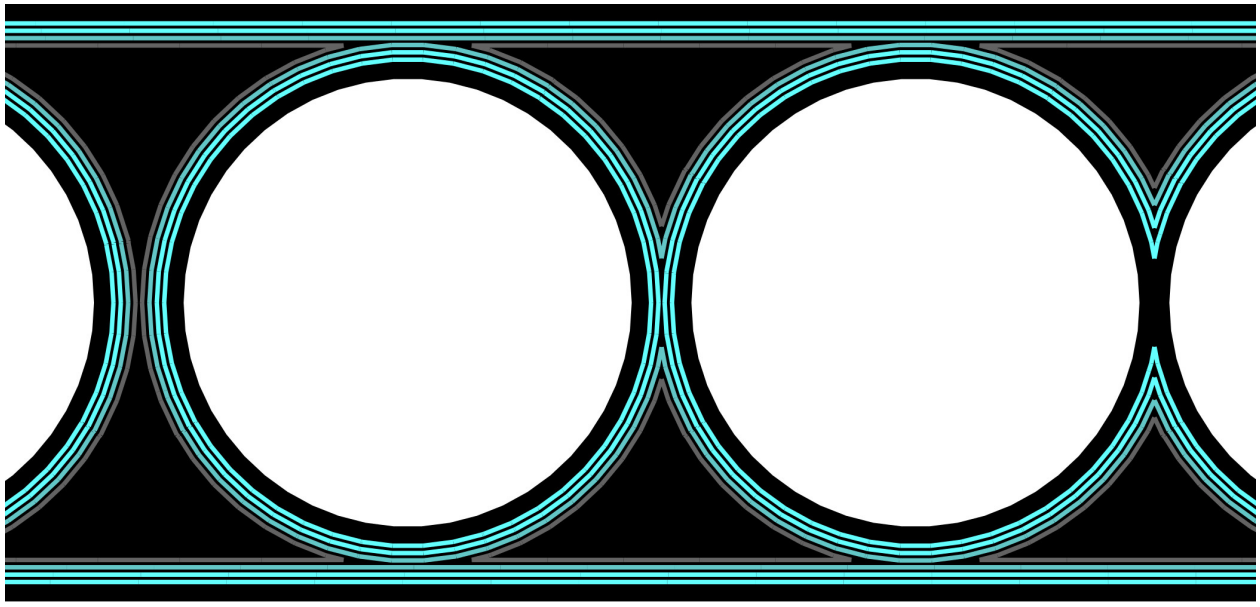

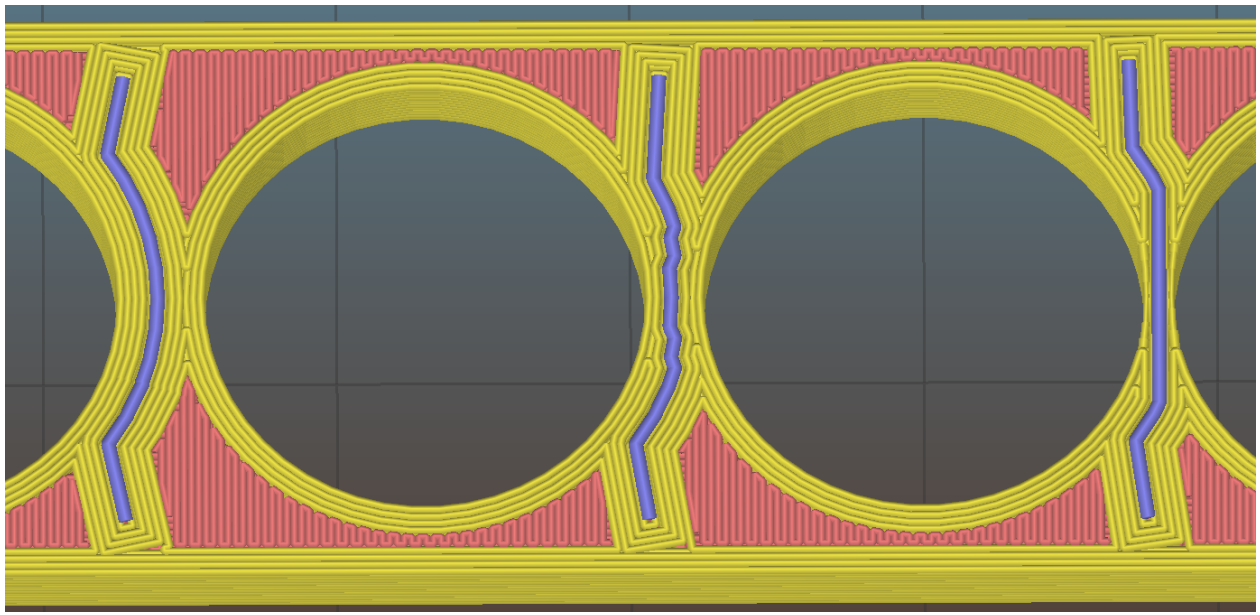

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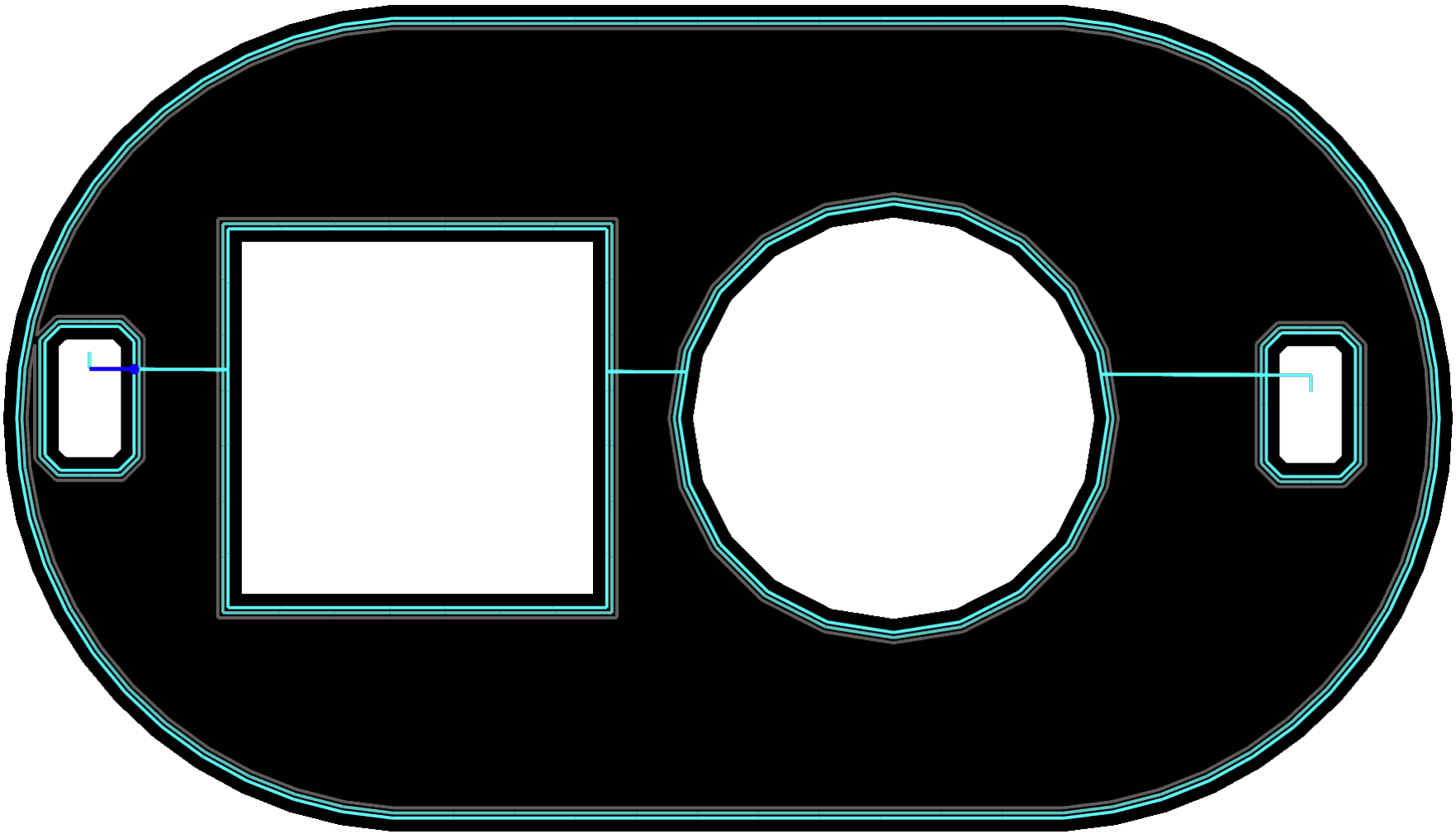

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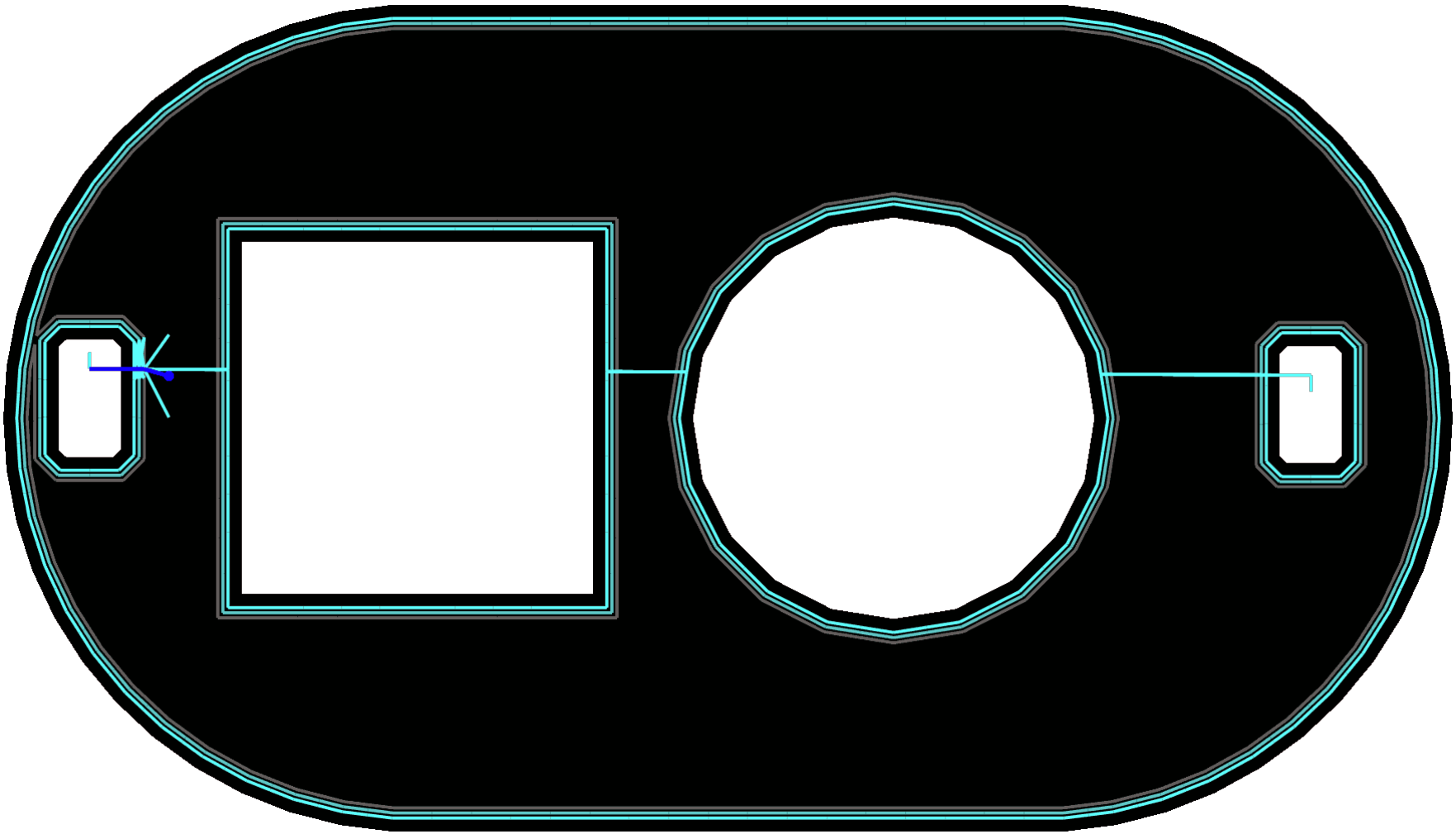

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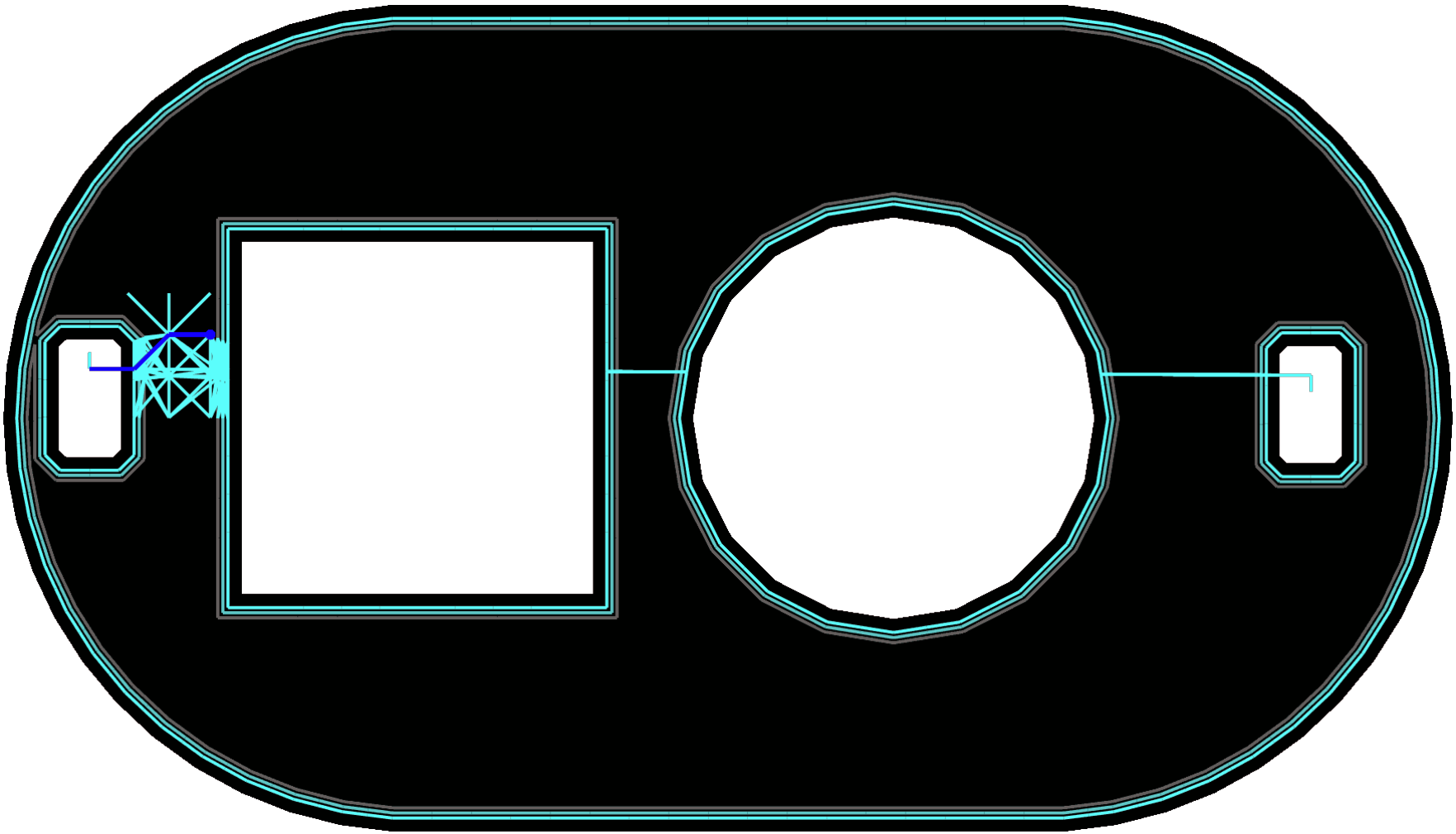

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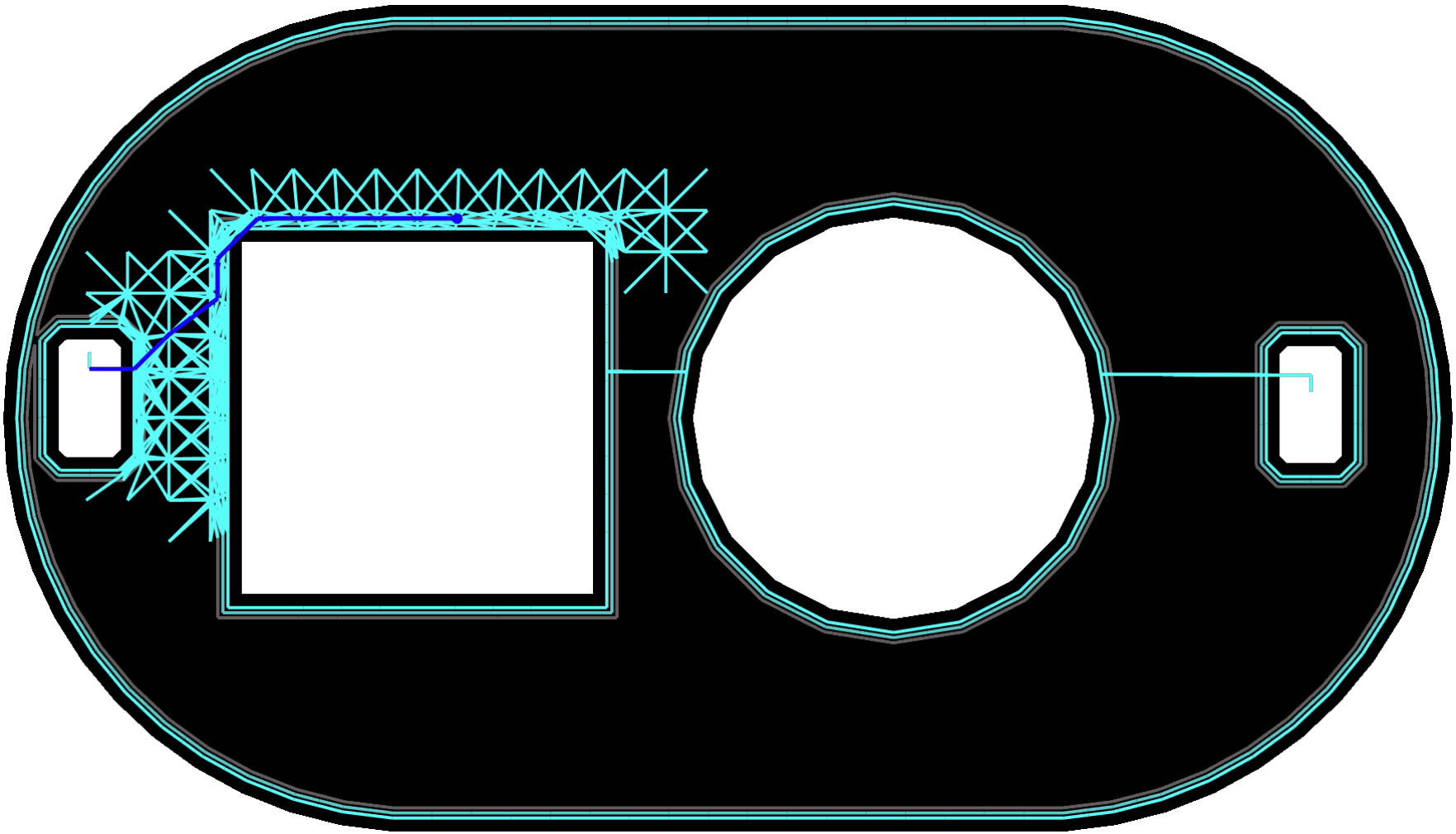
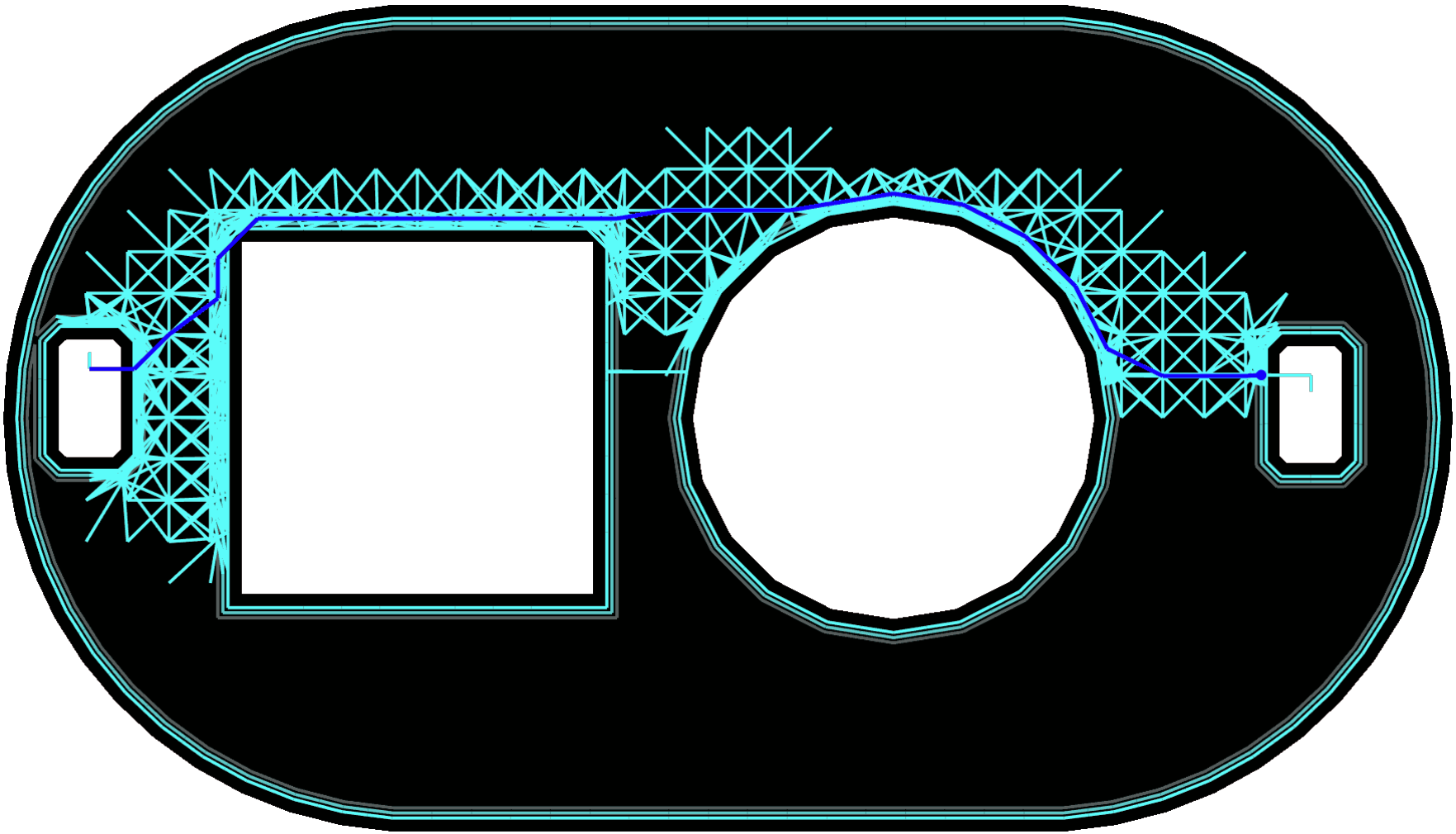
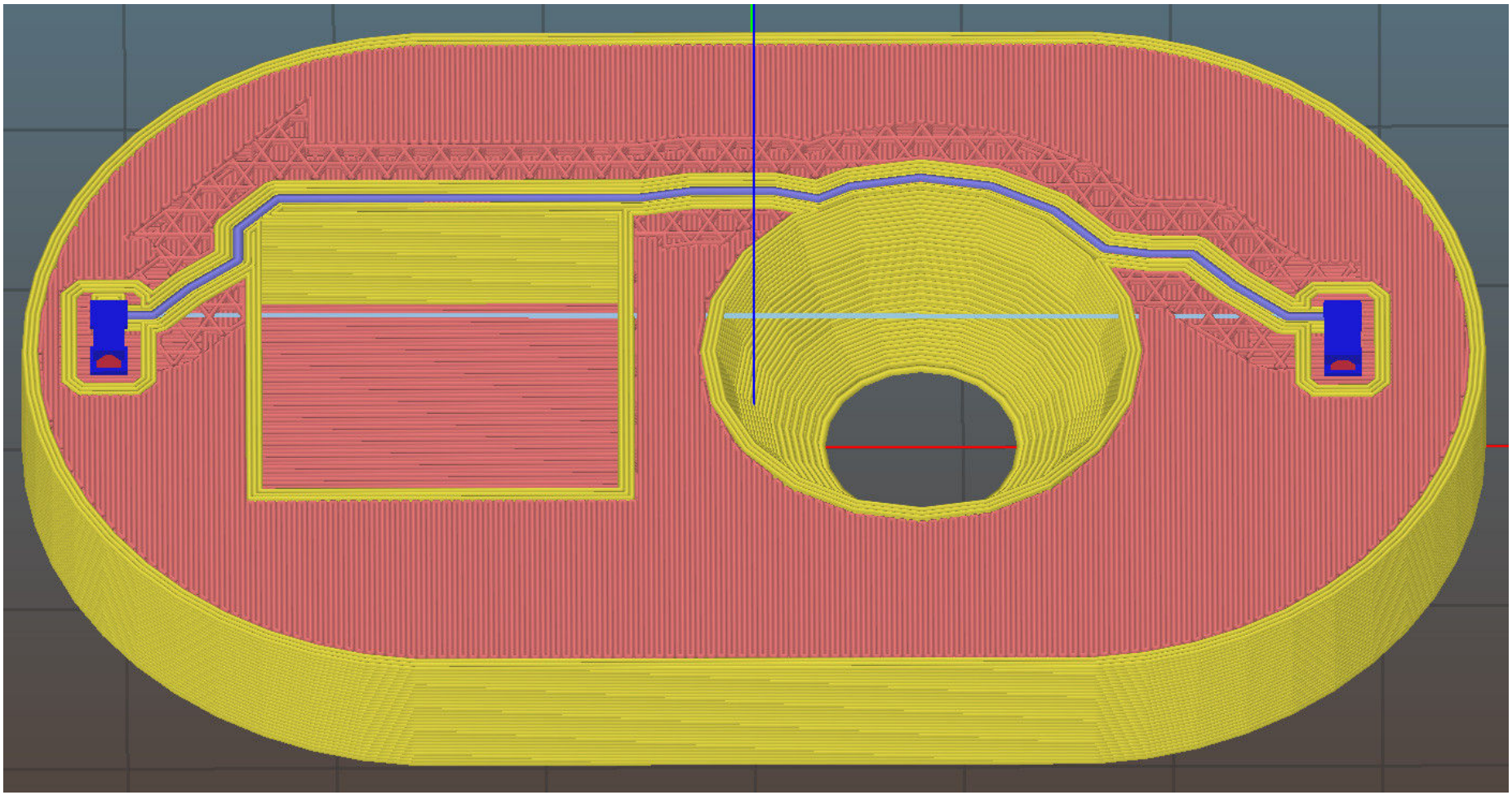


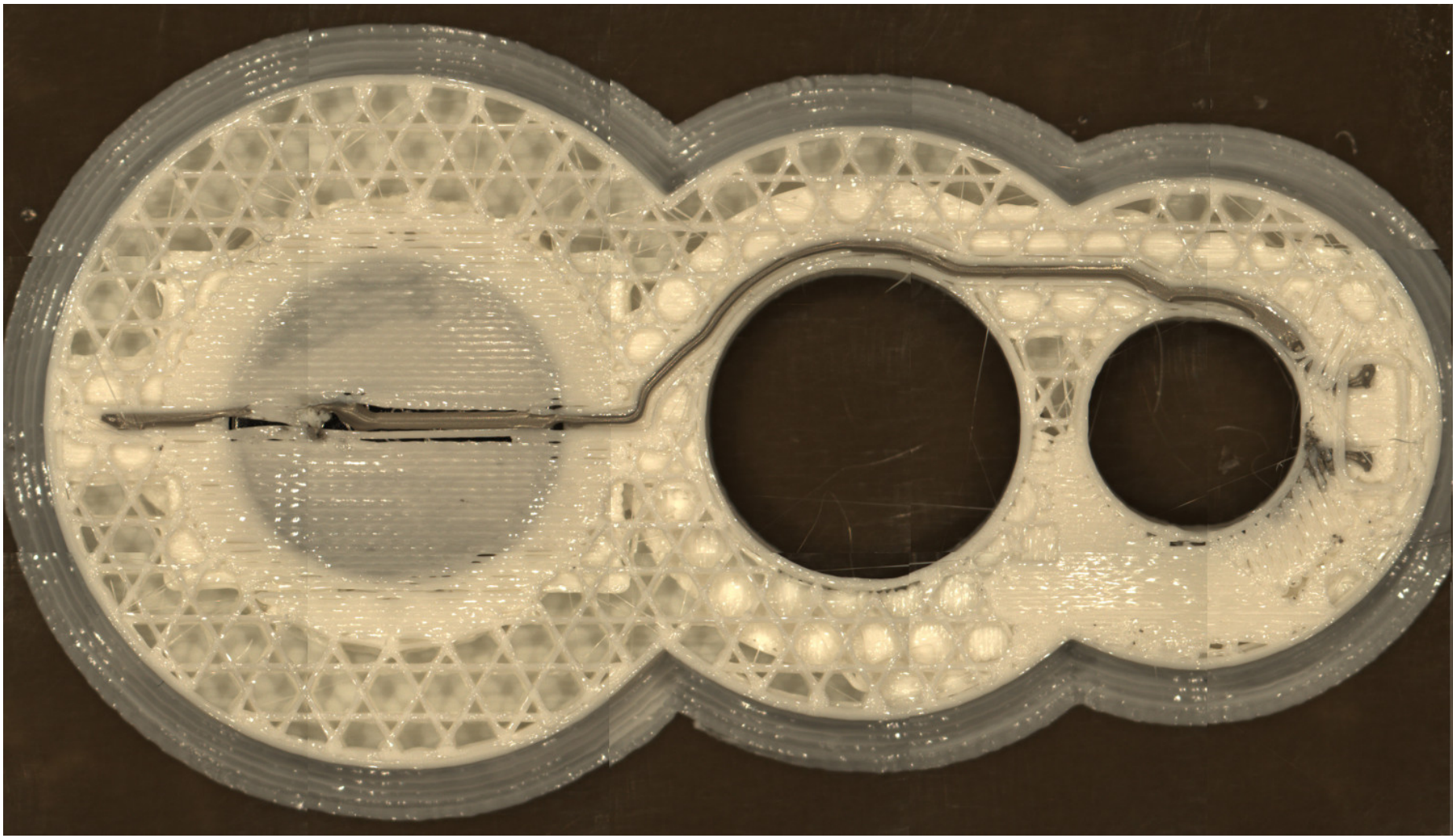
Planar Routing



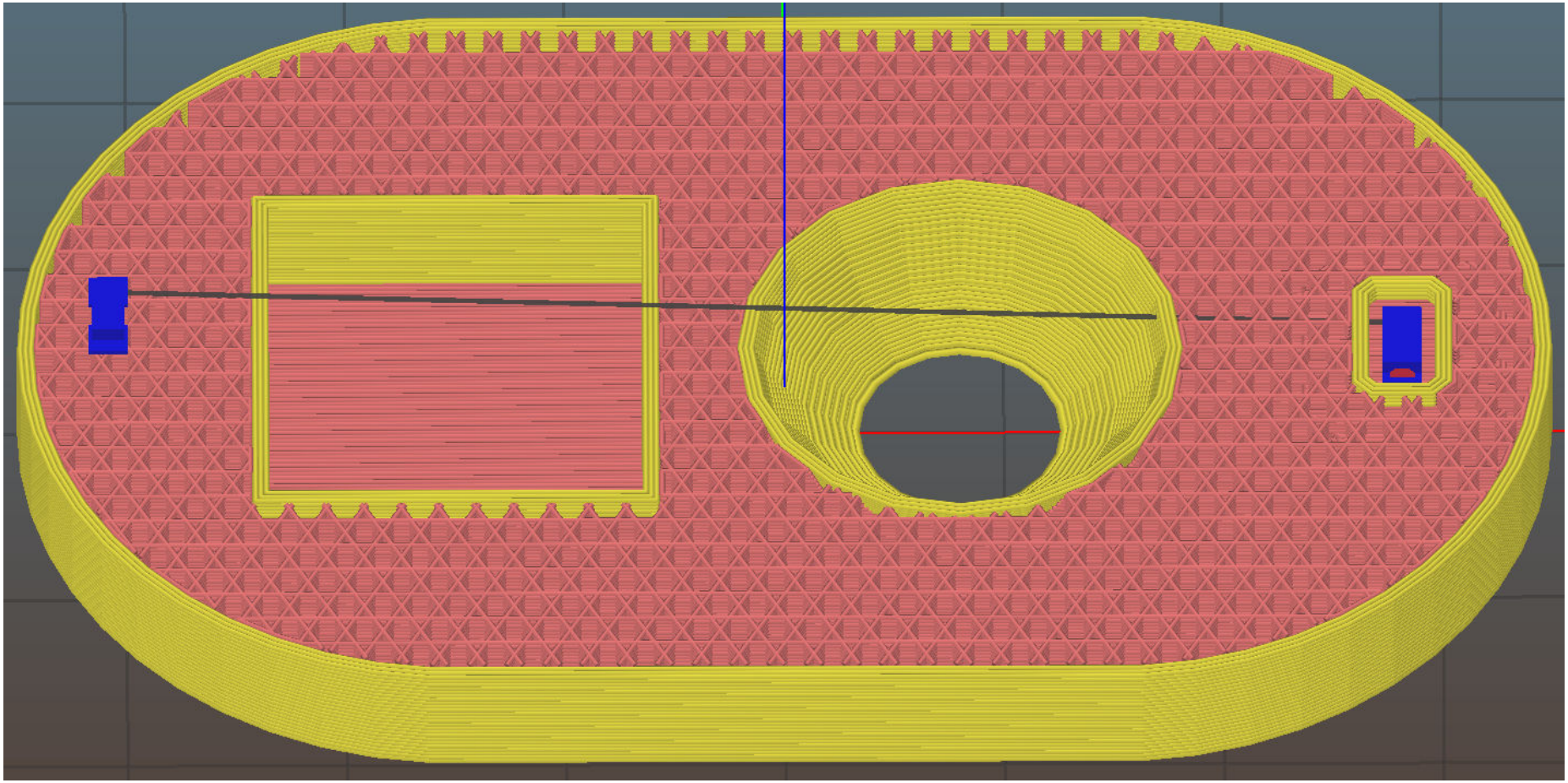
Planar Routing



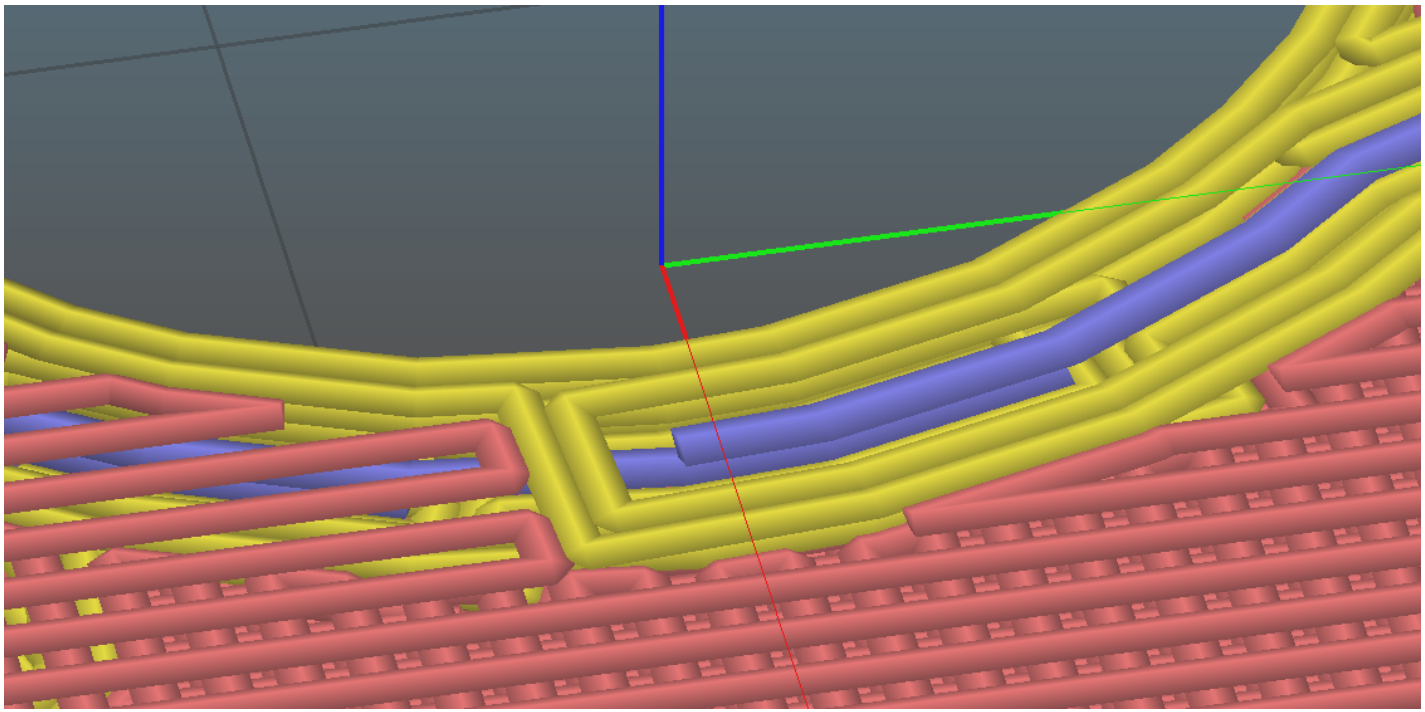
Planar Routing



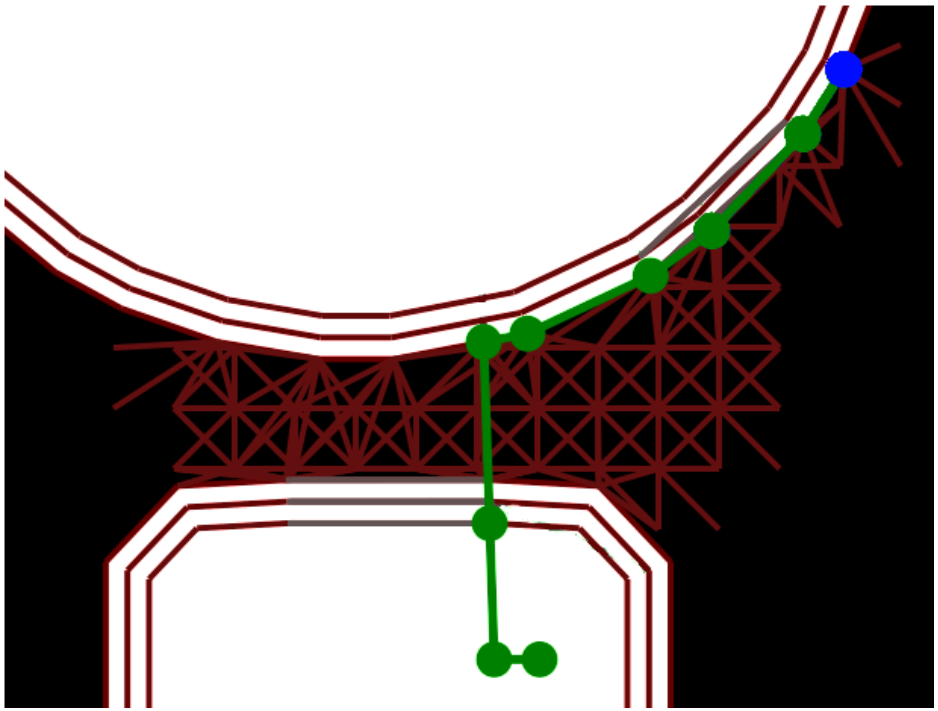
3D Routing



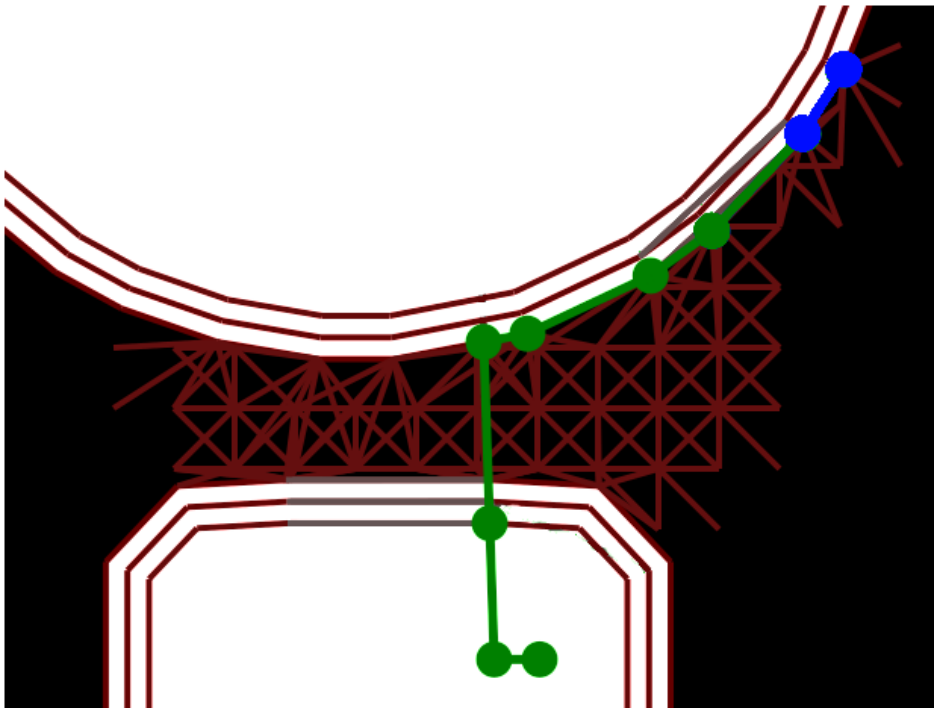
3D Routing



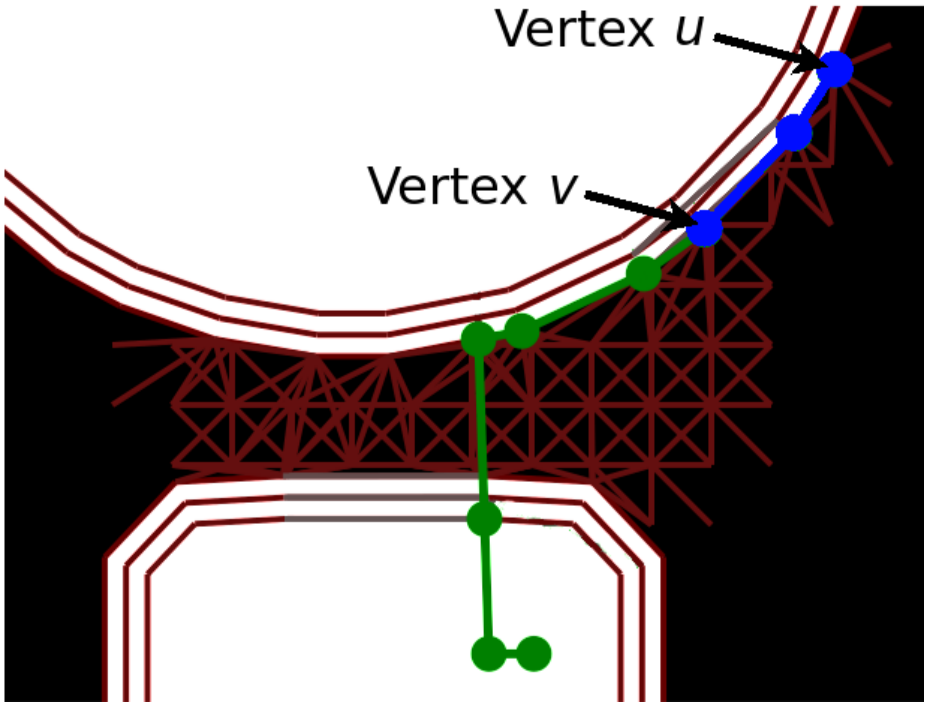
3D Routing



3D Routing

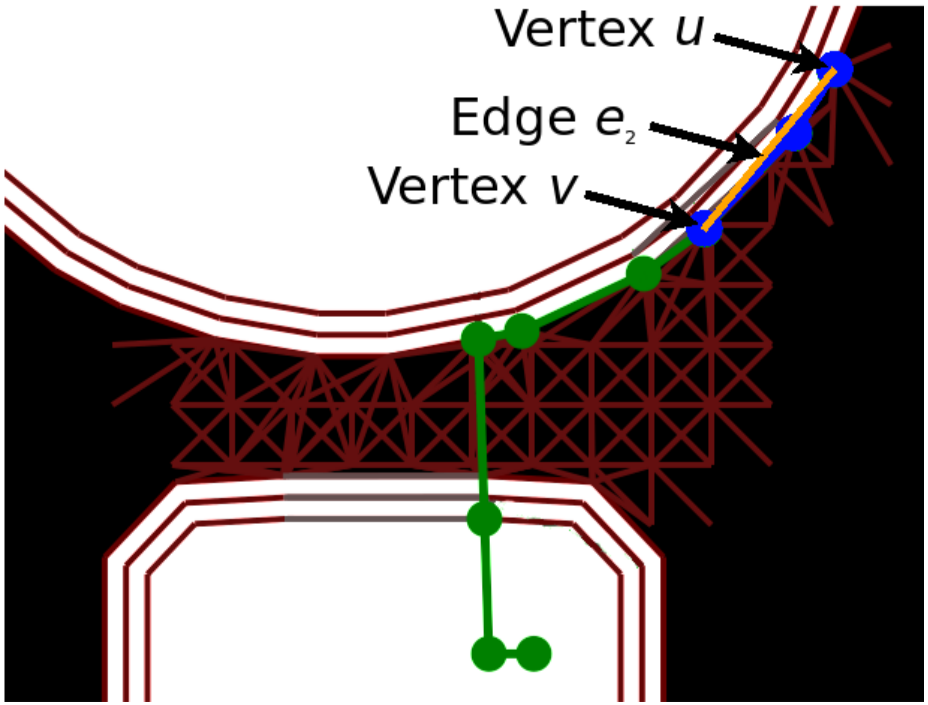


3D Routing



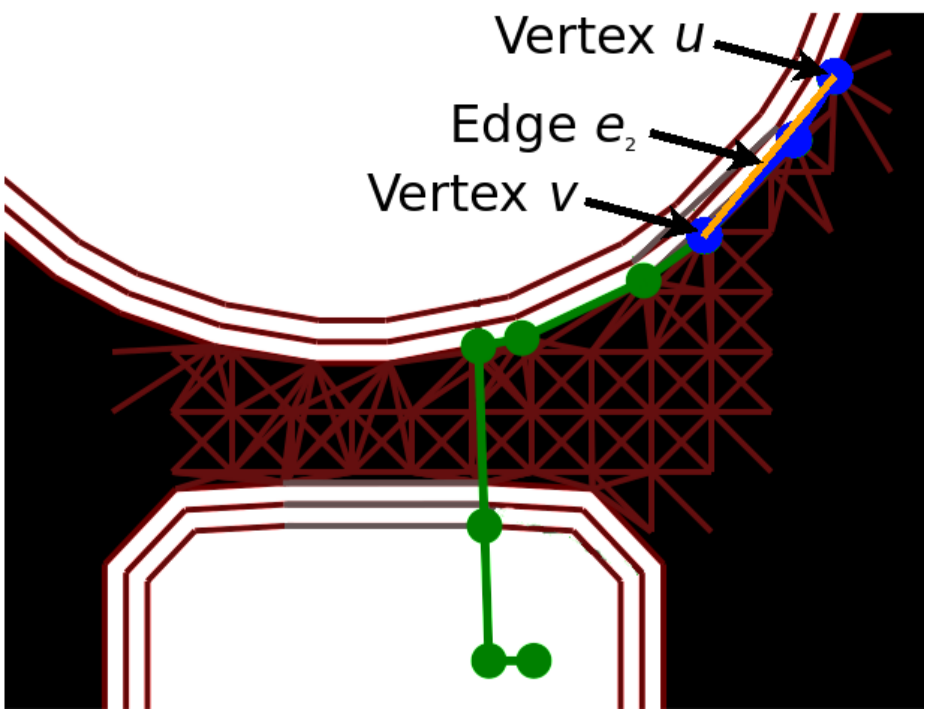
- overlap $= 2\text{mm}$
- grid_step_distance $\leq$ overlap

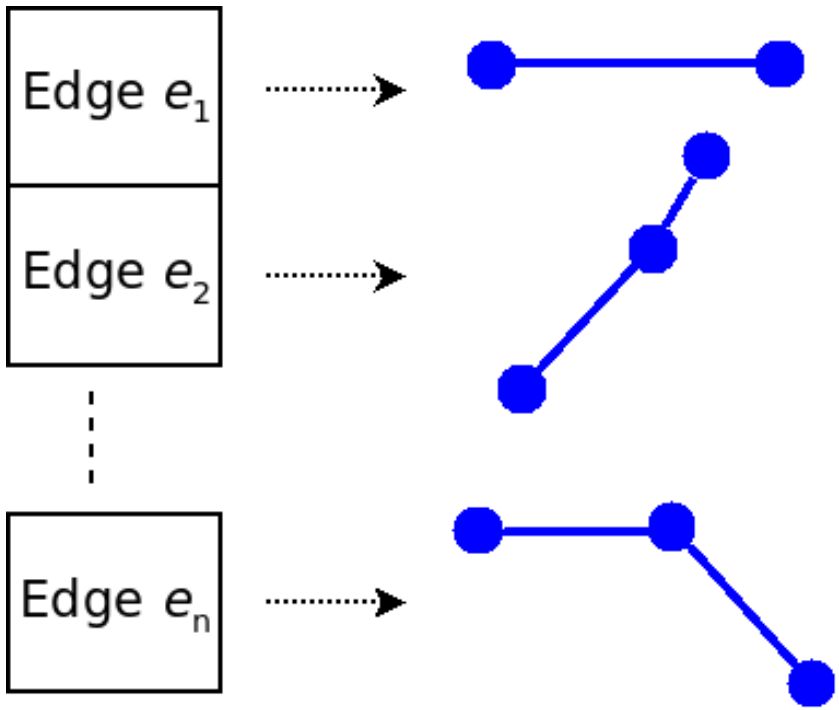
3D Routing



- overlap $= 2$mm
- grid_step_distance $\leq$ overlap

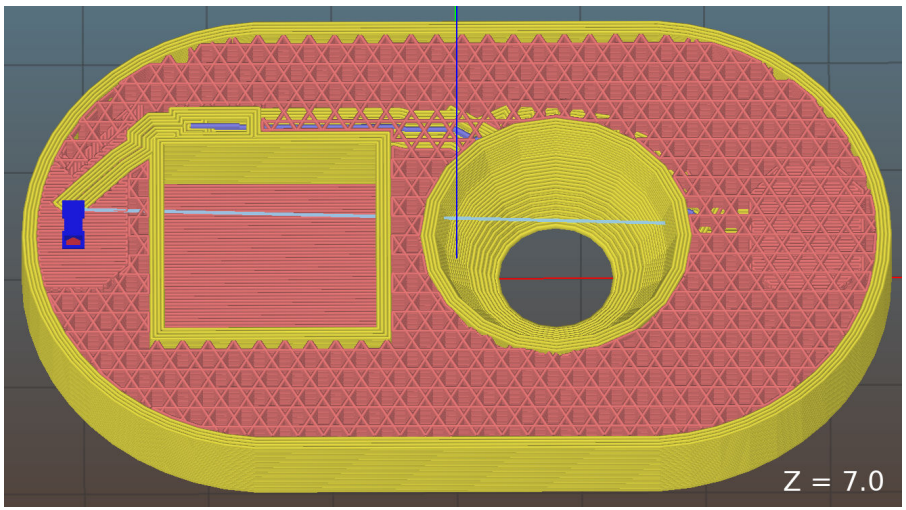
3D Routing

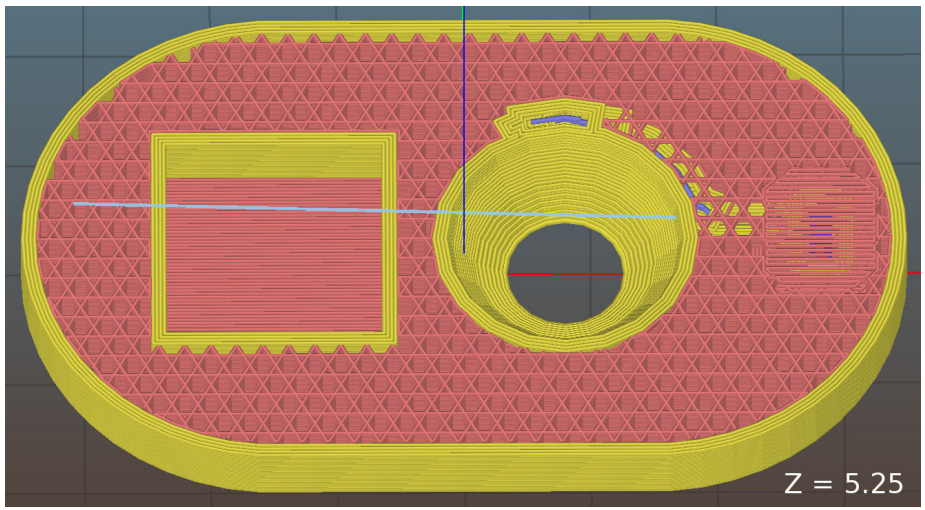




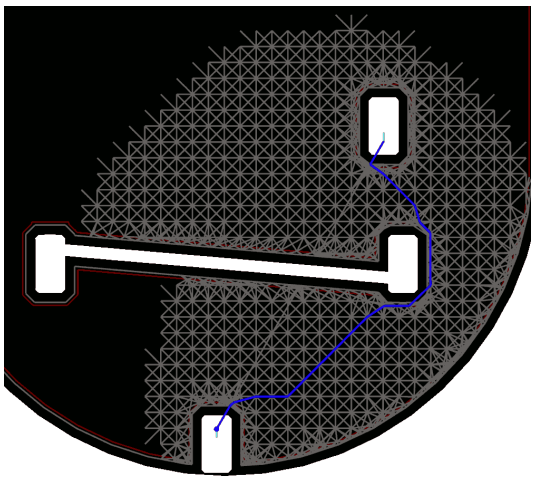
- overlap $= 2$mm
- grid_step_distance $\leq$ overlap

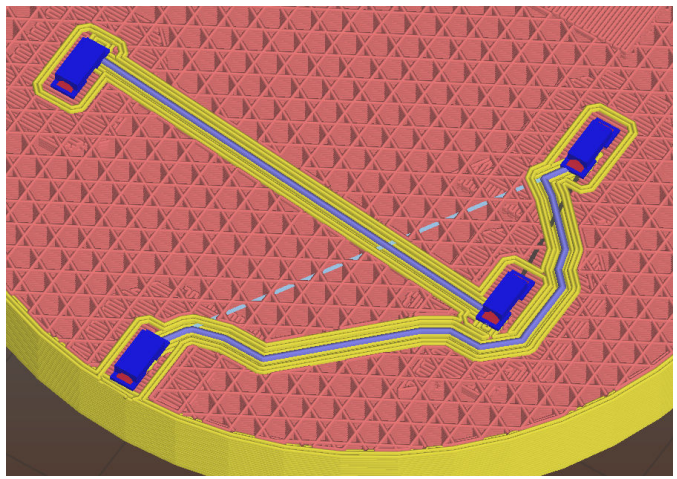
3D Routing - Results

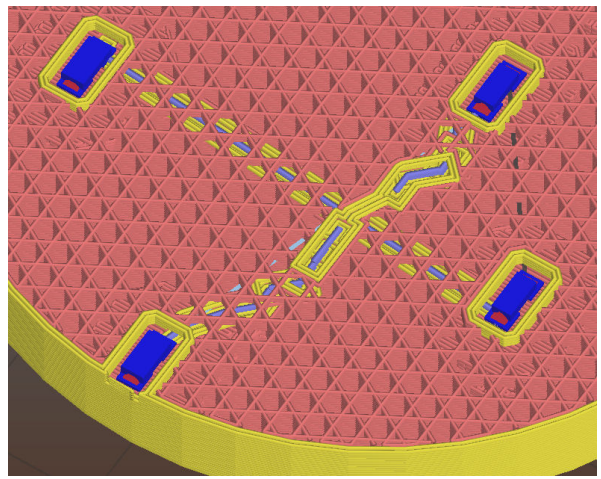




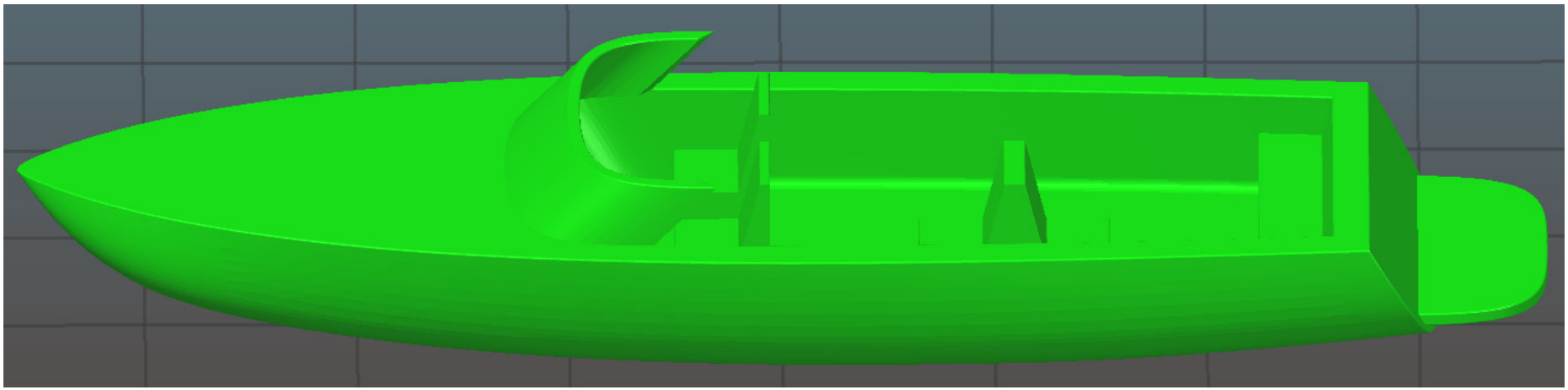
Collision Avoidance

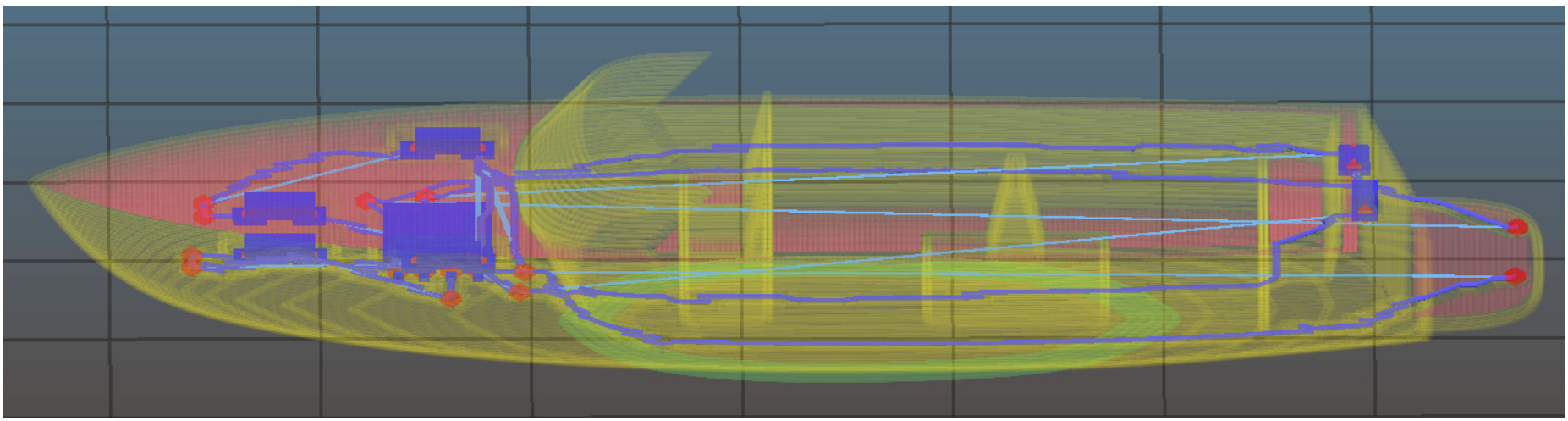






3D Routing Results

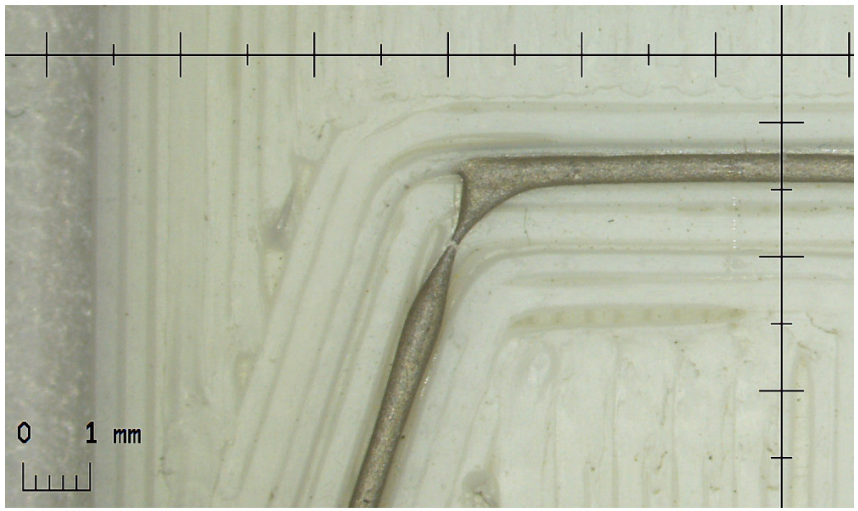




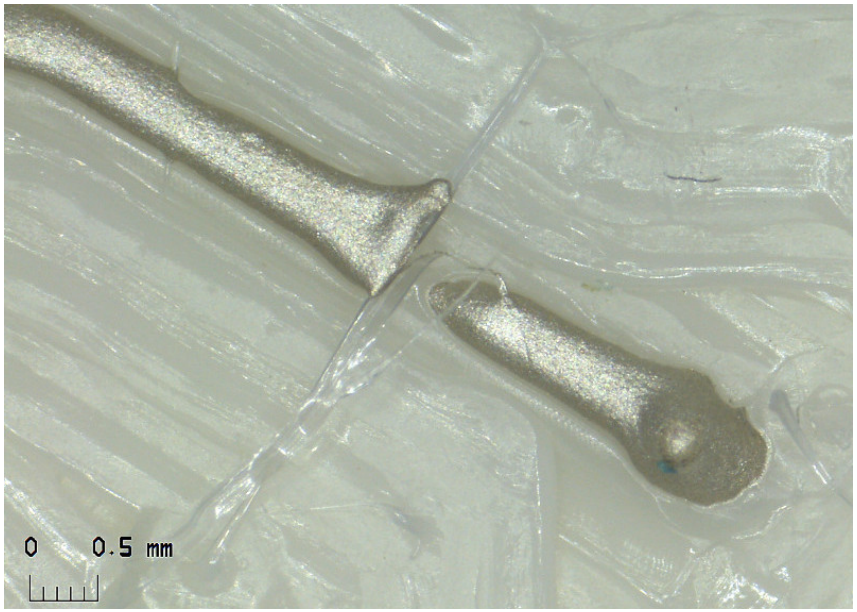
Inspection

[4]: Florens Wasserfall, Norman Hendrich, and Daniel Ahlers. Optical In-Situ Verification of 3D-Printed Electronic Circuits. In *Proceedings of the 15th IEEE Conference on Automation Science and Engineering (CASE)*, pages 1302–1307, Vancouver, 2019

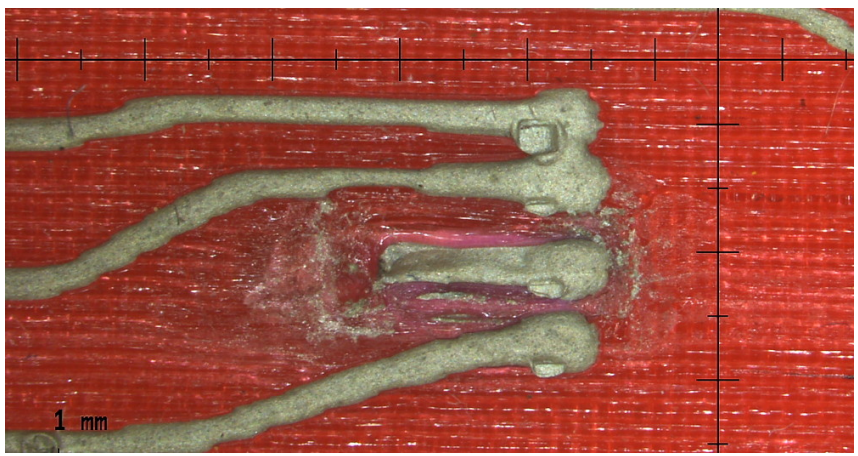
Common Issues



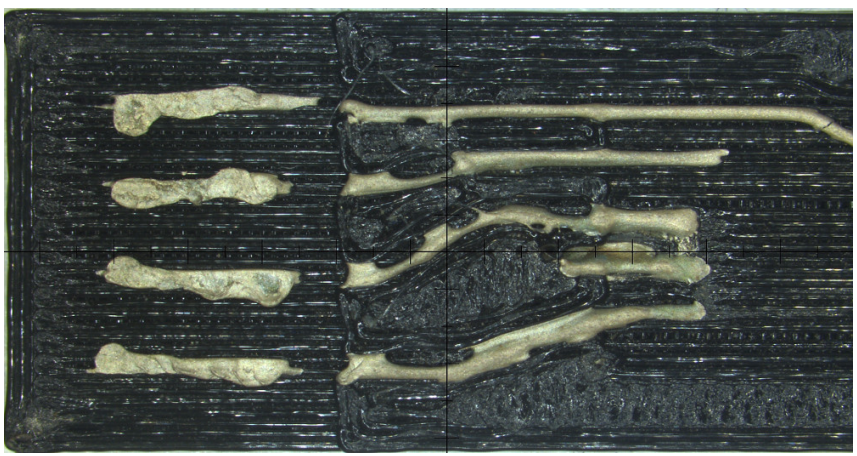
Underextrusion



Plastic strand

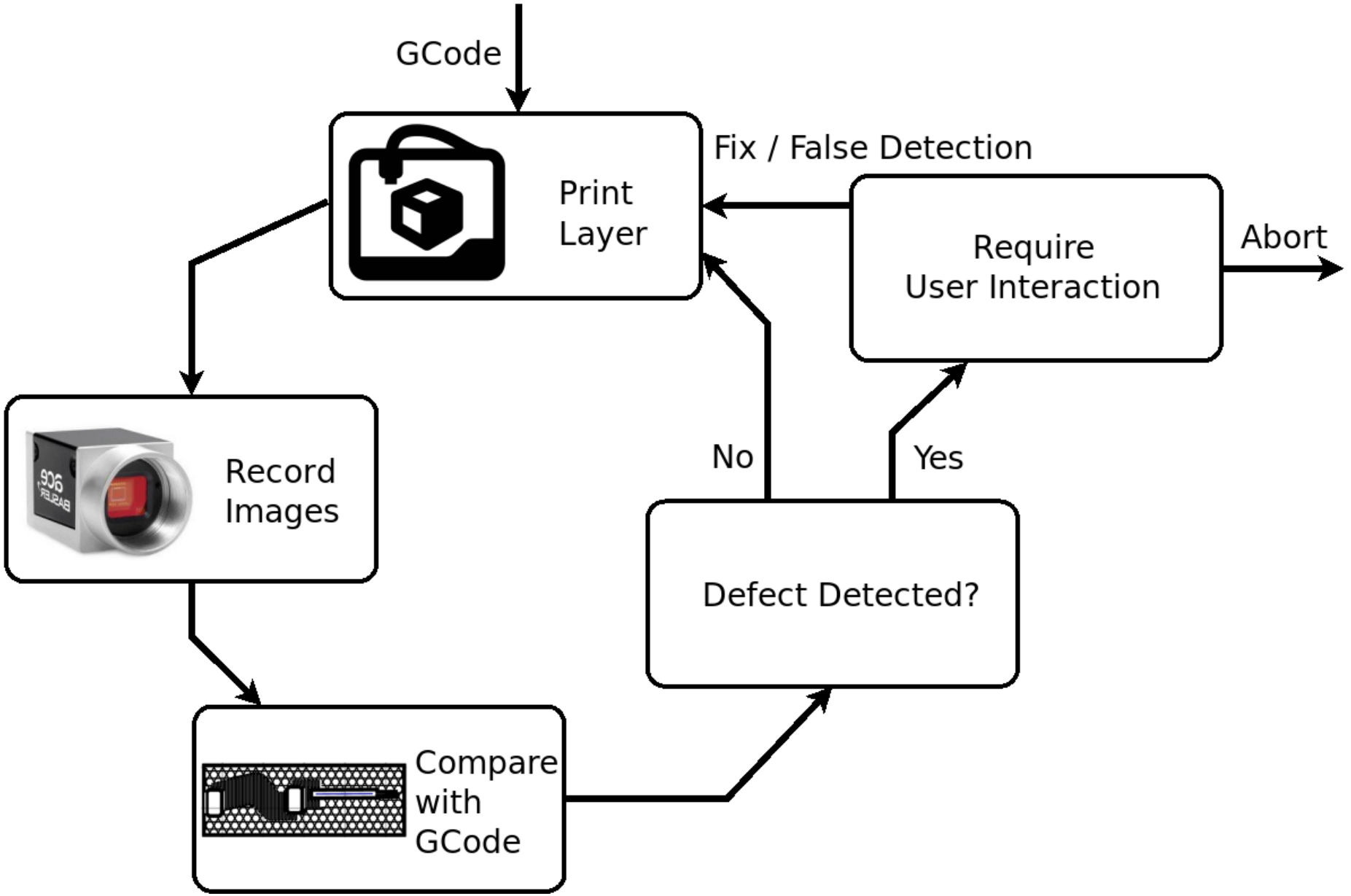


Short circuit

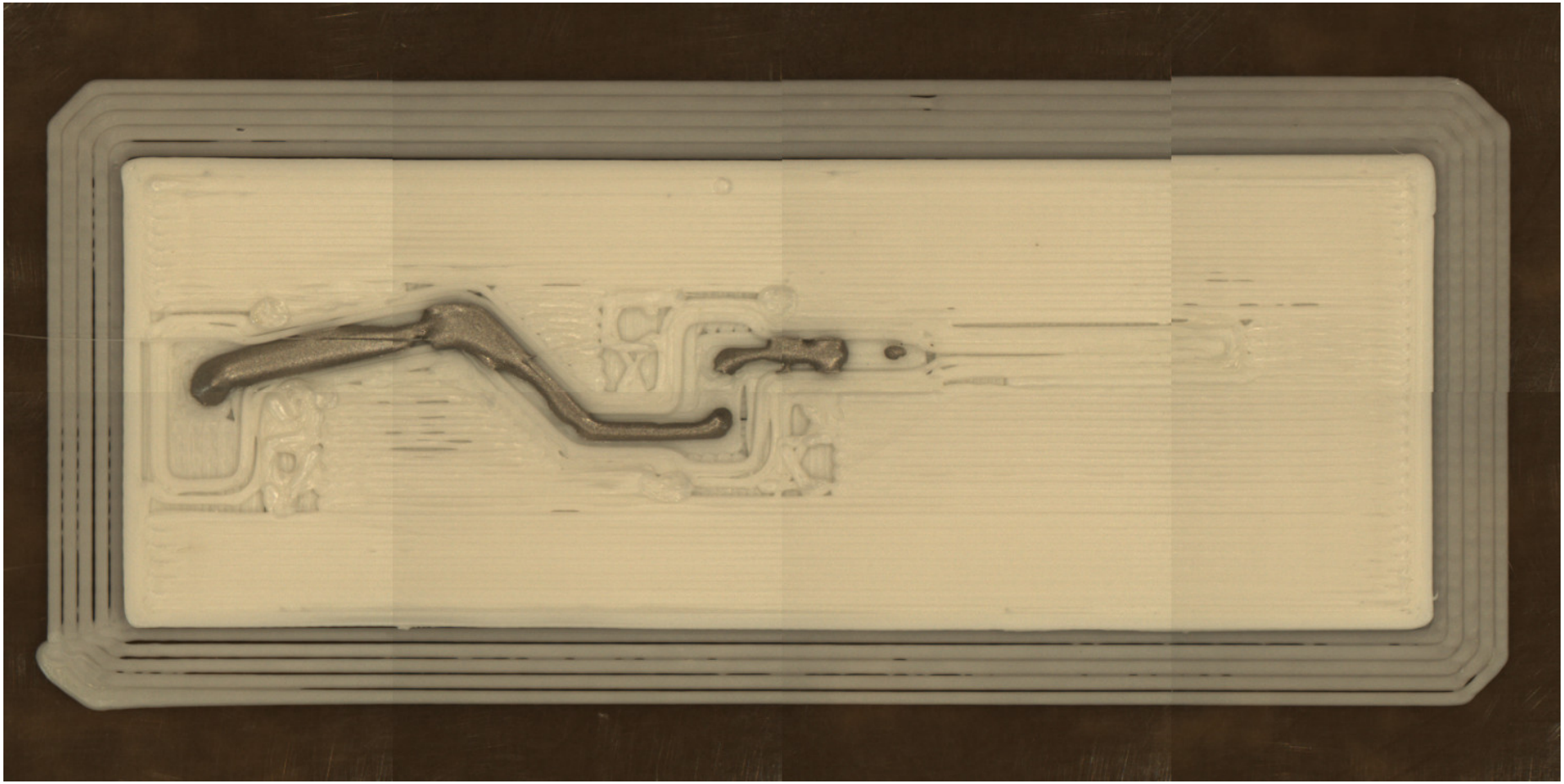


Surface structure

Detect Failure During Print-Time

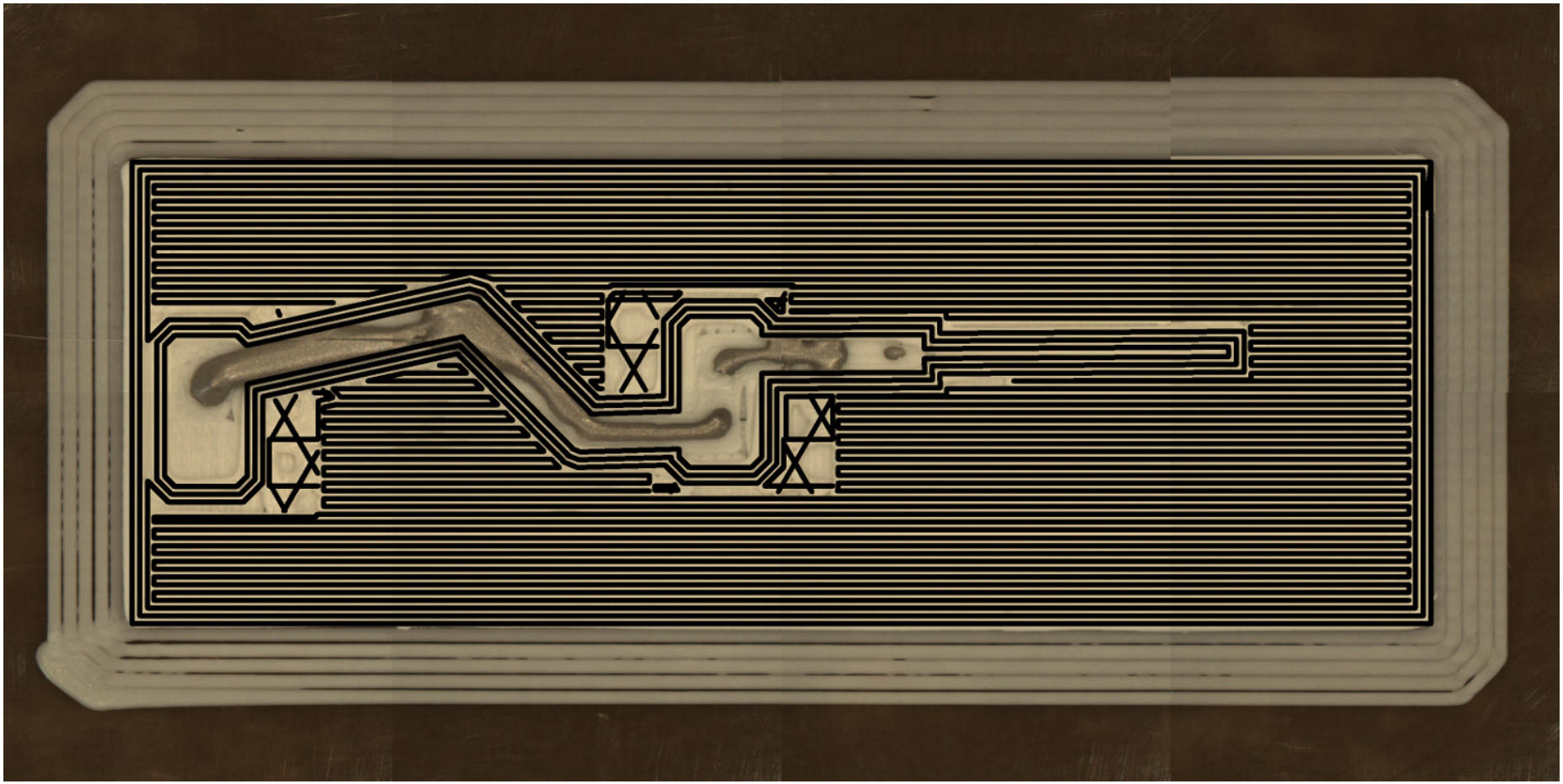


Identify Ink vs. Plastic



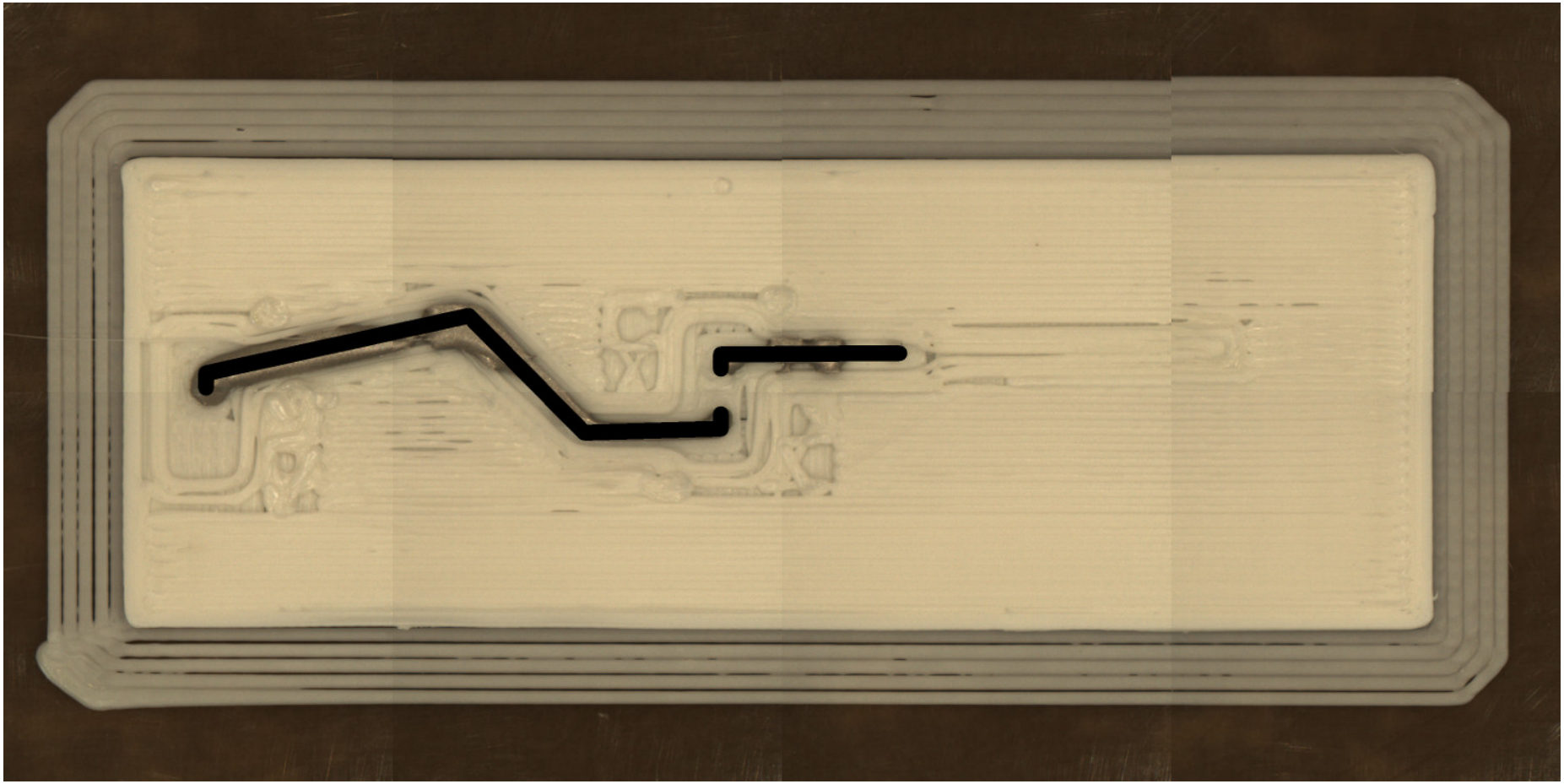
Raw image

Identify Ink vs. Plastic



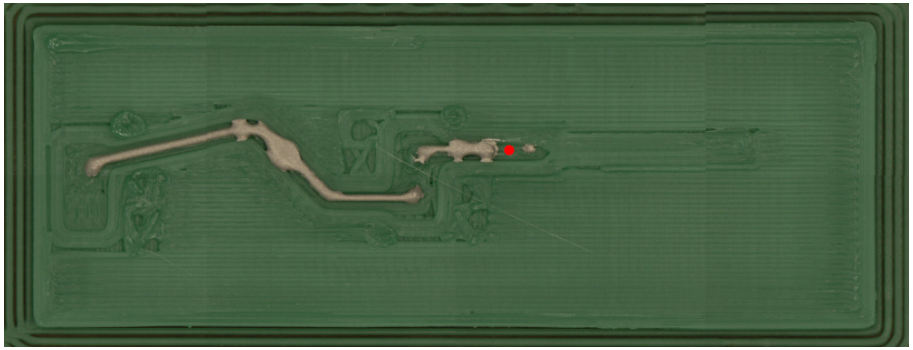
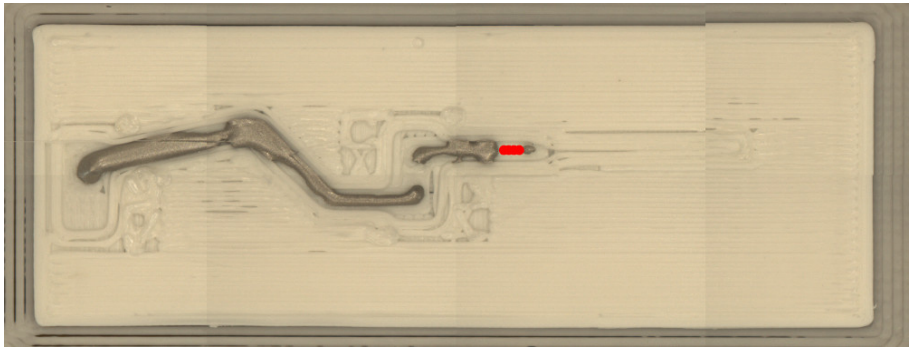
Overlay T0 (plastic extruder)

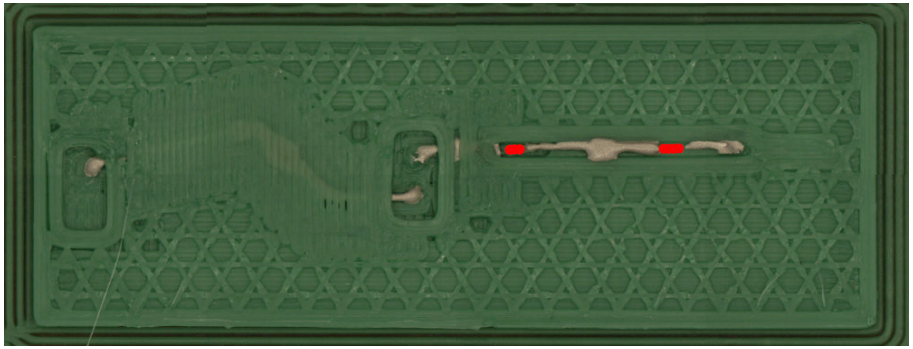
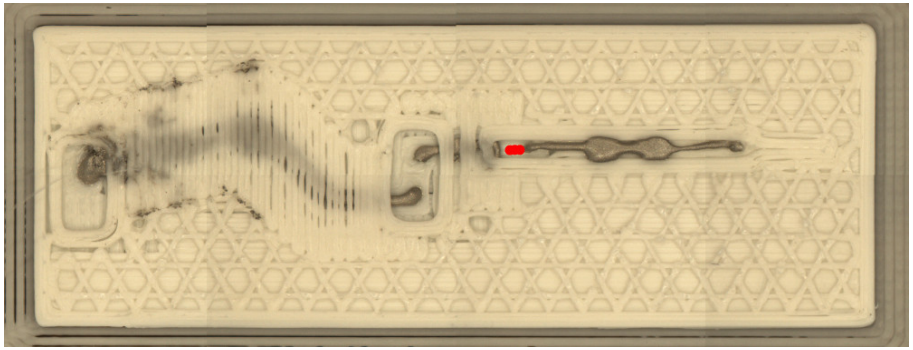
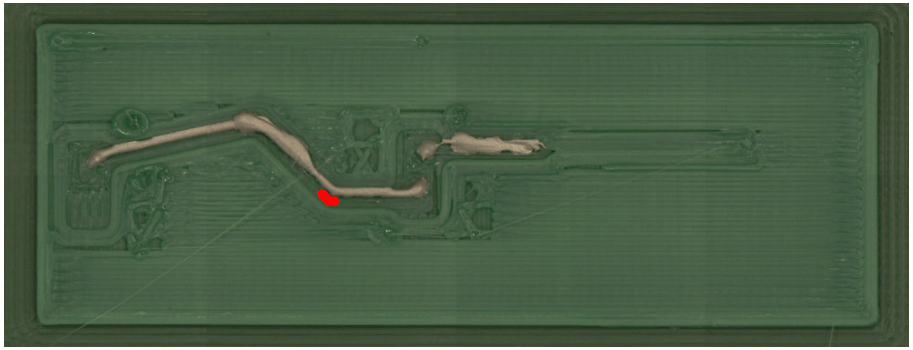
Identify Ink vs. Plastic



Overlay T1 (conductive extruder)

Detection Results

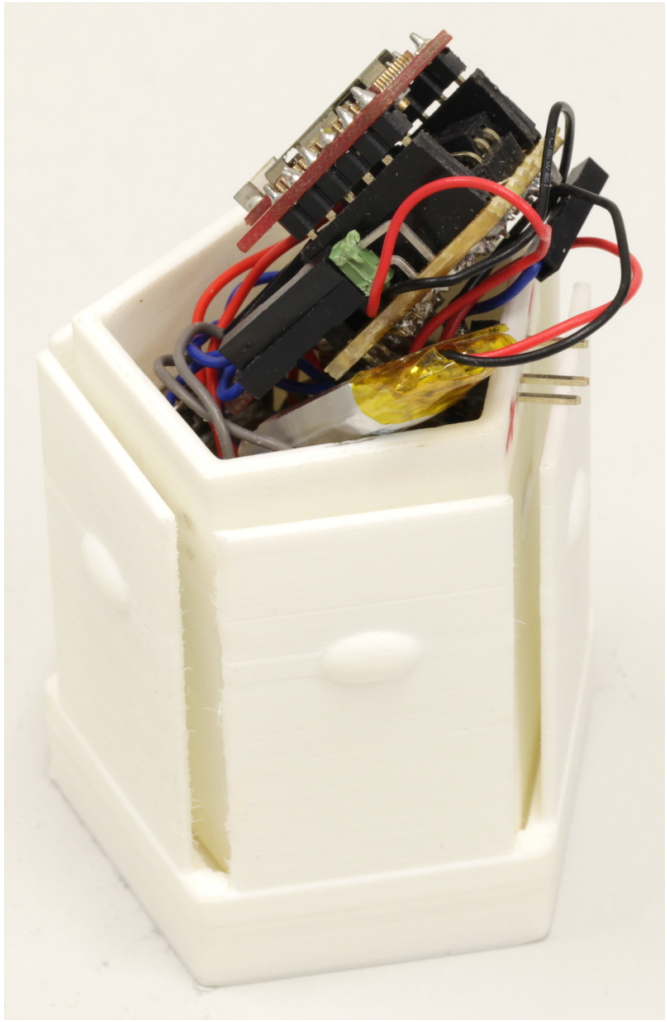




Evaluation

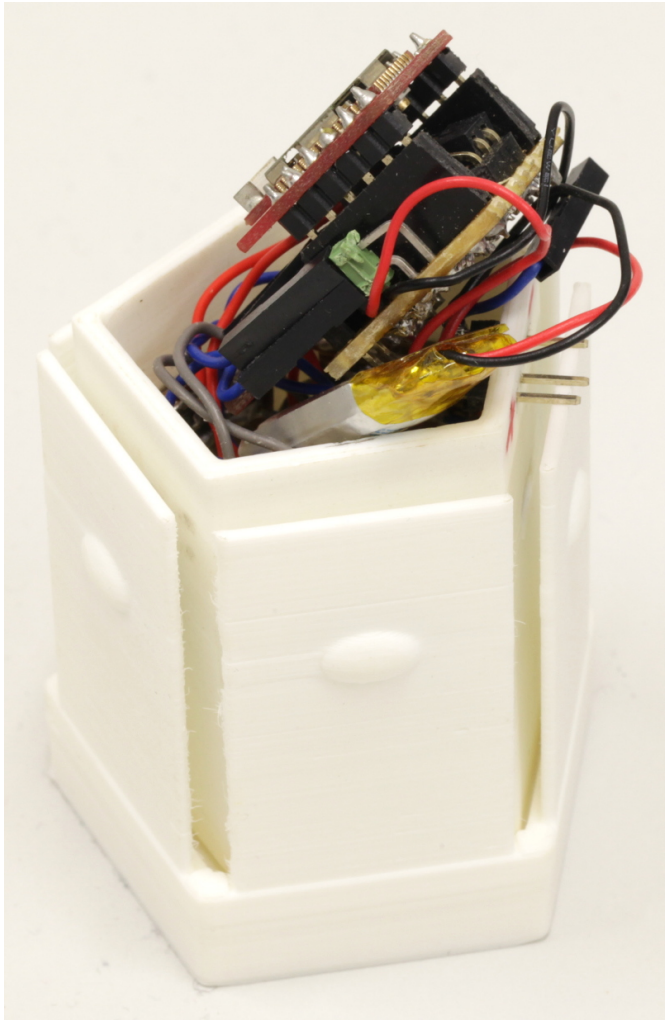
[5]: Florens Wasserfall, Norman Hendrich, Fabian Fiedler, and Jianwei Zhang.

3D-Printed Low-Cost Modular Force Sensors. In *Proceedings of the 20th Intl. Conference on Climbing and Walking Robots (CLAWAR)*, pages 485–492, Porto, 2017

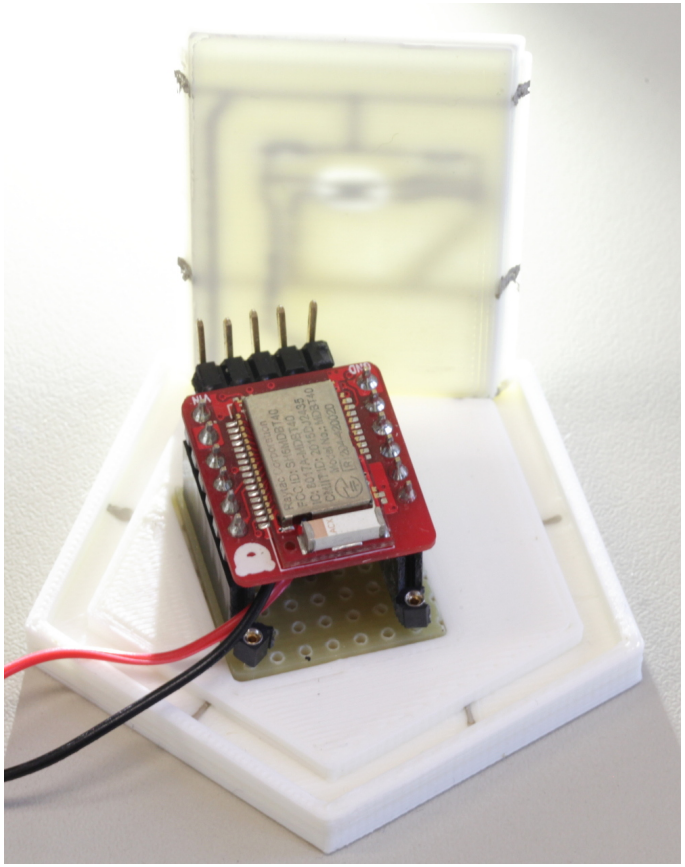
Instrumented Object

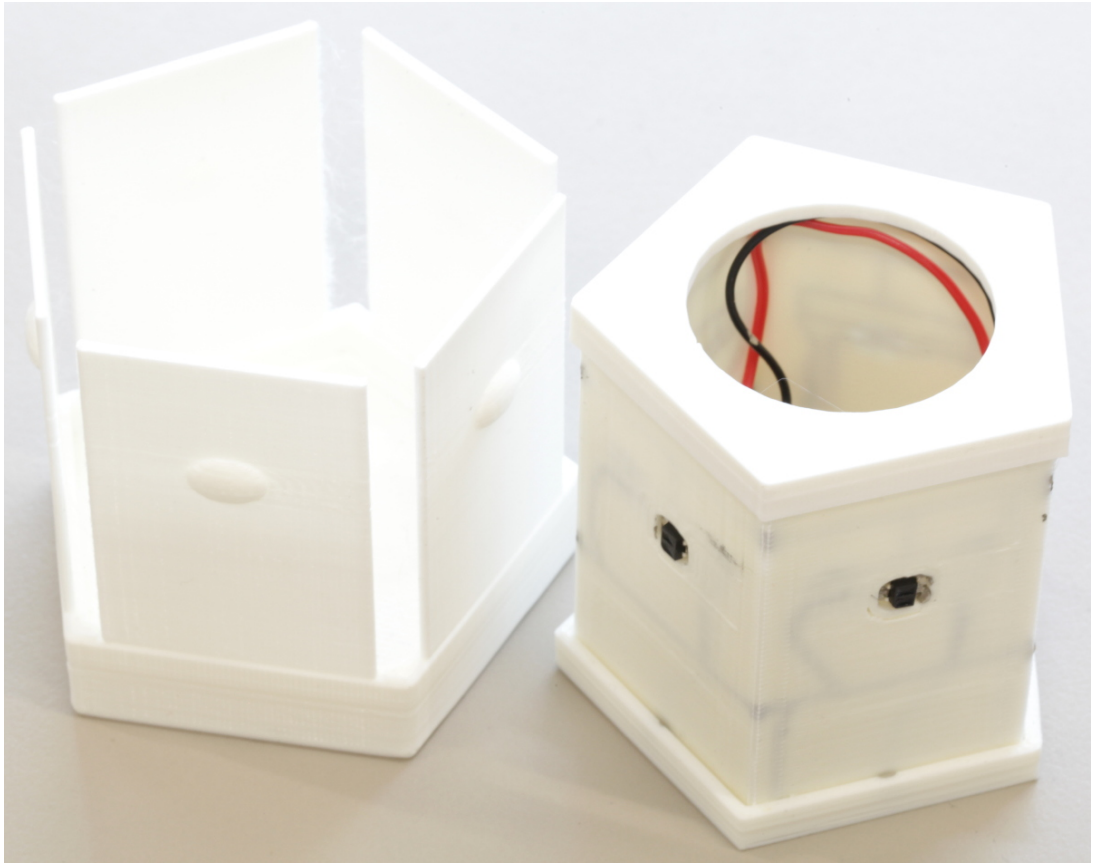


Instrumented Object



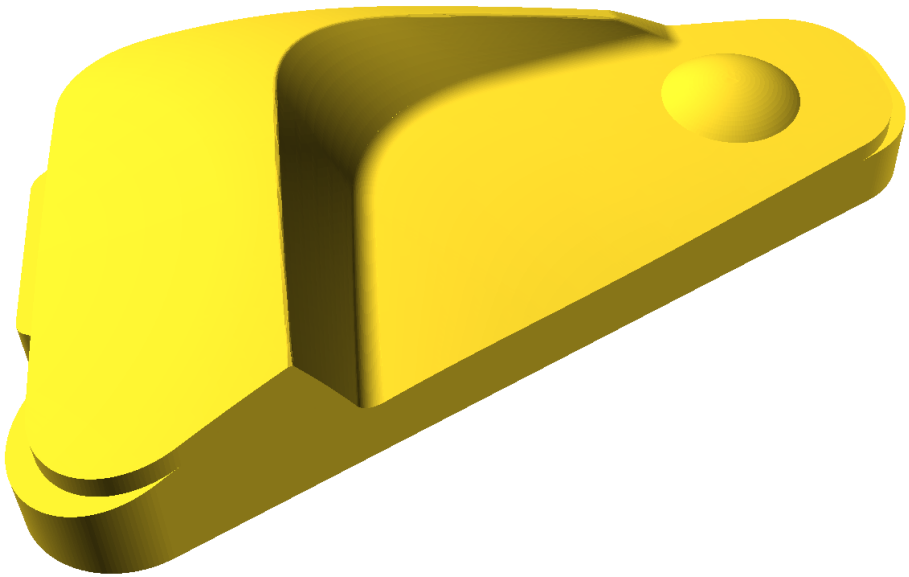
Instrumented Object

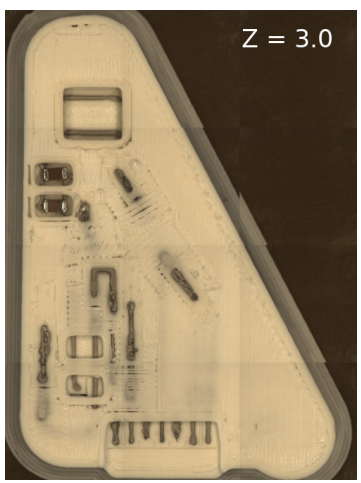


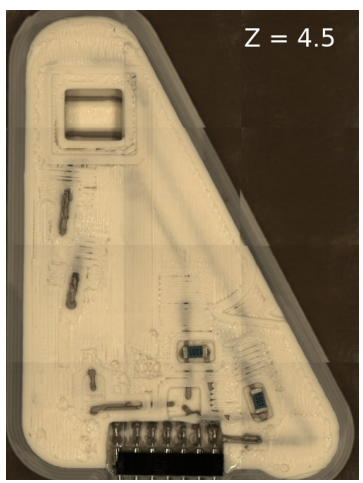


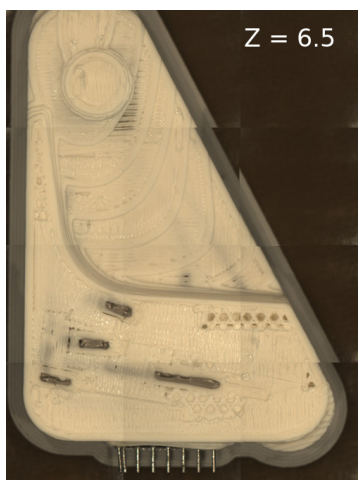
Instrumented Object – Demo

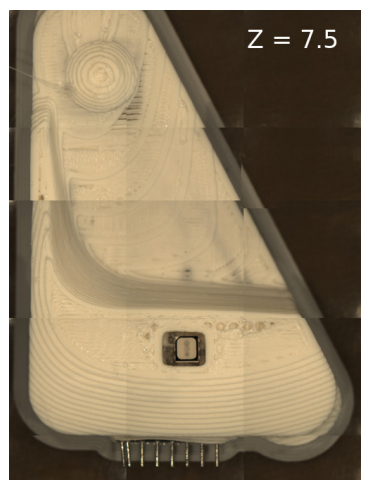
Integrated User Interface



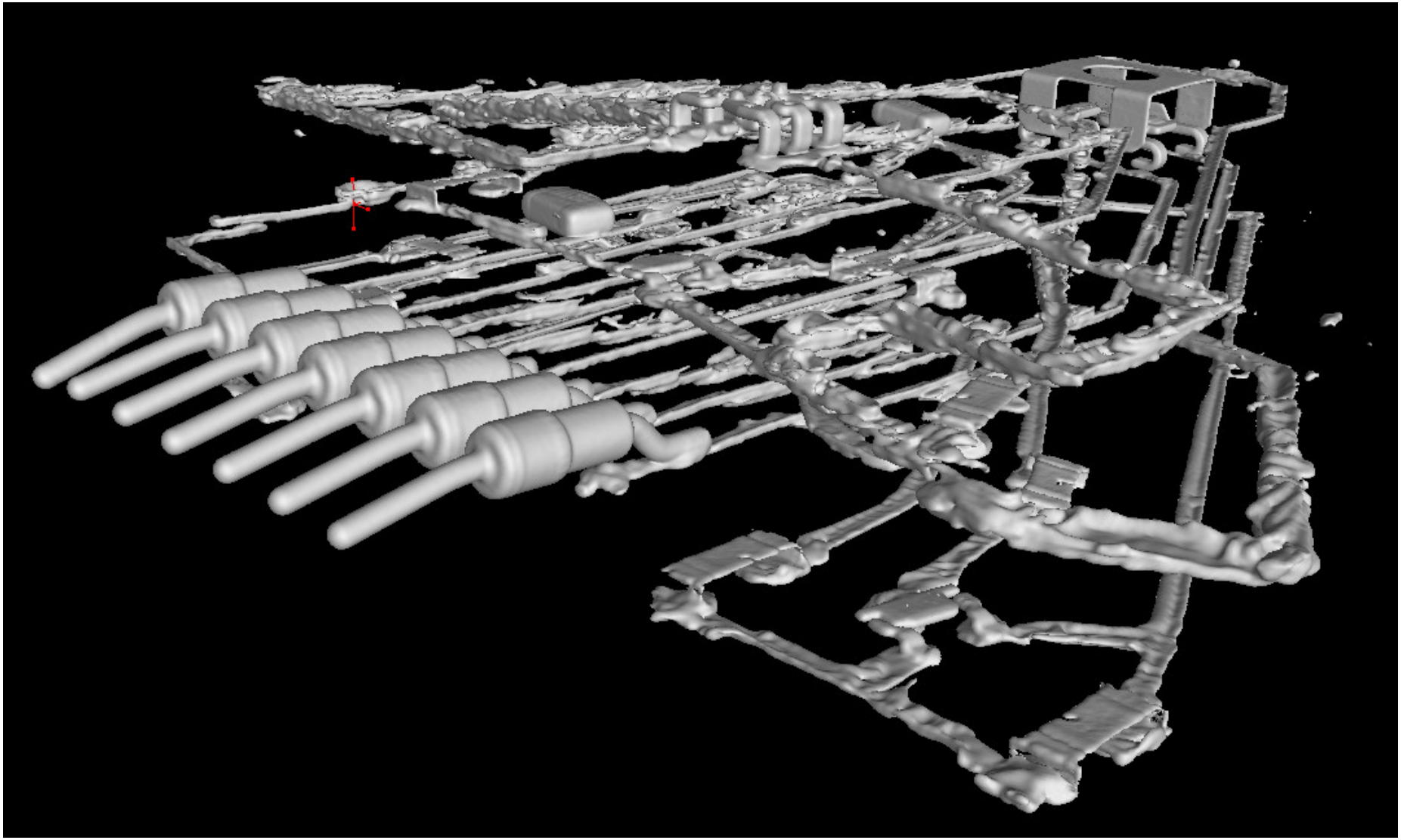








3D CT Image



Conclusion

Contributions

- Design- / Routing-Algorithms
- Toolchain for 3D-printed electronics
- Approach for automated visual process monitoring

Conclusion

Contributions

- Design- / Routing-Algorithms
- Toolchain for 3D-printed electronics
- Approach for automated visual process monitoring

Future Work

- Going professional!
- More reliable hardware
- 5-Axis system
- Routing on object surface

Q&A?

Download / Sourcecode:

tams.informatik.uni-hamburg.de/research/3d-printing/conductive_printing

—

github.com/platsch/Slic3r

—

github.com/platsch/OctoPNP

—

github.com/platsch/OctoCameraDocumentation

References

[1] Florens Wasserfall. Embedding of SMD populated circuits into FDM printed objects. In *Proceedings of the 26th International Solid Freeform Fabrication Symposium*, pages 180–189, 2015.

[2] Florens Wasserfall, Daniel Ahlers, Norman Hendrich, and Jianwei Zhang. 3D-Printable Electronics - Integration of SMD Placement and Wiring into the Slicing Process for FDM Fabrication. In *Proceedings of the 27th International Solid Freeform Fabrication Symposium*, pages 1826–1837, Austin, 2016.

[3] Florens Wasserfall. Topology-Aware Routing of Electric Wires in FDM-Printed Objects. In *Proceedings of the 29th International Solid Freeform Fabrication Symposium*, pages 1649–1659, Austin, 2018.

[4] Florens Wasserfall, Norman Hendrich, and Daniel Ahlers. Optical In-Situ Verification of 3D-Printed Electronic Circuits. In *Proceedings of the 15th IEEE Conference on Automation Science and Engineering (CASE)*, pages 1302–1307, Vancouver, 2019.

[5] Florens Wasserfall, Norman Hendrich, Fabian Fiedler, and Jianwei Zhang. 3D-Printed Low-Cost Modular Force Sensors. In *Proceedings of the 20th Intl. Conference on Climbing and Walking Robots (CLAWAR)*, pages 485–492, Porto, 2017.

[6] Florens Wasserfall, Norman Hendrich, and Jianwei Zhang. Adaptive Slicing for the FDM Process Revisited. In *Proceedings of the 13th IEEE Conference on Automation Science and Engineering (CASE)*, pages 49–54, Xi'an, 2017.

References (cont.)

[7] Daniel Ahlers, Florens Wasserfall, Norman Hendrich, and Jianwei Zhang. 3D Printing of Nonplanar Layers for Smooth Surface Generation. In *Proceedings of the 15th IEEE Conference on Automation Science and Engineering (CASE)*, pages 1737–1743, Vancouver, 2019.

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[9] Marc Bestmann, Bente Reichardt, and Florens Wasserfall. Hambot: An open source robot for robocup soccer. In *19'th RoboCup international Symposium, Hefei*, 2015.

[10] Dennis Krupke, Florens Wasserfall, Norman Hendrich, and Jianwei Zhang. Printable modular robot: an application of rapid prototyping for flexible robot design. *Industrial Robot: An International Journal*, 42(2):149–155, 2015.