Non-planar printing of construction-scale elements

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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 to deform 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.

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. This problematics is mapped in a master's thesis by Daniel Ahlers [5]. 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[6]. Only one project used non-planar printing in construction so far[7]. 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.
In 2015 Autodesk filed patent called Systems and methods for improved 3D printing [8]. It does not specifically say non-planar printing, but its description may refer to it. This patent refers to prinitng processes, like FDM. It does not include paste extrusion, which is used for concrete and clay printing.

Research questions:
When does it make sense to use non-planar printing and how significantly it can improve the final outcome? Can materials like concrete or clay benefit from non-planar printing similarly as plastic? Does it improve objects stability, rigidity and reduces cracking?

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

Research targets:

1. Develop non-planar slicing and printing workflow and test it on clay prinitng.
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.

2. Non-planar printing of construction-scale elements from concrete
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 open source 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.

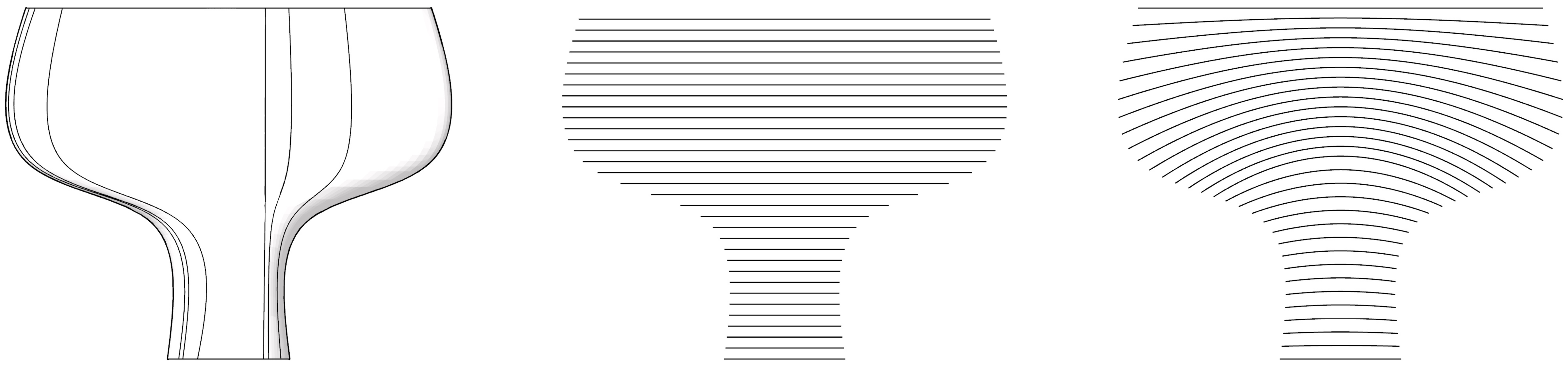

Fig. 1: 3D model with steep overhangs sliced planarly and non-planarly. Non-planar slicing adds extra resolution at overhangs, while layer count and amount of extruded material remains the same.

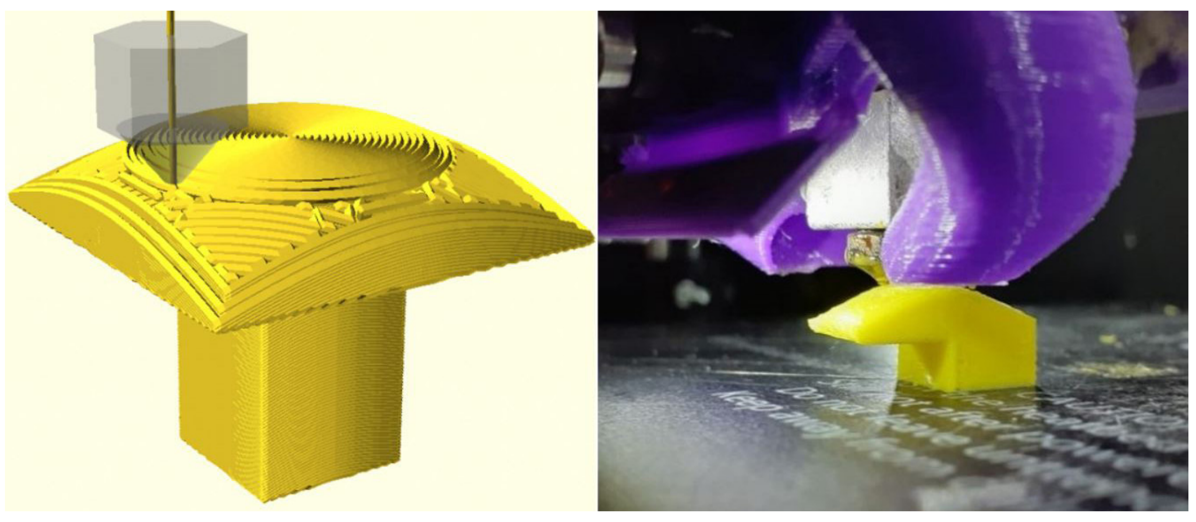

Fig. 2: Non-planar printing of plastic materials reduces the support structure for overhangs. Source: [3]

Fig. 3: Non-planar example of concrete printing. Source: [9]

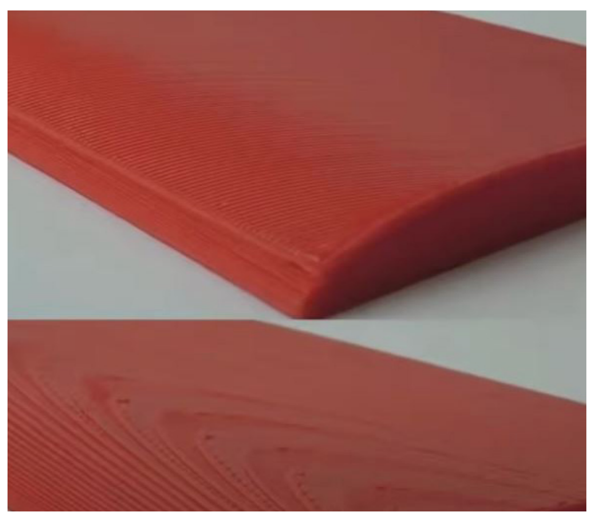

Fig. 4: Non-planar surface is smoother and more aerodynamic Source: [3]

Fig. 5: 6-axis robot can also tilt printing nozzle. Source: [4]

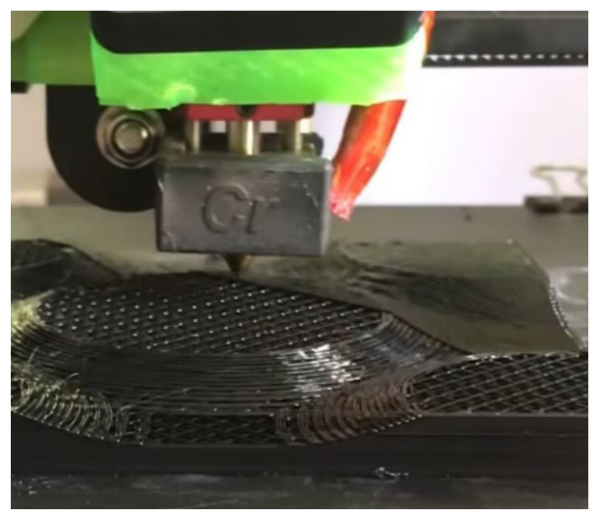

Fig. 6: Top layer is printed in a non-planar manner to achieve smoothness. Source: [5]

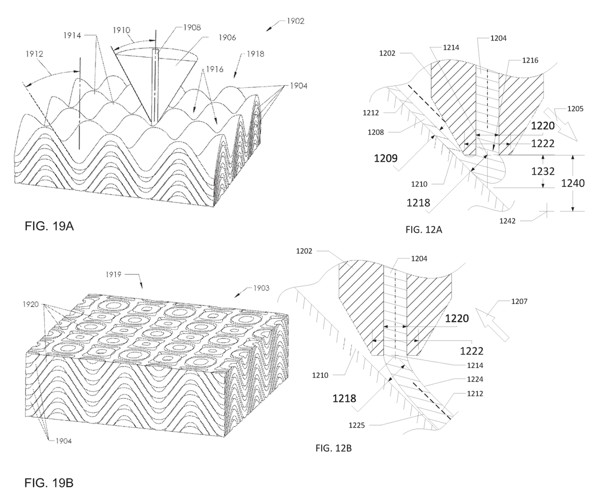

Fig. 7: Patent called Improved 3d printing technique resembles non-planar printing. Source: [8]

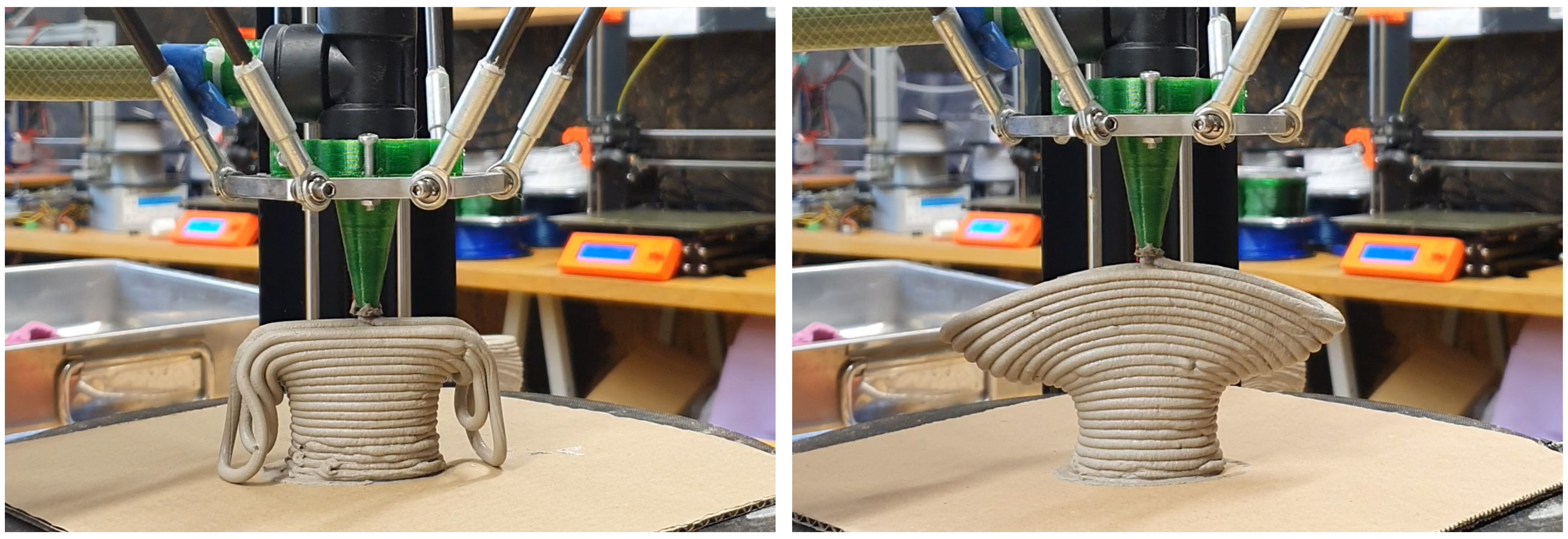

Fig. 8: Same object was printed planarly (left) and non-planarly (right). Planar printing started collapsing at steep overhangs. Non-planar printing sustained intended shape. Object was printed from clay, on delta printer with custom built paste extruder.

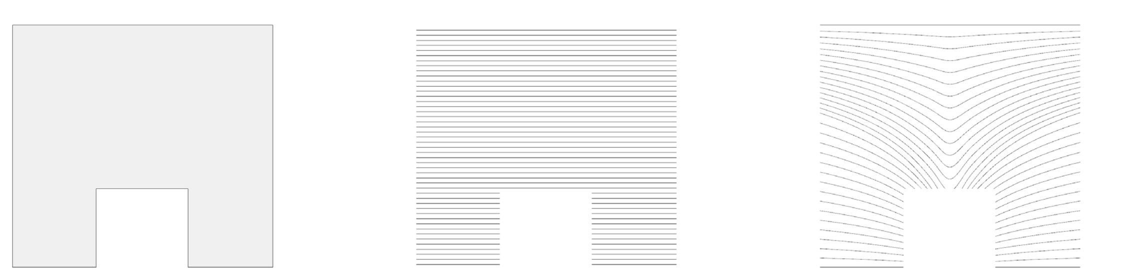

Fig. 9: Building openings for windows, doors, or plumbing can theoretically be printed non-planarly without any need of extra formwork. Vault-like layers could sustain pressure. However this approach needs testing.

Fig. 10: Wall sample sliced planarly and non-planarly. Cracks alongside layers might appear, if object is printed planarly (red line). It is caused by anisotropicity of the object. Connections between layers are weaker, than layers itself. However non-planar prinitng reduces anisotropicity of the object, therefore cracking is reduced (green line).

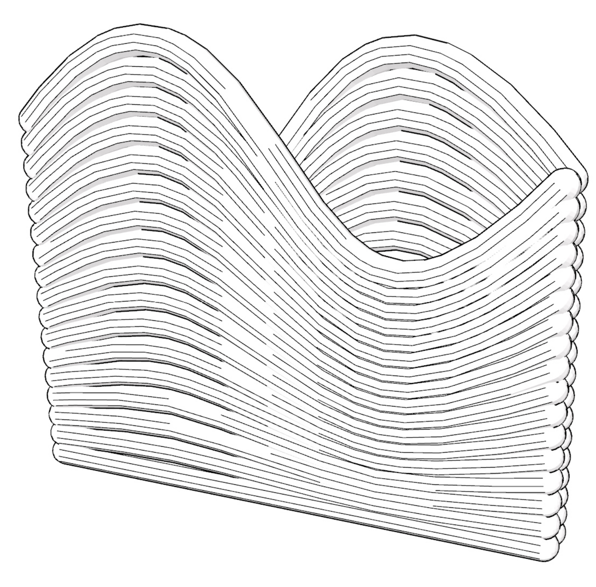

Fig. 11: Wire reinforcement can be laid on non-planar layers. If wall is composed out of two different non-planar layers, then reinforcement might be very efficient. This hypothesis also needs testing.

References:

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