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Wireframe Simplification of Parsed G-Codes to Improve Geometrical Quality of 3D Printing FEM Models

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95.7%
validation accuracy
4.27% force-displacement error

~25 min
full 50-iteration run
on standard hardware

up to 80%
lower computational load
vs. high-resolution volumetric meshes

6,776
beam elements
3,221 nodes in the validation model

From printer toolpath to predictive mechanics

A direct, reduced-order route that preserves filament orientation, porosity, and interlayer connectivity.

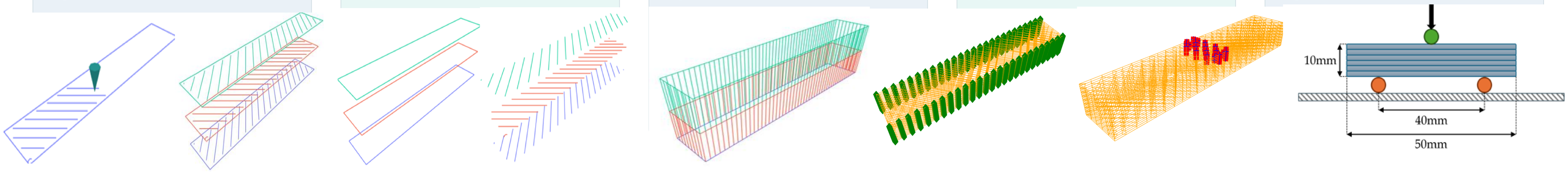
01 **READ G-CODE** – Extract X, Y, Z and extrusion E

02 **RECONSTRUCT** – Segment layers; classify walls and infill

03 **CONNECT** – Add stiff interlayer and wall-infill links

04 **BUILD FEM** – Instantiate 3D Euler-Bernoulli beams

05 **VALIDATE** – Replicate 3-point bending response

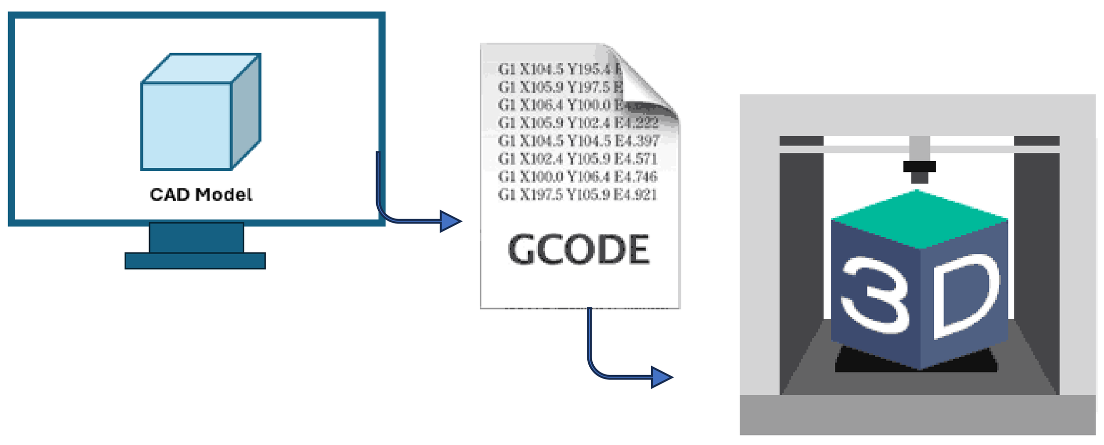


The design challenge

Continuum meshes hide the print path.

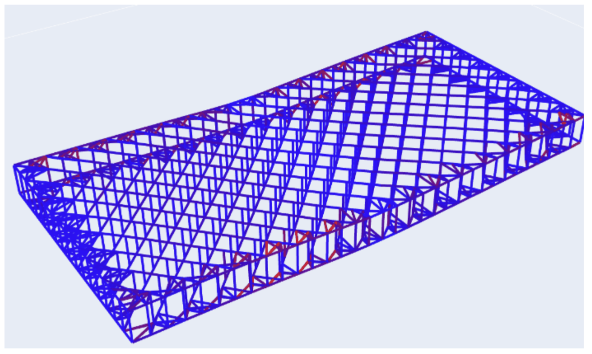
- CAD/STL solid meshes homogenize bead boundaries and pores.
- Filament-scale volumetric meshes can require millions of elements.
- G-code already contains the architecture that governs stiffness.

Objective: retain toolpath physics without volumetric-mesh cost.



Wireframe construction

- Unique Z values separate layers.
- Closed contours become walls; interior paths become infill.
- Artificial links enforce layer-to-layer and wall-infill continuity.

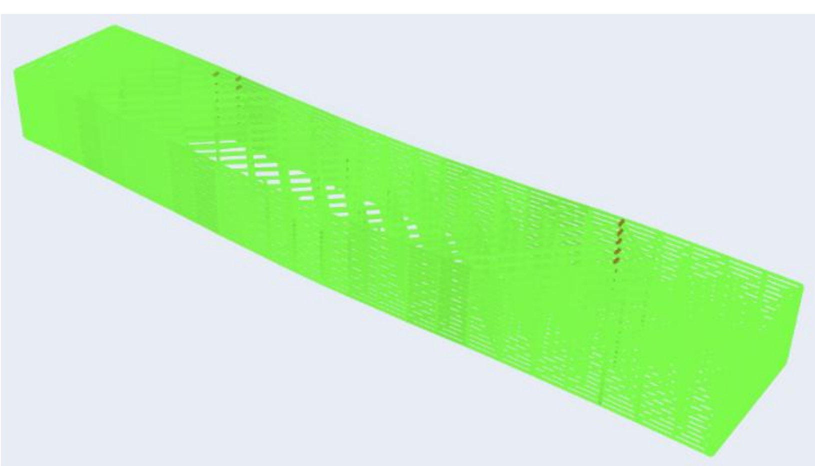


Reduced-order FEM formulation

$$K_{global} U = F_{global}$$

- 3D beam elements carry axial, bending, and torsional stiffness.
- Boundary conditions reproduce the physical support and loading geometry.
- Incremental updates capture changing orientation and stress state.

Validation mesh



3,221 nodes

6,776 elements

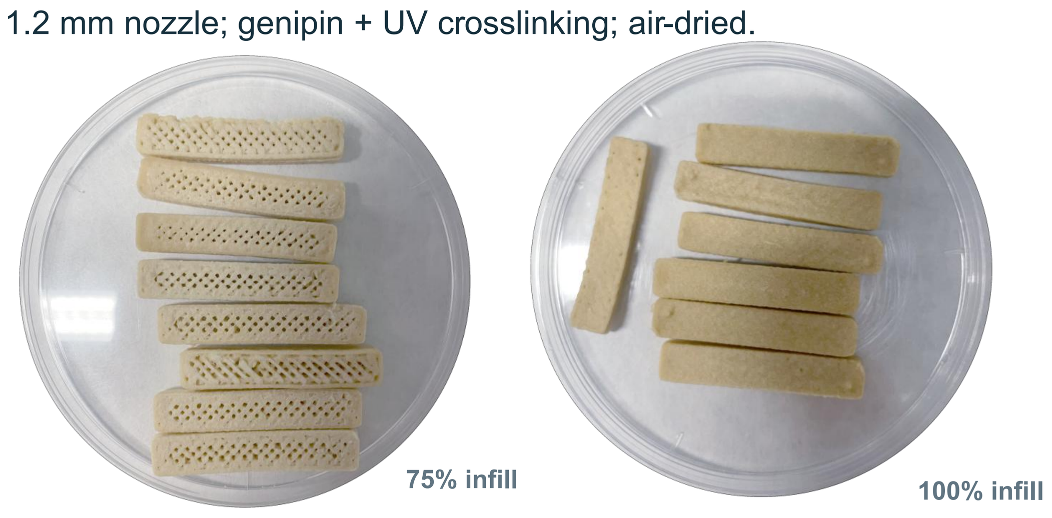
50 iterations

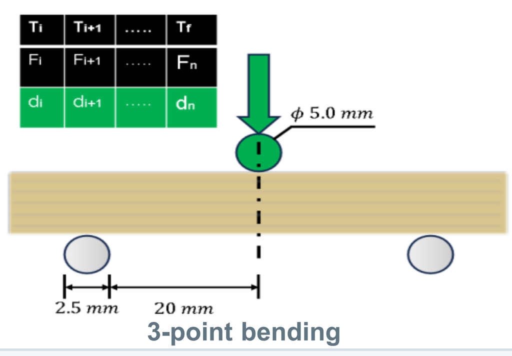
Euler-Bernoulli beams preserve the discrete filament network while sharply reducing degrees of freedom.

Experimental validation

Collagen scaffold test bed.

- COL25 collagen ink; 50 x 10 x 5 mm scaffolds.
- 75% porous and 100% infill architectures.
- 1.2 mm nozzle; genipin + UV crosslinking; air-dried.

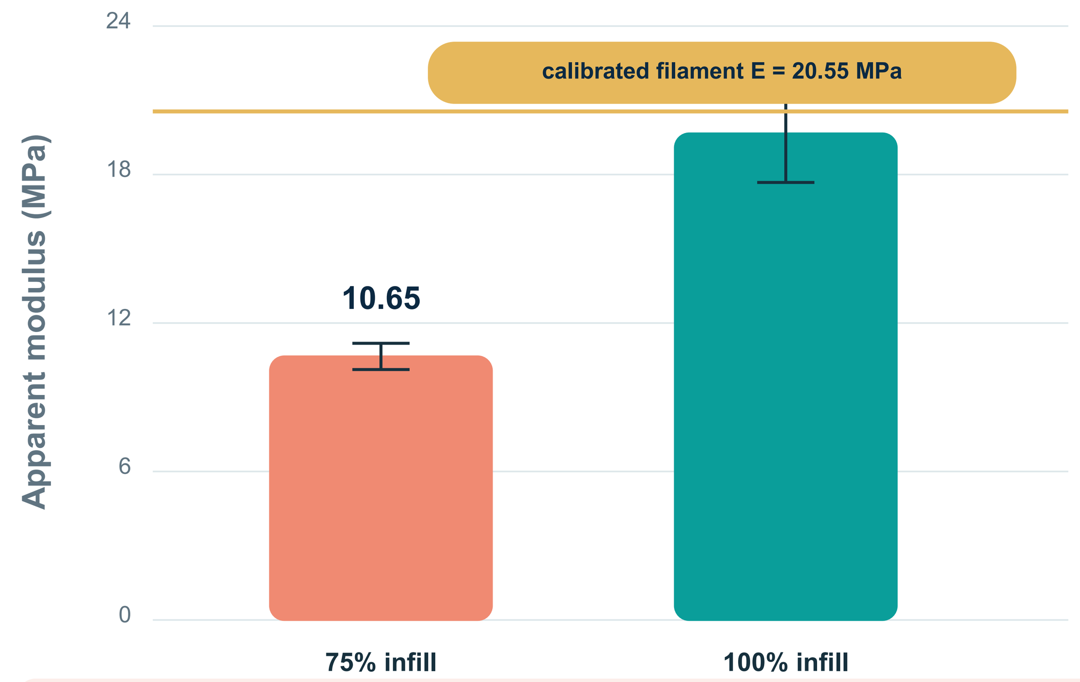




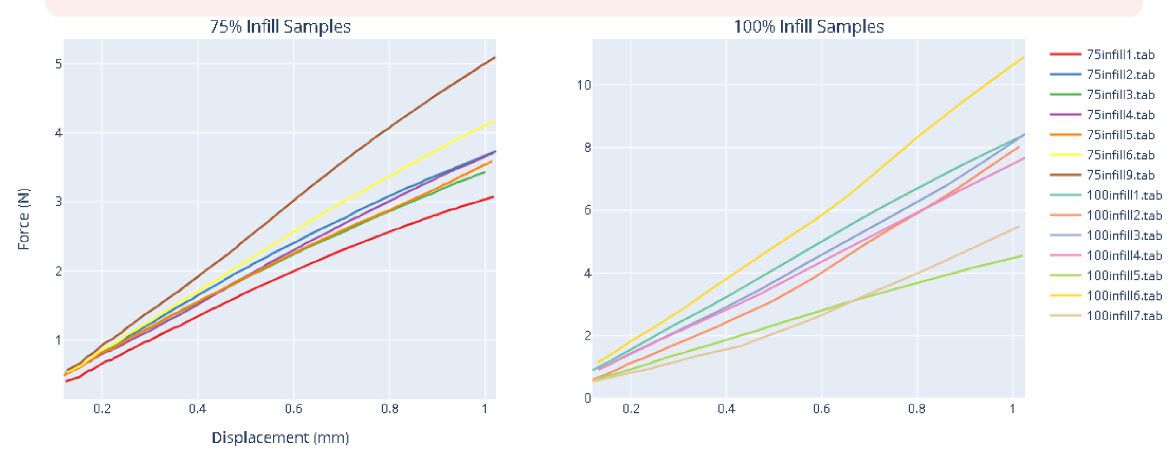
- Support span: 40 mm
- Midpoint speed: 1 mm/s
- FEM uses matching geometry and displacement

Architecture controls stiffness

Porosity reduced apparent modulus by ~46%.



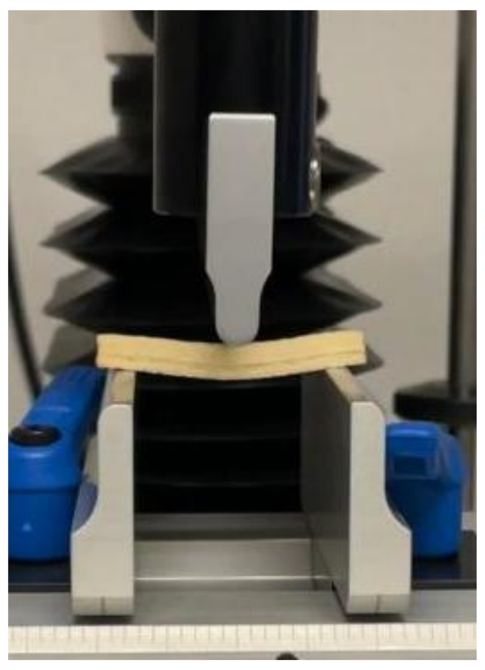
10.65 ± 0.53 MPa → 19.66 ± 1.98 MPa



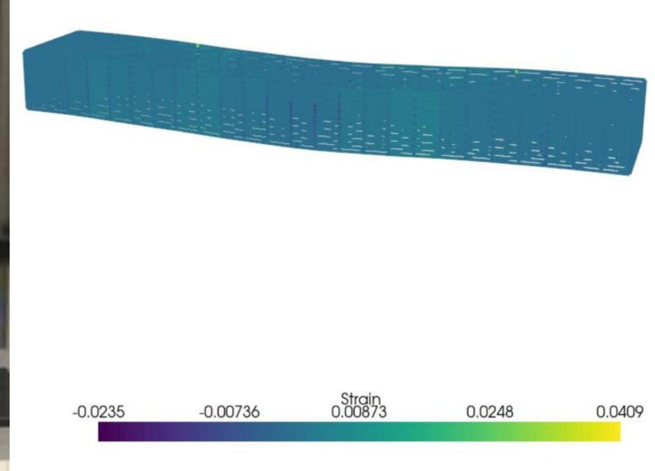
Force-displacement curves separate clearly by infill architecture.

FEM validation

Toolpath-driven response matched experiment.



3-point bending test



Simulated strain field

4.27%
curve error
best-fidelity 75% sample

20.55 MPa
optimal filament E
close to 100% baseline

- Predicted deformation mode agrees with the physical bending test.
- Residual mismatch is consistent with viscoelasticity and microstructural rearrangement not included in the linear-elastic beam law.

Computational efficiency

Wireframe run	Traditional high-resolution model
~25 min	up to 120 h

20-moduli calibration sweep: ~8.5 h on Ryzen 9 6900HX / 32 GB RAM

Conclusion & next steps

- G-code can serve directly as a mechanically meaningful model geometry.
- Beam networks retain infill, orientation, porosity, and filament-scale load paths.
- The framework enables rapid scaffold iteration on standard hardware.

Next: interlayer adhesion + viscoelastic constitutive laws

TAKE-HOME MESSAGE

A G-code-derived wireframe can predict porous scaffold mechanics accurately in minutes - without erasing the filament architecture that drives performance.

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