A 3D Printing Application and 3-Axis Non-planar Surface Generation

MECH 325 Presentation

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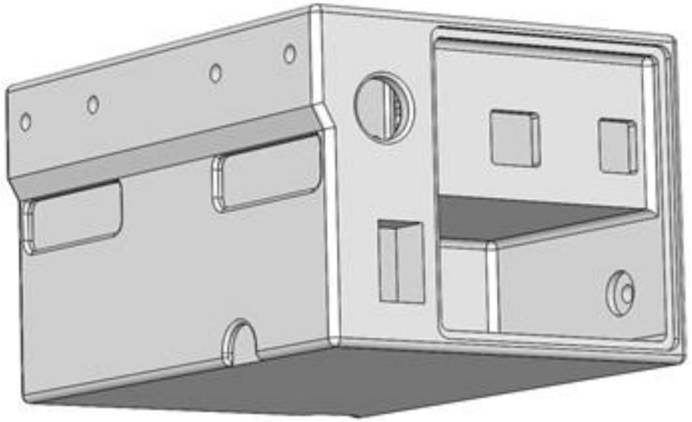
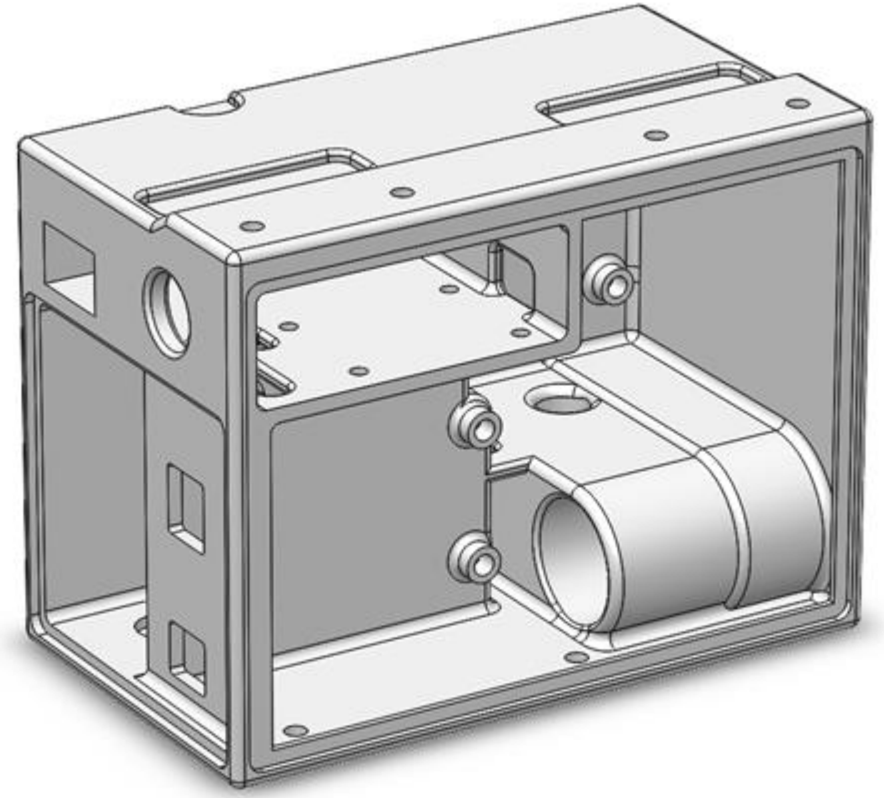
Interfacing CAD with 3D Printing

Application from senior design project

Senior Design Project: Electronics Box

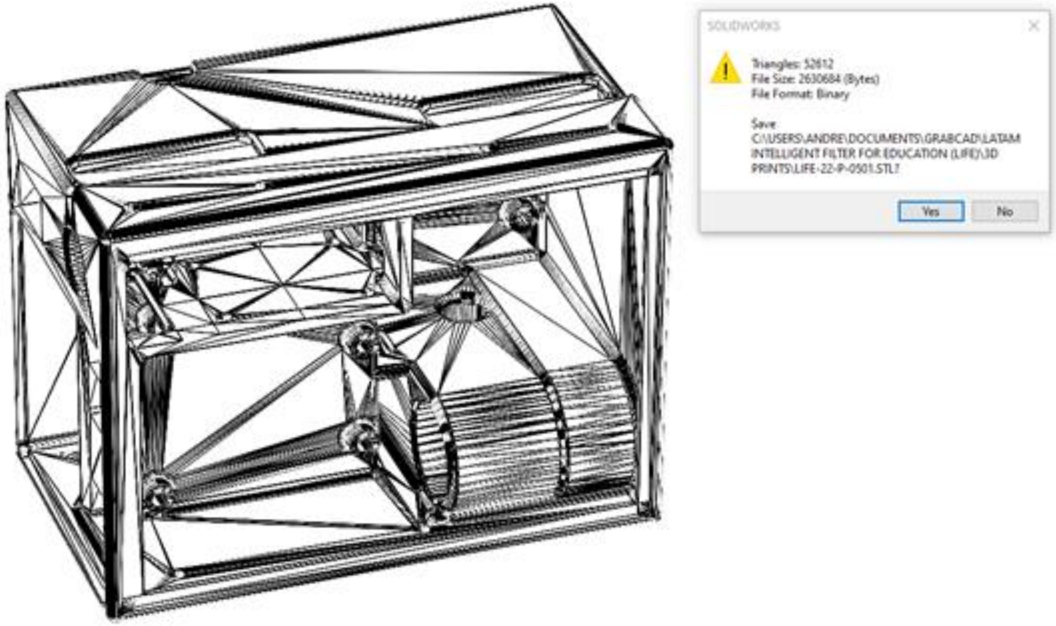
- **Fully takes advantage of 3D printing**
  - Complex geometries
  - Holes, fillets, etc. can be added anywhere
- **Designed for 3D printing**
  - Only two areas need support
  - Bridging is mostly ok
- **SOLIDWORKS (.sldprt file)**





SLDPRT → STL

- STL Stands for stereolithography
- Commonly used for 3D printing and CAD
- Universally recognized, nearly all 3D printers
- Series of linked triangles to approximate the original part
- A more complex feature gets more triangles
    - A higher resolution



SolidWorks: saving a part as an .stl

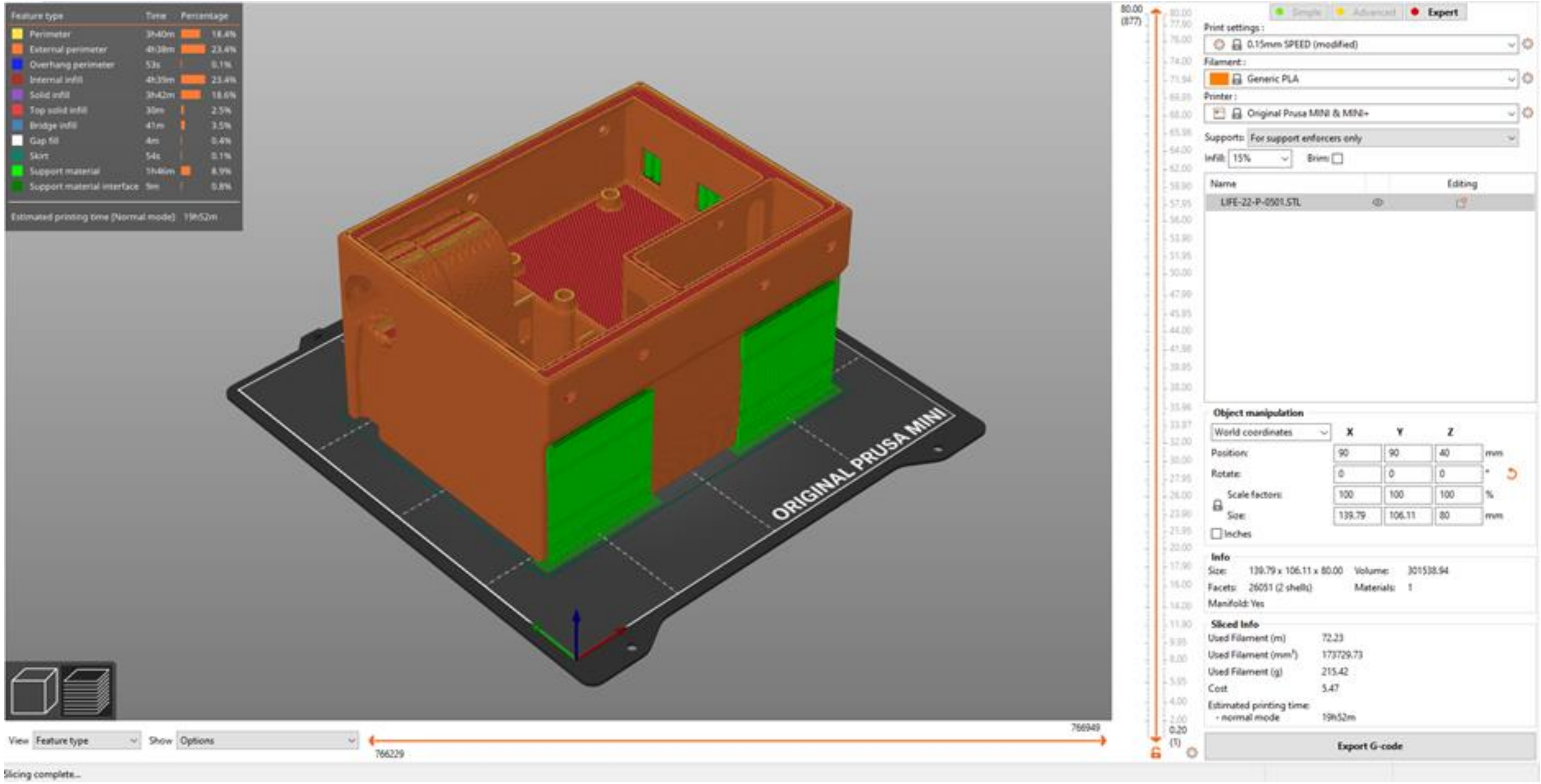
Ref: https://www.adobe.com/creativecloud/file-types/image/vector/stl-file.html

Slicing

- **A 3D Printer requires gcode**
- **A slicer program does a whole bunch of things**
  - Orient, scale, translate the part on the build plate
  - Graphically shows a layer preview
  - Change temperatures, infill percent, add supports
  - Raft, brim, skirt
- **A gcode file includes**
  - Printer setup (preheat commands, homing, mesh bed leveling)
  - Set absolute/relative positioning
  - Print movements
  - Extruder extrude/retract
  - Fan speeds
  - Temperatures

PrusaSlicer-2.3.3

Prusa MINI+
(https://www.prusa3d.com/)



.gcode file

- Opened with Notepad
- Gcode will change depending on the printer and software
    - PRUSA MINI
- 870,877 Lines
- Skirt: a line around the part

Example from the skirt

```
;TYPE:Skirt
;WIDTH:0.42
G1 F1200.000
G1 X18.402 Y34.163 E0.03013
G1 X19.088 Y33.791 E0.02449
G1 X19.855 Y33.661 E0.02437
G1 X160.137 Y33.661 E4.39845
G1 X160.929 Y33.797 E0.02520
G1 X161.633 Y34.191 E0.02532
G1 X162.163 Y34.795 E0.02520
G1 X162.461 Y35.542 E0.02520
G1 X167.035 Y66.044 E0.96707
G1 X167.039 Y144.158 E2.44923
M73 P0 R1191
G1 X166.973 Y144.687 E0.01668
G1 X166.792 Y145.187 E0.01668
G1 X166.504 Y145.634 E0.01668
G1 X166.123 Y146.006 E0.01668
G1 X165.422 Y146.384 E0.02496
G1 X164.640 Y146.509 E0.02484
G1 X22.062 Y144.638 E4.47081
G1 X21.221 Y144.527 E0.02660
G1 X20.485 Y144.248 E0.02468
G1 X19.776 Y143.770 E0.02680
G1 X19.377 Y143.368 E0.01775
G1 X18.995 Y142.833 E0.02063
G1 X18.717 Y142.207 E0.02147
G1 X18.524 Y141.101 E0.03521
G1 X17.486 Y43.842 E3.04965
G1 X17.497 Y35.813 E0.25173
G1 X17.761 Y34.952 E0.02824
M204 S1250
```

Prusa-specific G-codes*

M0, M1: Stop the printer (stop or unconditional stop)

G23: Move to Origin (Home)

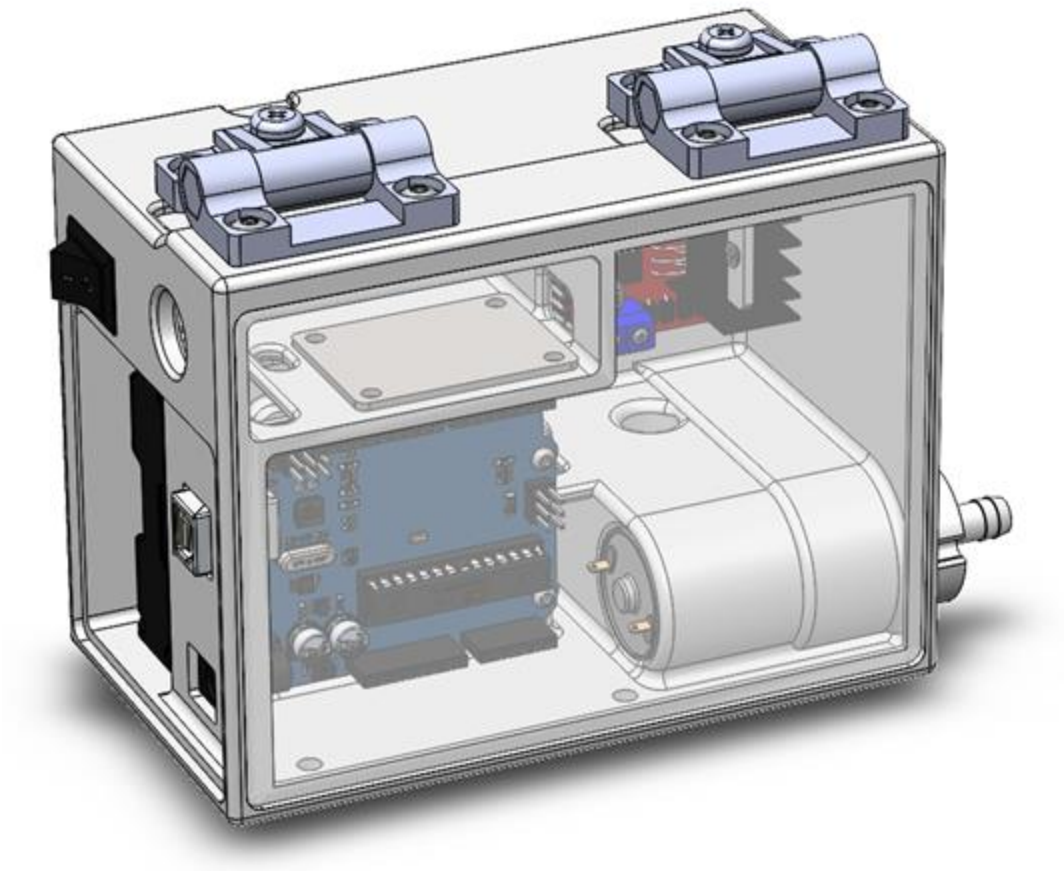
G1 [X | Y | Z | E | F | S] (Linear)

X: the position to move to on the X-axis
Y: the position to move to on the Y-axis
Z: the position to move to on the Z-axis
E: The amount to extrude between the starting point and ending point
F: the feedrate per minute of the move between the starting point and ending point (if supplied)
S: the position to move to on the X-axis

G2 [X | Y | I | E | F] (Clockwise Arc)
G3 [X | Y | I | E | F] (Counter-Clockwise Arc)

I: the point in X space from the current X position to maintain a constant distance from
J: the point in Y space from the current Y position to maintain a constant distance from

*Ref: https://help.prusa3d.com/en/article/prusa-specific-g-codes_112173



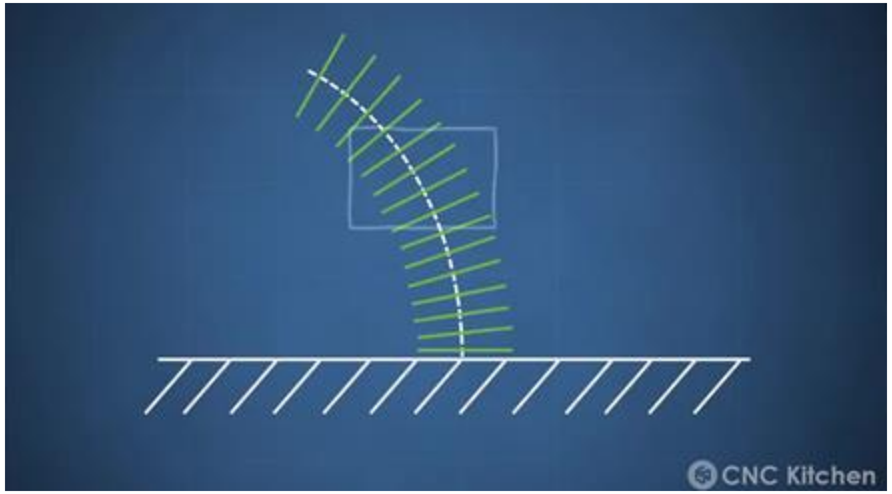

ELEGOO
UNO R3

Non-planar Surface Generation with 3-axis 3D Printers

Exploring the limits of 3-axis

Youtube - CNC Kitchen

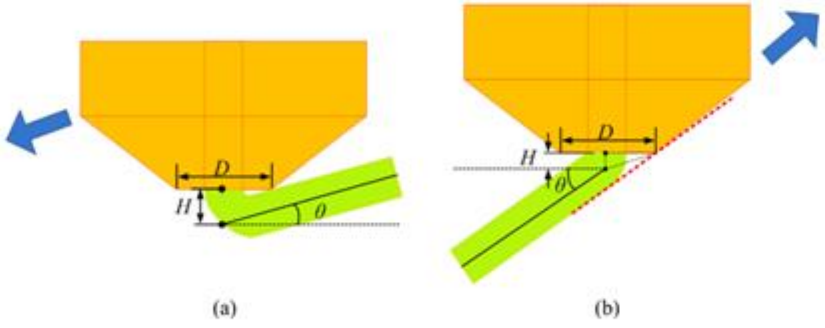
- **Uses a 3-axis printer in a non-planar way**
- **Generate a spline**
  - Start tangent perpendicular to build plate
- **Planar (XY) gcode transformed (swept) along the spline**
  - Python script
- **Extruder scale factor**
  - Inner and outer bends
  - “Local” layer height
- **The spline is longer than the original height**
  - Interpolate



CNC Kitchen (https://www.youtube.com/watch?v=0XaaUXOwzTs)

Curved Layer Fused Deposition Modeling (CLFDM)

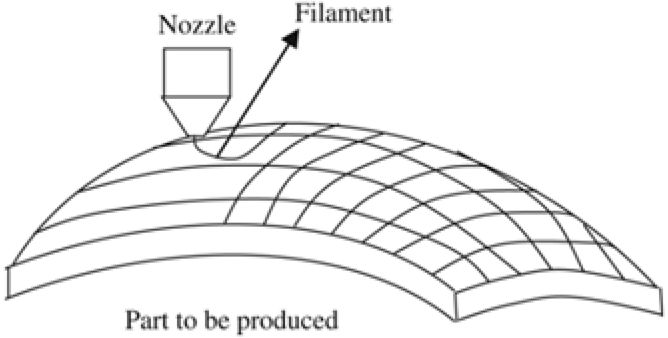
- **Print over different z-heights to improve surface quality**
  - Combination of planar and CLFDM
    - Only the top surface (exterior) is non-planar
    - The remainder is stepped
- **A 5-axis printer would follow the surface directly**
- **For a 3-axis printer**
  - The nozzle is a limiting factor



Nozzle tip with the target location of the filament with different moving directions. (Jin, Y. et al., 2016).

Different FDM printer nozzles with (c) being an ideal choice (Ahlers, D., & Zhang, J.)

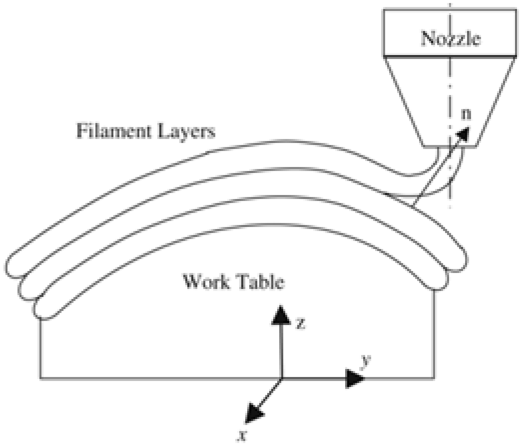
Curved Layer Fused Deposition Modeling (CLFDM)*



- **The curved surface is defined as a parametric surface**
  - A slicer generates the toolpaths along the surface
- **First surface layer is generated through surface fitting from part geometries (STL triangles)**
  - B-spline parametric surface
- **Remaining layers are from an offset (typically top/bottom/perimeters > 1 layer)**

The offset is defined by $$P_{\text{off}} = P(u, v) + n\alpha$$

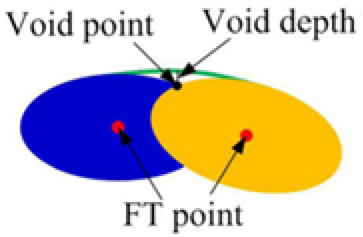
Where the normal vector from the parametric surface is $$n = \frac{P_u \times P_v}{|P_u \times P_v|}$$



*Ref (including figures): Chakraborty, D., Aneesh Reddy, B., & Roy Choudhury, A. (2008).

Curved Layer Fused Deposition Modeling (CLFDM)*

- **STL file: numerous triangles to approximate the original part**
  - The B-Spline fitting points are chosen from the vertices of triangles
  - Reduce number of triangles with error tolerance
    - Unnecessary to keep all triangles
    - Cost of accuracy
- **Extruder Path Generation**
  - Filament target (FT)
    - i.e. location of filament after leaving the nozzle
  - Path interval: lateral distance between adjacent filaments
    - There will be voids
  - Must account for overlap, try to minimize voids
- **A slicer generates gcode**



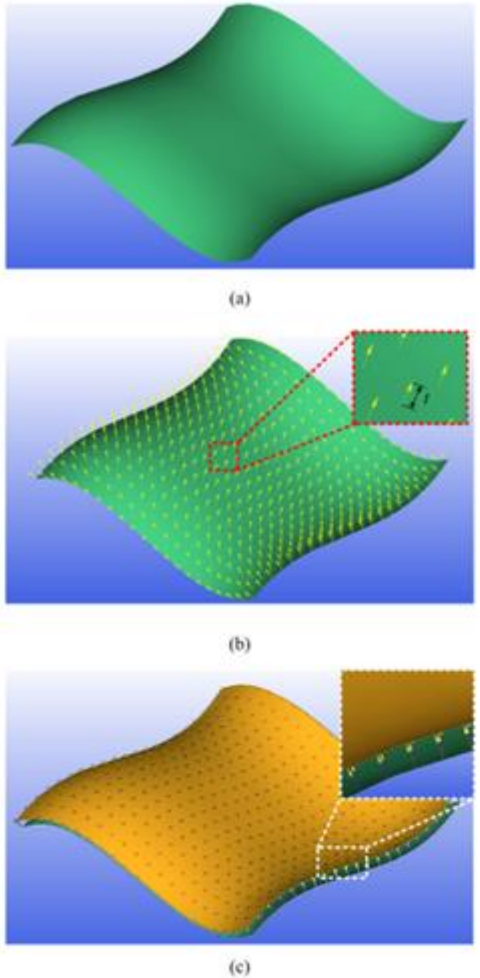


Fig. 7 Normal offsetting of a B-spline surface. **a** Reference slicing surface (RSS). **b** Generation of offsetting point sets. **c** Surface fitting based on point sets

*Ref (including figures): Jin, Y. et al. (2016).

Non-Planar Results

(a)

(b)

Ref: Ahlers, D., & Zhang, J.

References

Ahlers, D., & Zhang, J. (n.d.). *3D printing of nonplanar layers for smooth surface generation* (thesis).

Chakraborty, D., Aneesh Reddy, B., & Roy Choudhury, A. (2008). Extruder path generation for curved layer fused deposition modeling. *Computer-Aided Design*, *40*(2), 235–243. https://doi.org/10.1016/j.cad.2007.10.014

Jin, Y., Du, J., He, Y., & Fu, G. (2016). Modeling and process planning for curved layer fused deposition. *The International Journal of Advanced Manufacturing Technology*, *91*(1-4), 273–285. https://doi.org/10.1007/s00170-016-9743-5

Non-planar 3D printing by bending G-code - youtube. (2022, February 19). Retrieved March 10, 2022, from https://www.youtube.com/watch?v=0XaaUXOwzTs