Second doctoral workshop – Short paper
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Tutor: prof. Dr. Henri Hubertus Achten
PhD topic: 3D tisk betonu pomocí robotů
Research topic: Non-planar printing of construction-scale elements

Issue identification:

While CAD model is being prepared for printing, it is cut by a series of horizontal planes to extract nozzle path for each print layer. Therefore 3D printing mainly operates in X and Y coordinates. The Z axis is lifted up only when first layer is finished and printer steps up to the next layer. Sloping surfaces are typically printed as steps of increasing layers. If increment between two layers is too big, object starts deforming and eventually collapses. Printing of overhangs, cantilevers and vaults is limited. While using plastic, it is possible to print extra support construction, which is later removed. However this process is not possible for concrete, or clay printing. Non-planar printing might overcome this setback by adding extra layers to parts where they are necessary.

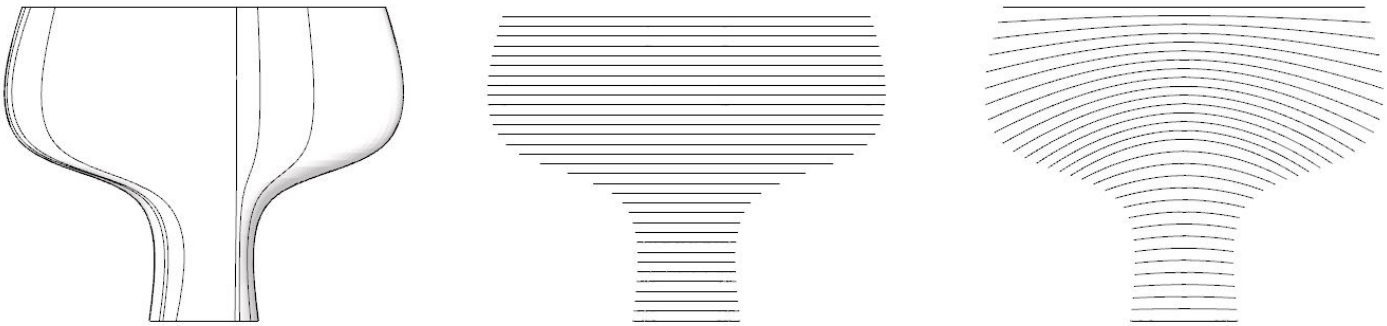

Fig. 1: 3D model with steep slopes sliced planarly and non- planarly. Non-planar slicing adds extraresolution at slopes, while layer count remains same. Source: my own design

Current state of the art:

Non-planar 3D printing was first presented for FDM[1] printers in 2016 Hackaday article[2]. Authors describe non-planar printing as true 3D printing, compared to the traditional process, where the Z axis is moving only during transfer to the next layer (the original process is referred to as 2,5D printing). Most of the experiments were done on desktop FDM printers[3] [4]. Its goal was to create a smoother finish layer with better aerodynamics. Desktop printers' construction limits use of non planar printing, because print head components may bump into printed objects, nozzles may scratch an already printed layer. To unfold the full potential of non-planar printing at least a 4-axis printer has to be used. Very successful experiment was presented with a 6-axis industrial robot, which printed a horizontal beam, without support[5]. Only one project used non-planar printing in construction so far[6]. This technique was used to print complicated vault pieces out of concrete. Non-planar printing seems very promising in the plastic printing industry and I would like to test its usefulness in concrete and clay printing. It reduces the effect of anisotropy of printed objects, reduces horizontal cracking alongside horizontal layers and allows printing of overhangs.

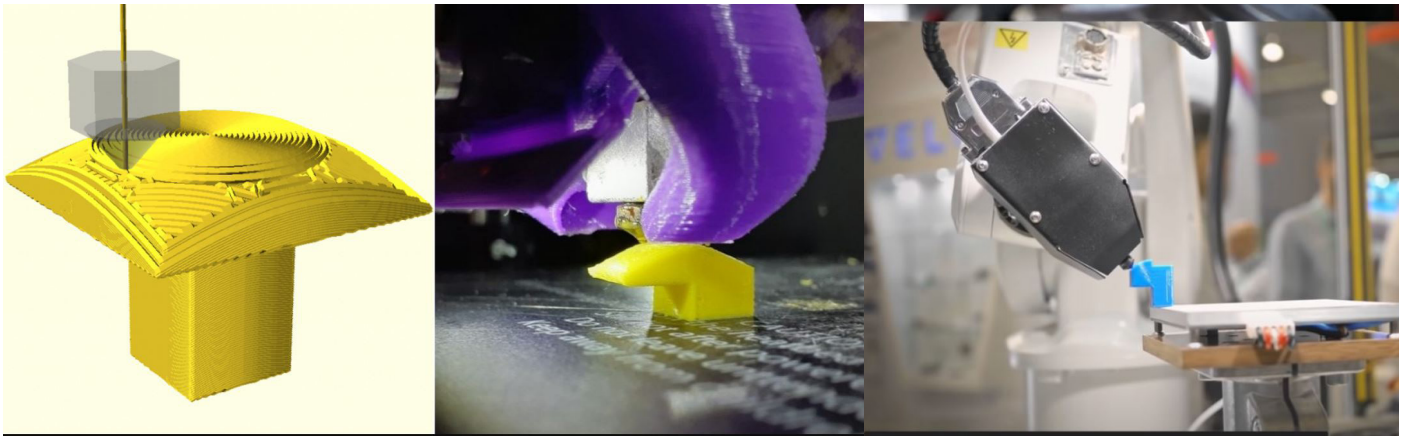

Fig. 2: Non-planar printing of plastic materials reduces the support structure for overhangs. Ideal printer for non-planar printing has more than 3 axes, so nozzle can be tilted. Source: [3,4]

Fig. 3: Non-planar example of concrete printing. Source: [6]

My research question:
Can non-planar slicing improve construction scale printing?

Strategic target:
Examine advantages of FDM non-planar printing and its potential implementation in construction-scale printing.

What i want to map:
When does it make sense to use non-planar printing and how significantly it can improve the final outcome. If materials like concrete or clay can benefit from non-planar printing similarly as plastic. And if it improves objects stability and if non-planar print with reinforcement can work similarly as reinforced concrete.

Tactical targets:
1. Develop non-planar slicing and printing workflow.
Non-planar slicing requires advanced software and hardware. From software perspective no available slicers allow non-planar printing. Print file has to be generated by a custom script. Printer itself has to be modified to prevent collisions of print and printhead. For small scale, cheap and rapid testing I constructed a clay printer. I test and develop both software and hardware on it. Best printer to use would be a 6-axis robot, which can tilt nozzle, print under an angle, thus reducing the risk of bumping its printhead into the print.

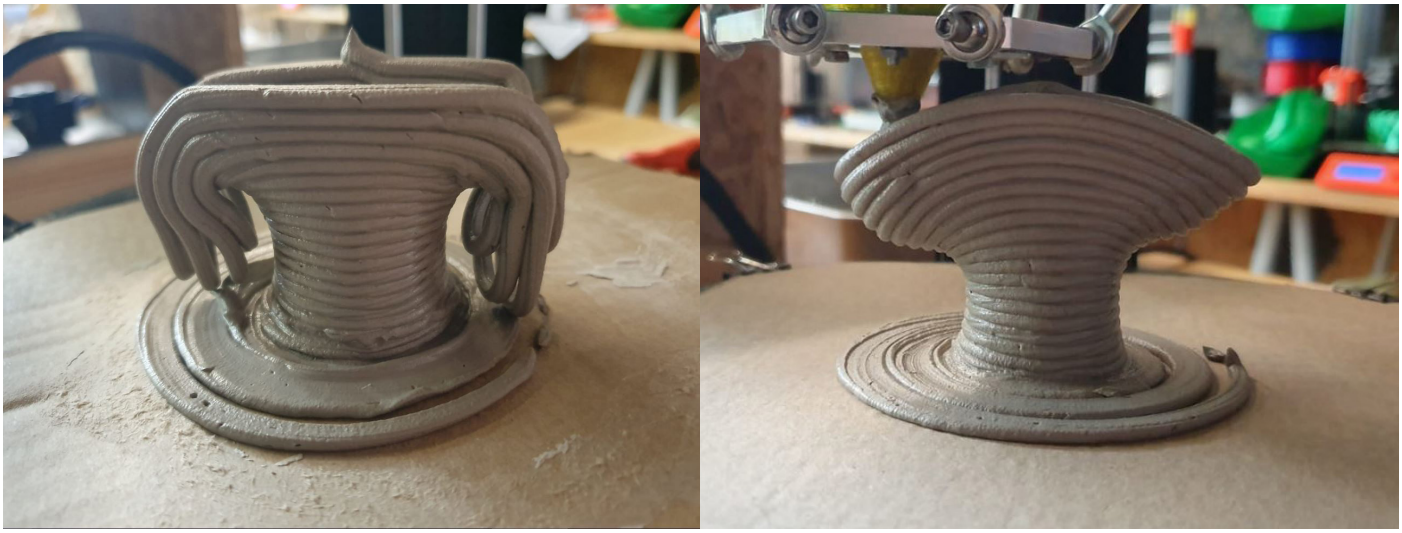

Fig. 4: Planar print example on the left with collapsing layers compared to non-planar print with stable overhangs. Source: my own experiments

2. Non-planar printing of construction-scale elements
With a 6-axis robot I will print construction - scale elements like walls, or columns, vaults. There will be two different prints for each CAD model. One will be printed using planar slicing and second by non--planar slicing. Then I will compare them together how much they deviate from the 3D model and test their load capacity. Adding extra reinforcement in a form of carbon fibre between layers might improve stability even more.

3. Create plug-in for Grasshopper
Knowledge gained from two previous targets will be used for creating an easy to use plugin, which analyses any CAD file and if needed, designs non-planar slicing. This plugin might be especially helpful for printing vaults and reinforced walls.

Methodology:

For Objective 1: Empirical, observational
Research question: What is the optimal workflow of non-planar data preparation and how to assure printer parts will not bump into the print.
Evaluation criteria: How easy is it to prepare data and print non-planar object
Observed variables: How much time does it take to prepare non-planar print compared to planar print.

For Objective 2: Empirical, experiment, observation, measurement
Research question: What is the difference between non-planar and planar print? Evaluation criteria: Aesthetics - shape deviations of the CAD model compared to printed object planarly and non-planarly. Functional – load capacity.
Observed variables: correlation between aesthetic and functional quality

For Objective 3: Empirical, experiment, measurement
Research Question: Could I automate model evaluation and in case of complicated model design automatic addition of non-planar layers?
Evaluation criteria: when and how much the geometry of architectural elements will need to be changed in order to get successfully printed.

Program:
2022: Experimental printing of complex elements from clay
2023: Experimental printing of complex elements from concrete
2024: Make Grasshopper plugin for non-planar printing

References:
[1] Haghsefat, Kianoush & Tingting, Liu. (2020). FDM 3D Printing Technology and Its Fundemental Properties.

[2] Walter, M., 2022. 3D Printering: G-Code Post Processing With Perl. [online] Hackaday. Available at: <https://hackaday.com/2016/07/20/3d-printering-g-code-post-processing-with-perl/#more-213850> [Accessed 13 August 2022].

[3] Uham, T., 3D Printing of Nonplanar Layers for Smooth Surface Generation , Youtube.com. 2022. [online] Available at: <https://www.youtube.com/watch?v=km1lvuva5mI> [Accessed 15 August 2022].

[4] Teaching tech, Achieve true 3D printing with non planar slicing , Youtube.com. 2022. [online] Available at: <https://www.youtube.com/watch?v=gmePlcU0TRw> [Accessed 15 August 2022].

[5] Sanladerer T., Simultaneous 6-axis 3D printing!, Youtube.com. 2022. [online] Available at: <https://www.youtube.com/watch?v=A_ldCmWCrOI&t=390s> [Accessed 15 August].

[6] Vertico, 2022. Concrete Printed Shell Pavilion Revealed. [online] Vertico.xyz. Available at: <https://www.vertico.xyz/hpa> [Accessed 16 August 2022].

[7] Schipper, R. et al.: Double curved concrete printing: printing on non-planar surfaces. SPOOL4(2), 17-21 (2017).