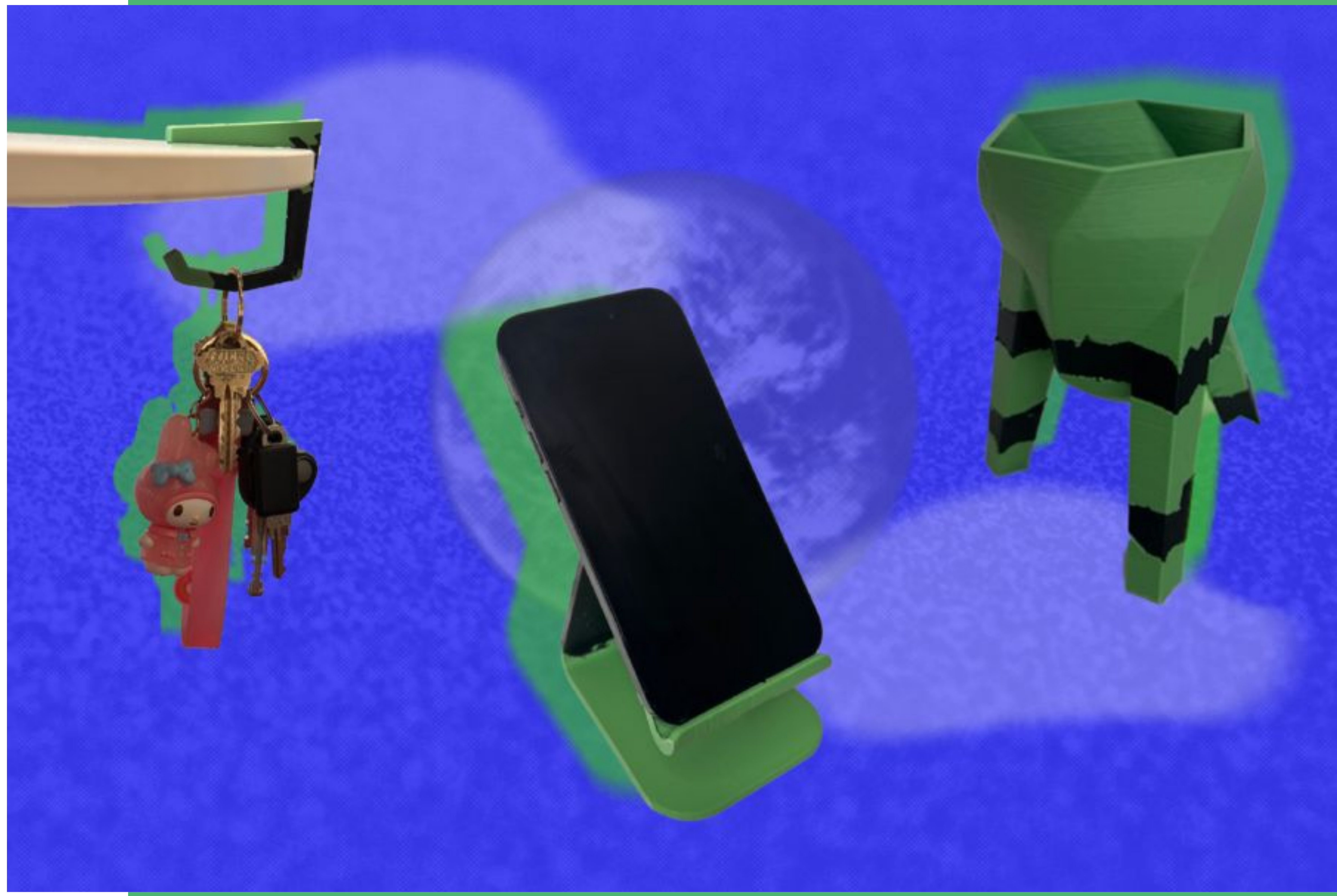
SustainaPrint: Making the Most of Eco-Friendly Filaments



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34% of all 3D prints are discarded as waste, contributing significantly to environmental issues

- 3D printing generates a lot of waste: scraps, failed prototypes, support materials.
- PLA is the most popular 3D printing material.
- Although PLA is “biodegradable”, when discarded in landfill, PLA waste takes **between 100 to 1,000 years to degrade**.

How can we facilitate the use of more recycled materials in 3D printing?

Filaments such as PLA can be recycled by melting down and re-extruding them, for example using a machine like **Filabot:**

How can we facilitate the use of more recycled materials in 3D printing?

Recycled filaments face **mechanical degradation.**

Prior work has found tensile strength reductions of up to 50% when recycling.

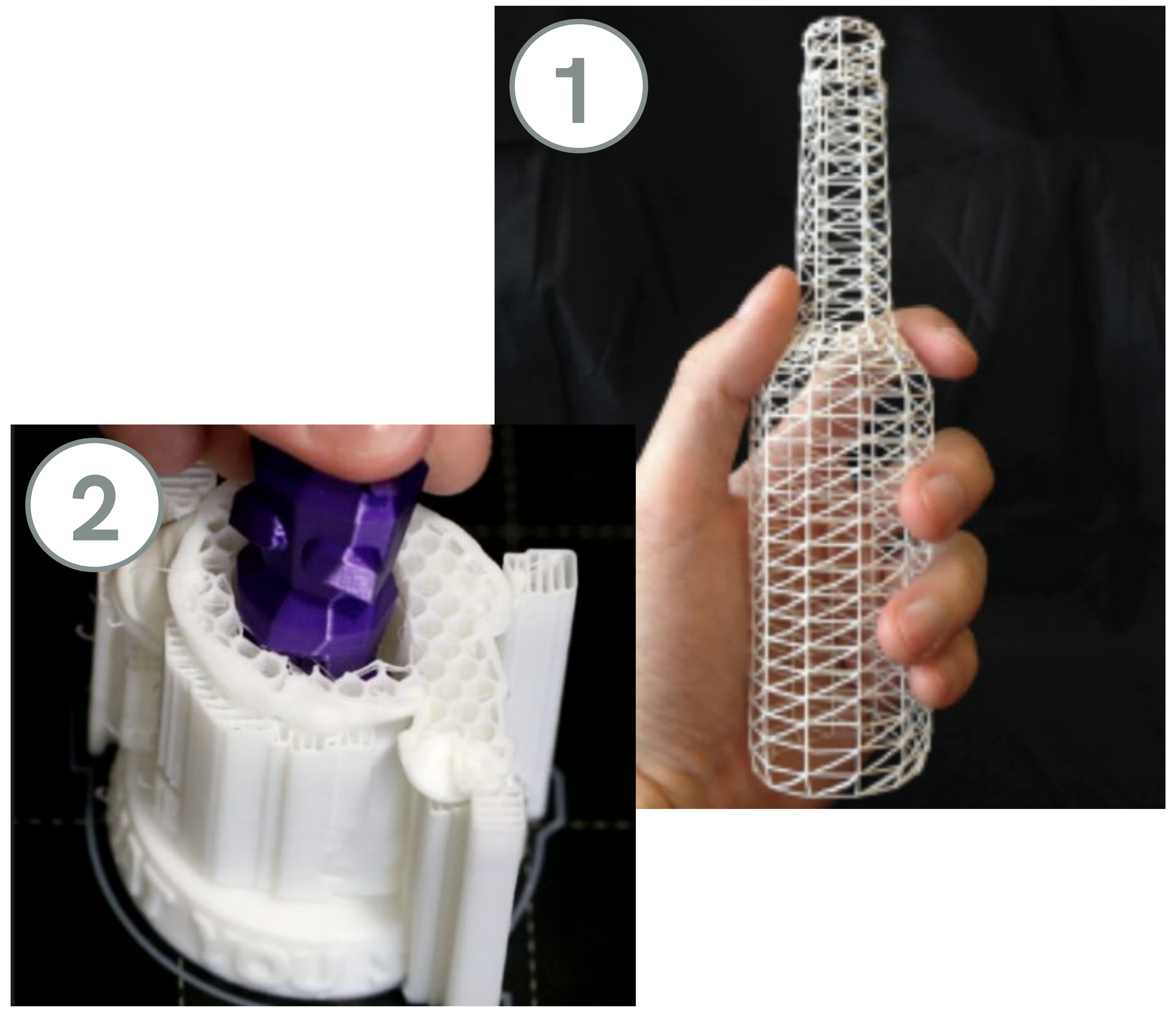
Table 1. Results from mechanical tests: short-beam strength reported as mean value ± standard deviation.

PLA filament	Short-beam strength (MPa)
Virgin	119.1 ± 6.6
One time-recycled	106.8 ± 9.0
Twice recycled	108.5 ± 9.9
Three times recycled	75.0 ± 16.2

Lanzotti, Antonio, et al. "A comparison between mechanical properties of specimens 3D printed with virgin and recycled PLA." *Procedia Cirp* 79 (2019): 143-146.

Related Work in Sustainable Fabrication

Geometry-focused approaches

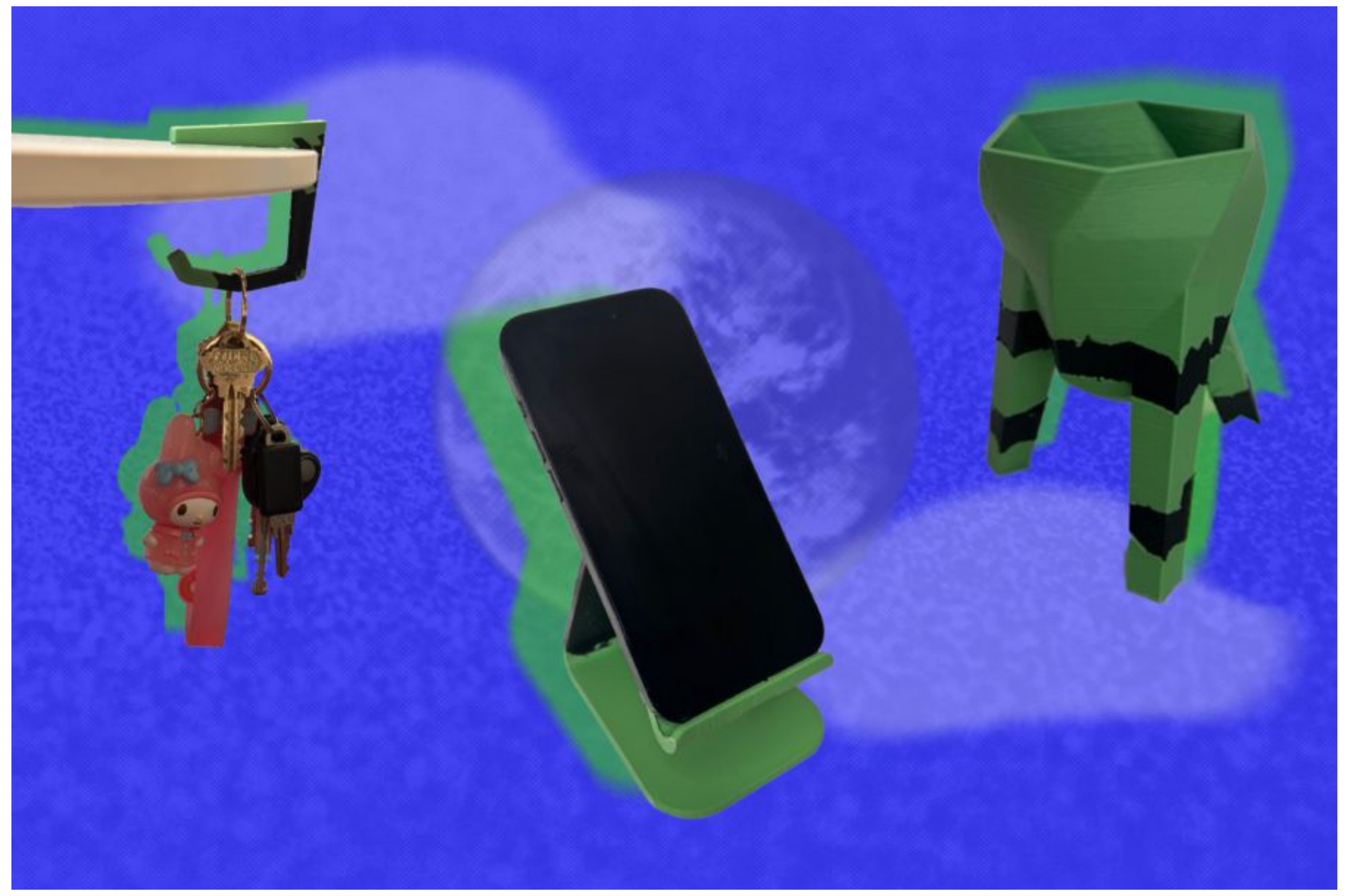


Prior work reduces waste by changing object form (e.g., scrap reuse, wireframe previews).

Material-focused approaches

Eco-friendly or recycled filaments exist, but often **suffer degraded mechanical strength.**

SustainaPrint's intersection



SustainaPrint combines geometry-aware simulation with material-aware assignment.

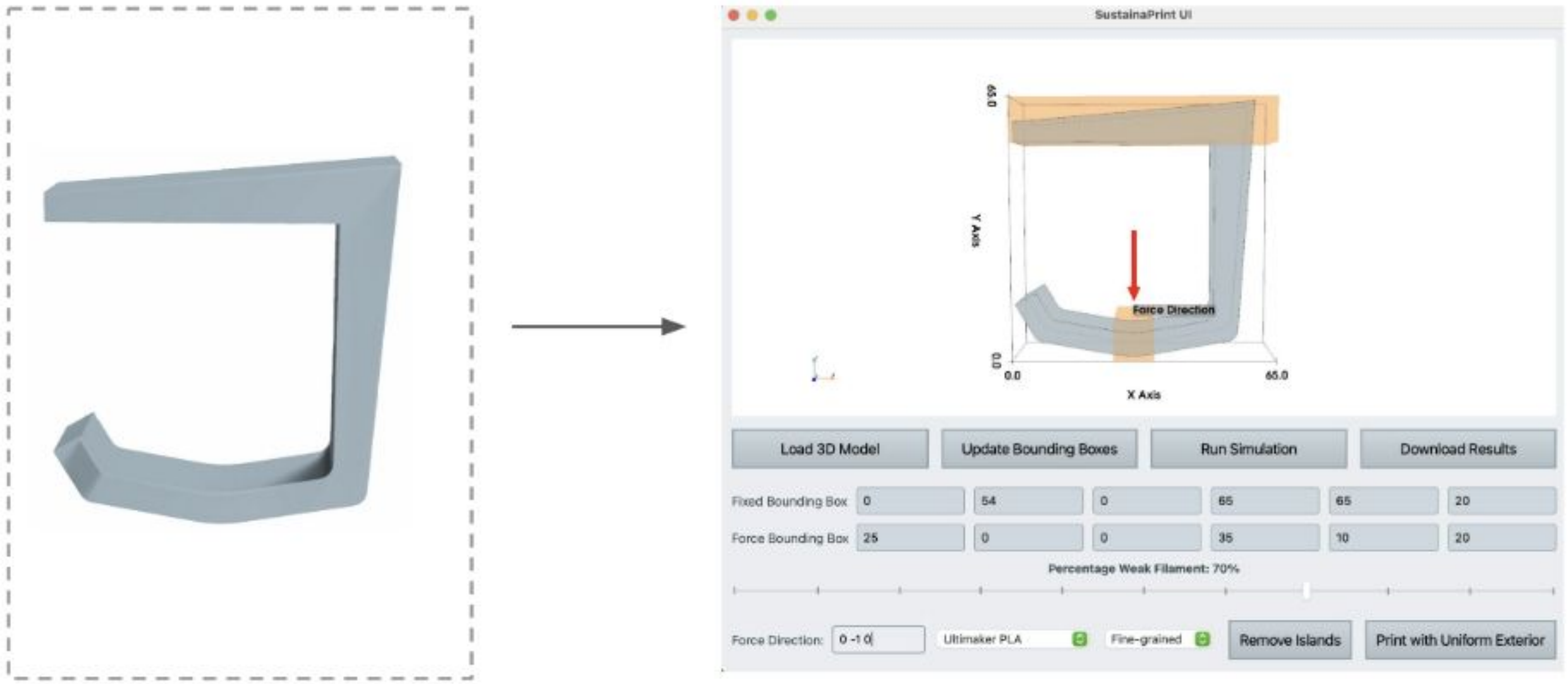
[1] Mueller, Stefanie, et al. "WirePrint: 3D printed previews for fast prototyping." *Proceedings of the 27th annual ACM symposium on User interface software and technology*. 2014.
[2] Wall, Ludwig Wilhelm, et al. "Scrappy: Using scrap material as infill to make fabrication more sustainable." *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 2021.
[3] Rivera, Michael L., S. Sandra Bae, and Scott E. Hudson. "Designing a sustainable material for 3D printing with spent coffee grounds." *Proceedings of the 2023 ACM designing interactive systems conference*. 2023.
[4] Zhu, Jingwen, Lily Winagle, and Hsin-Liu Kao. "Ecothreads: Prototyping biodegradable e-textiles through thread-based fabrication." *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*. 2024.

SustainaPrint System Overview

ⓐ Input Model

SustainaPrint strategically combines eco-friendly and virgin filaments by simulating stress to assign stronger material to critical regions, maximizing sustainable filament use without compromising structural integrity.

SustainaPrint System Overview



ⓐ Input Model ⓑ SustainaPrint UI

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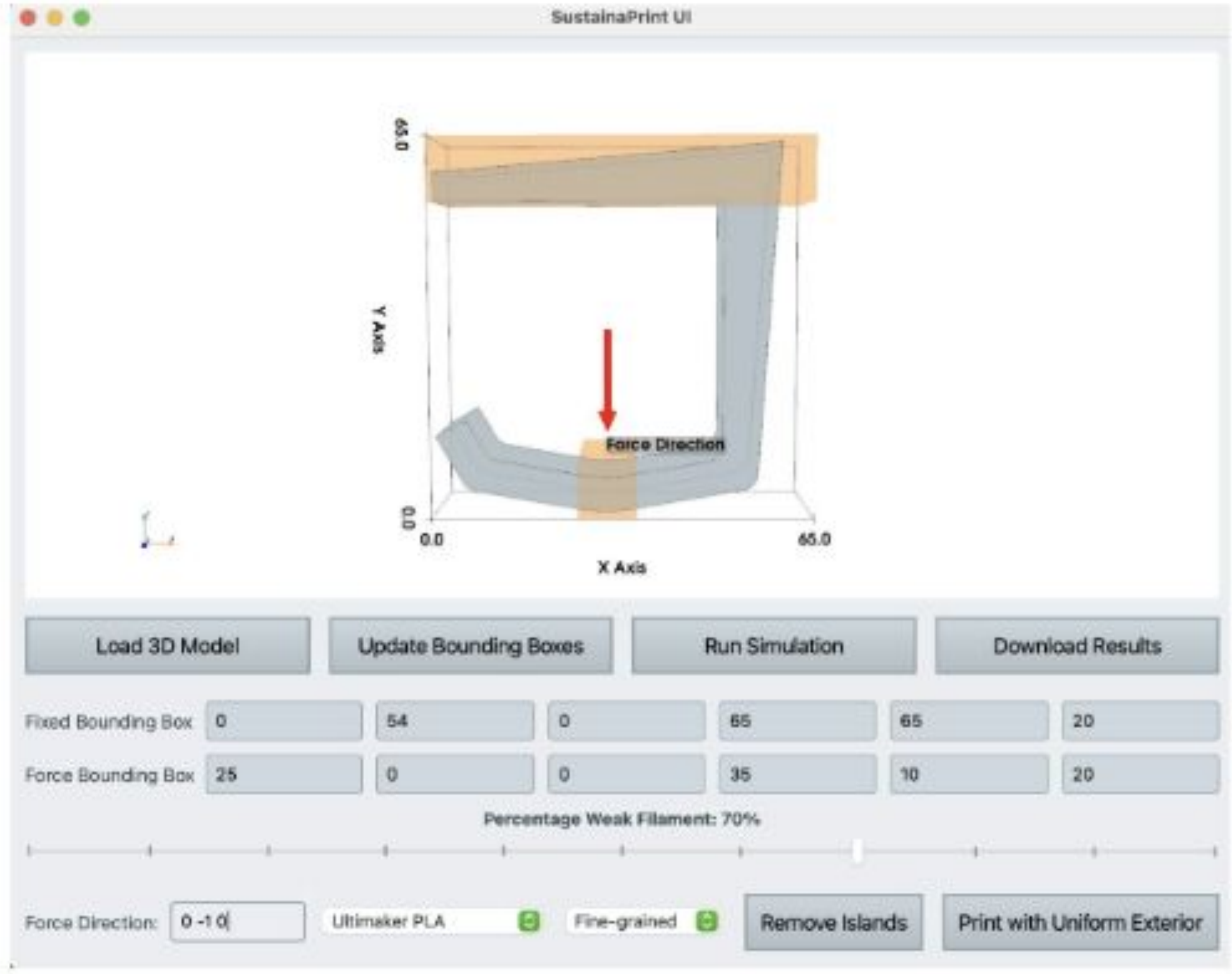
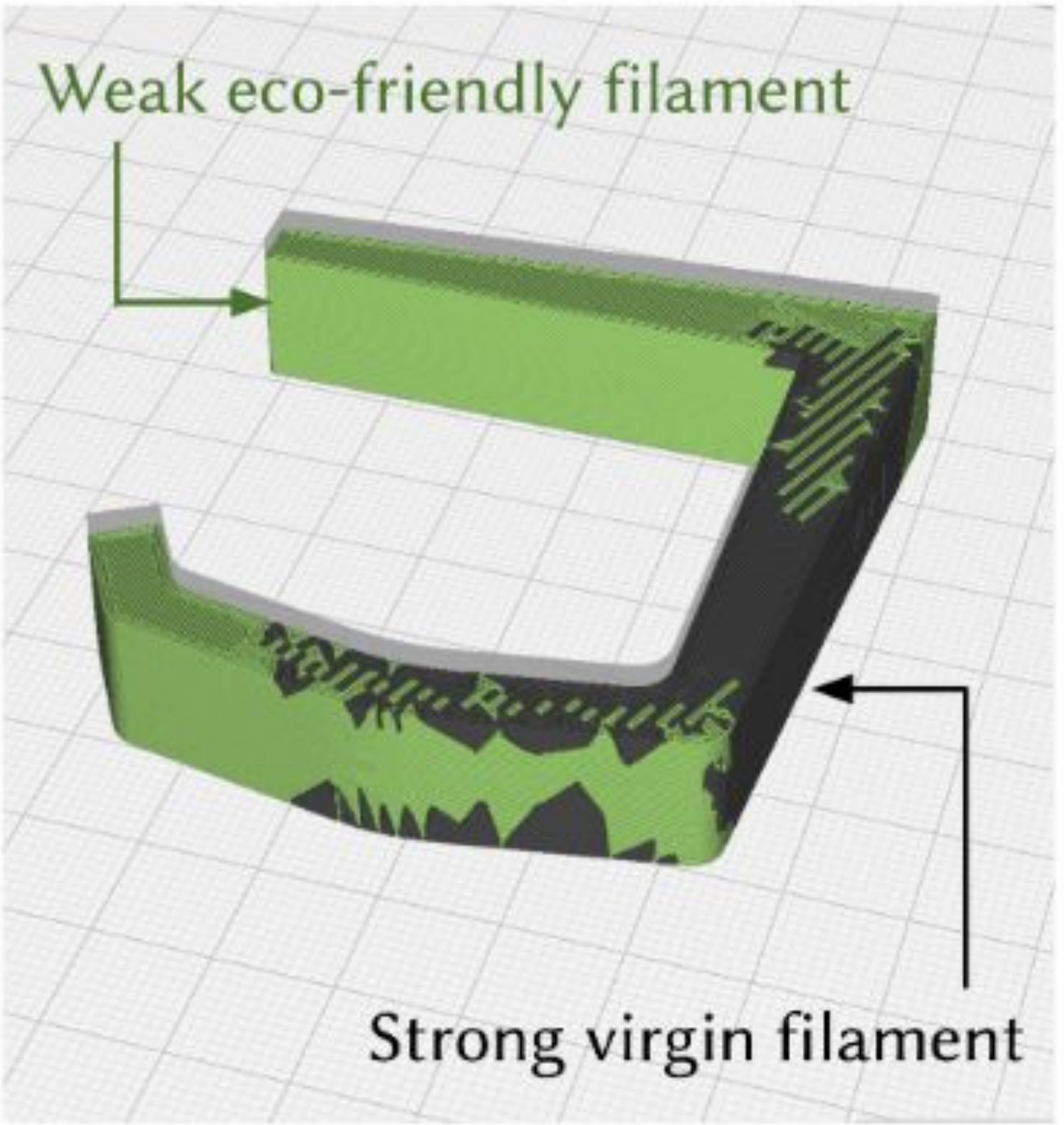
SustainaPrint System Overview

ⓐ **Input Model**



ⓑ **SustainaPrint UI**



ⓒ **Slice and Print**

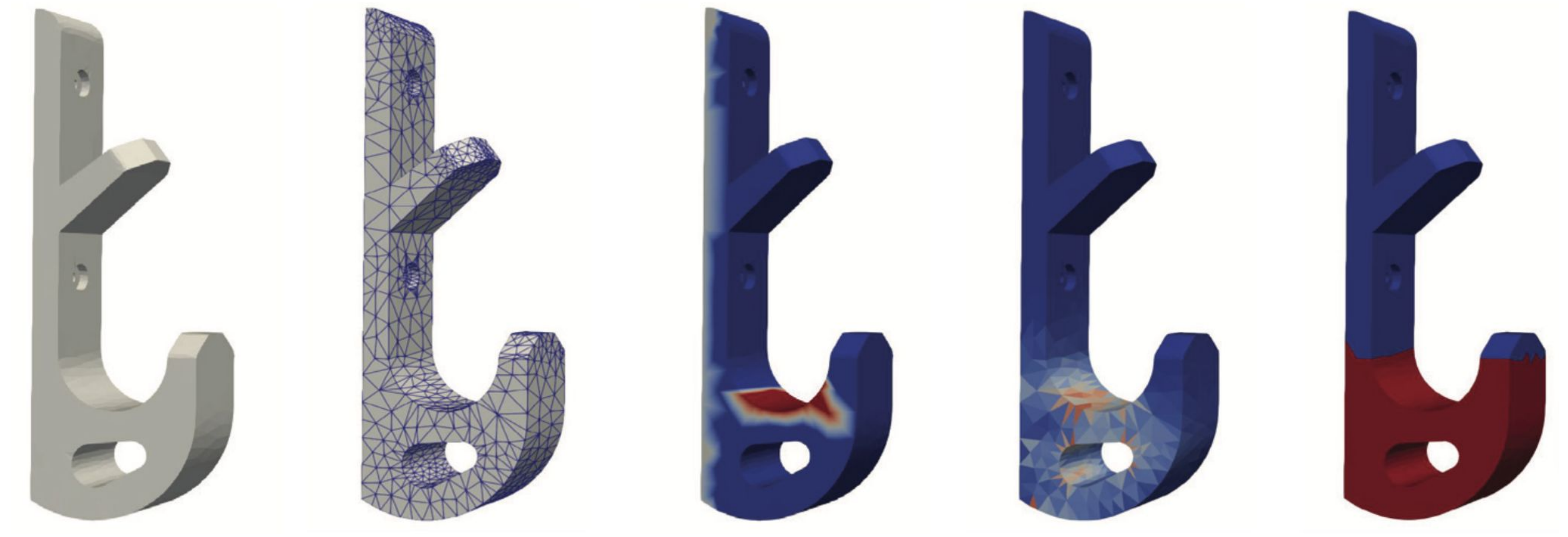
▶ SustainaPrint strategically combines eco-friendly and virgin filaments by simulating stress to assign stronger material to critical regions, maximizing sustainable filament use without compromising structural integrity.

SustainaPrint System Overview

ⓐ Input Model ⓑ SustainaPrint UI ⓒ Slice and Print ⓓ Use

SustainaPrint strategically combines eco-friendly and virgin filaments by simulating stress to assign stronger material to critical regions, maximizing sustainable filament use without compromising structural integrity.

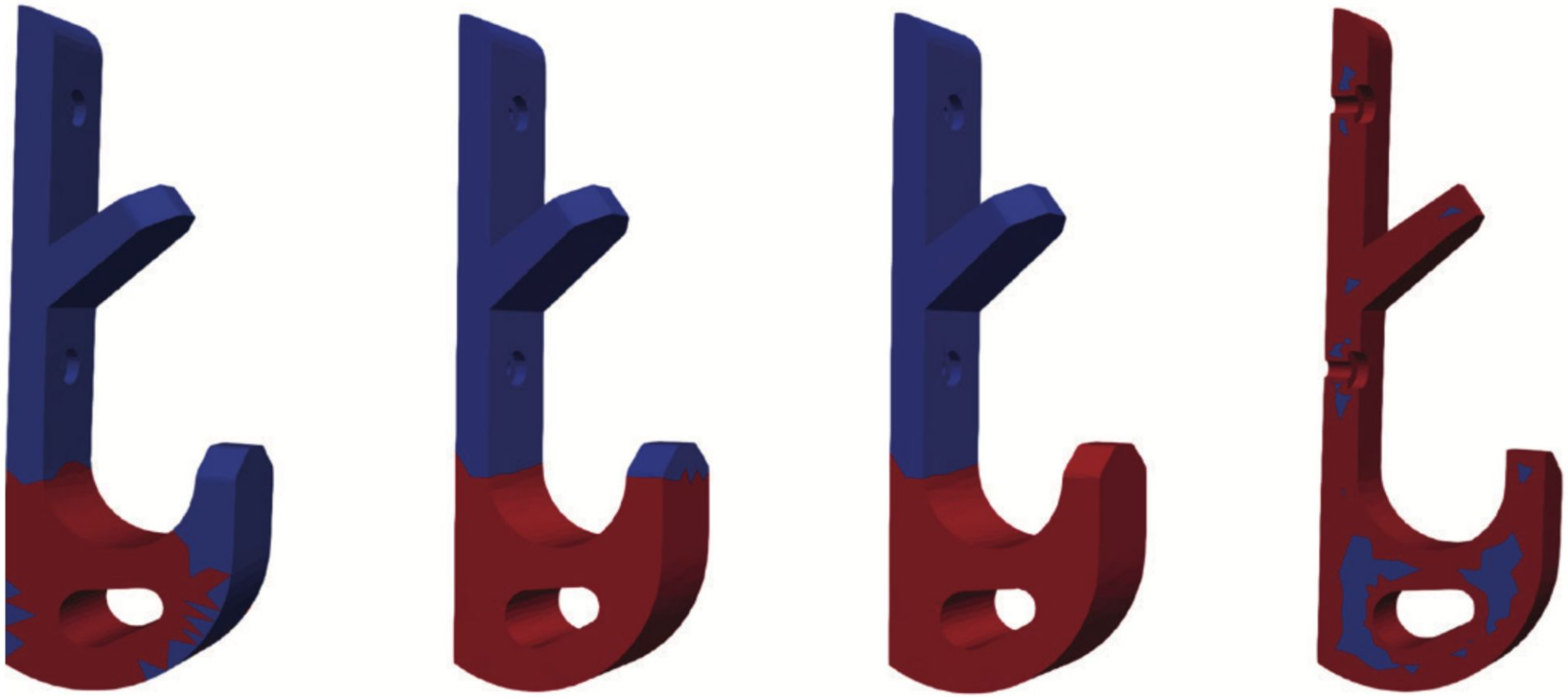
Mechanical Simulation & Segmentation



Input Model | Convert to Mesh | Define Boundary Conditions | Simulate | Segment

SustainaPrint uses **finite element analysis (FEA) to identify high-stress regions** and applies two segmentation modes to assign strong or eco-friendly filament, balancing strength and printability.

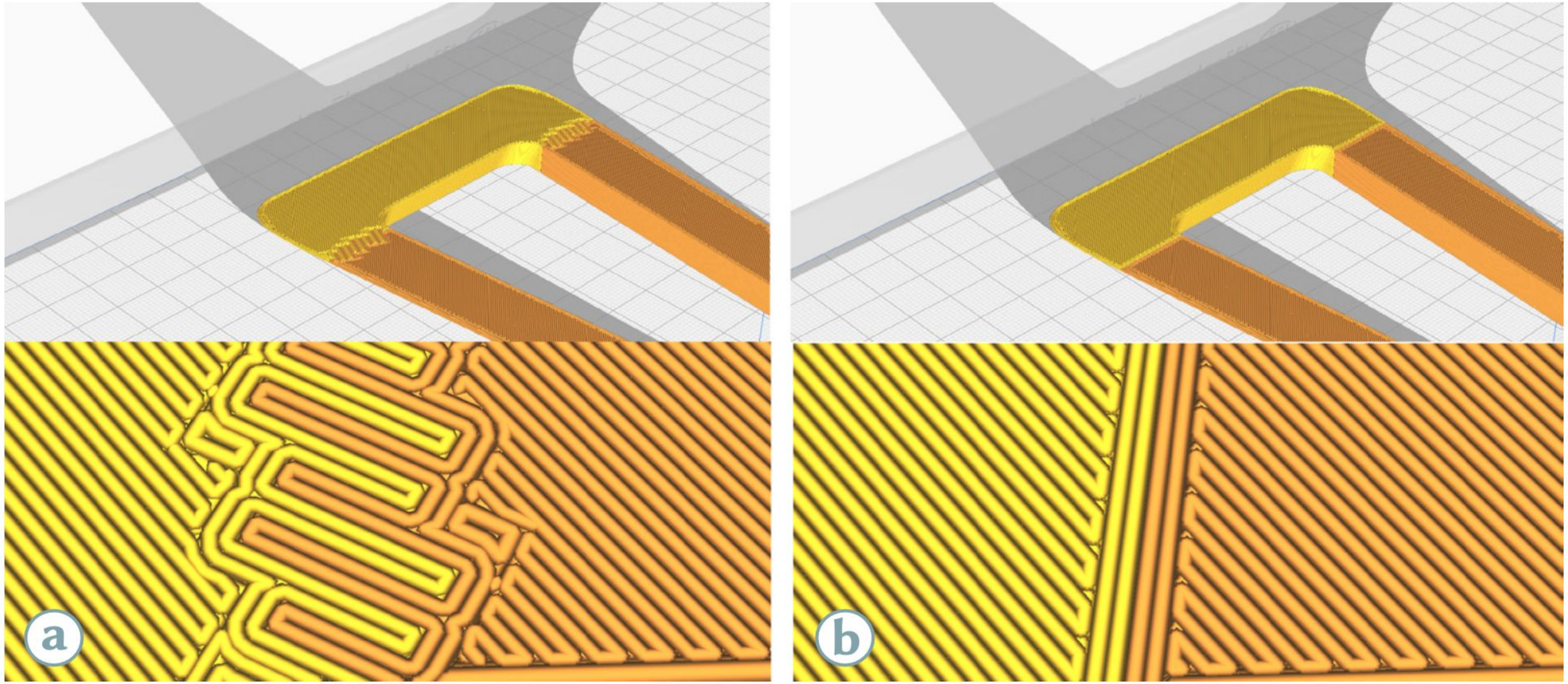
Printability Heuristics



Original | Layer Threshold | Island Removal | Uniform Skin

Heuristics like island removal, uniform outer shells, and interlocking interface structures enhance print quality and bonding in dual-material 3D prints.

Interlocking Interface Structures



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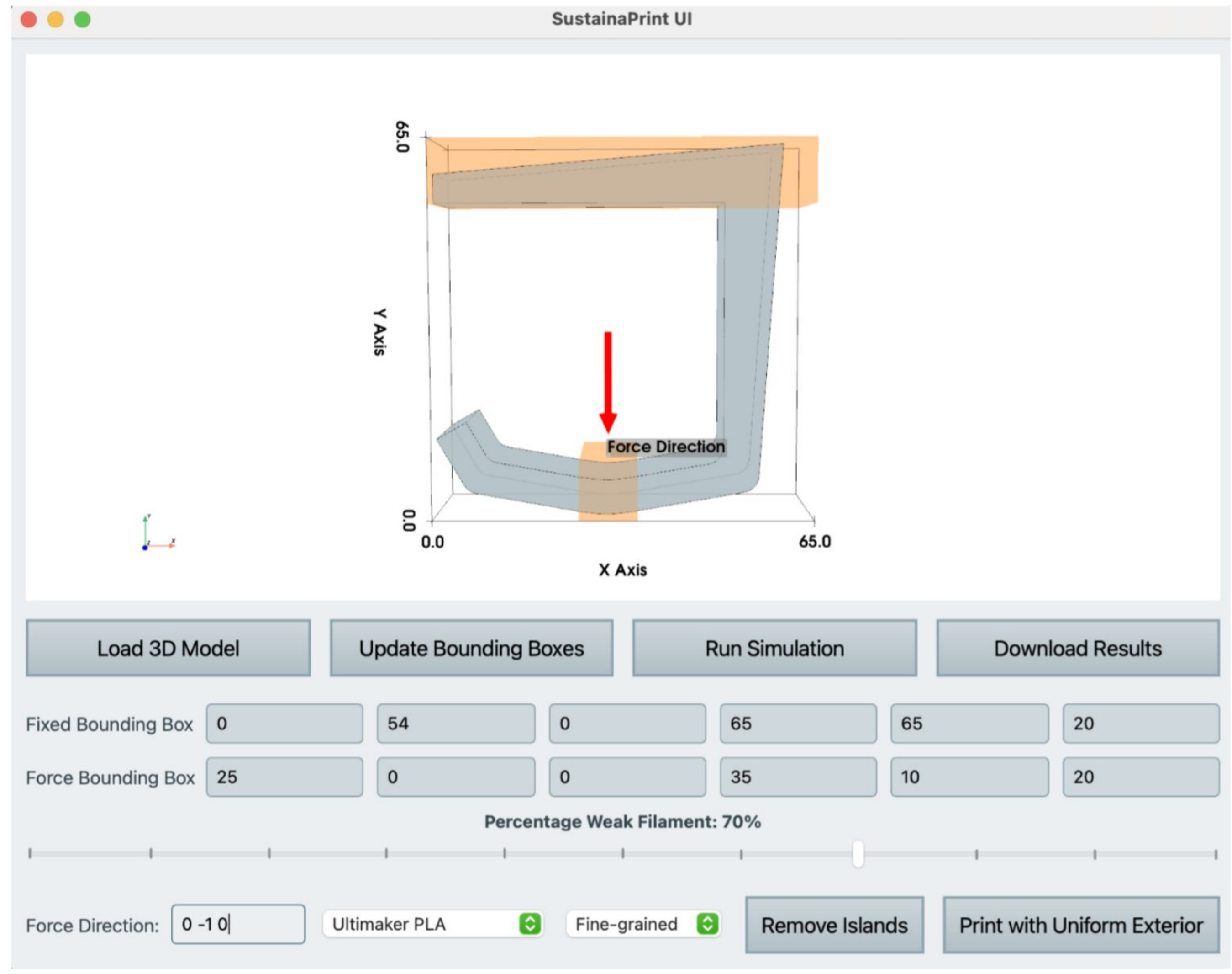
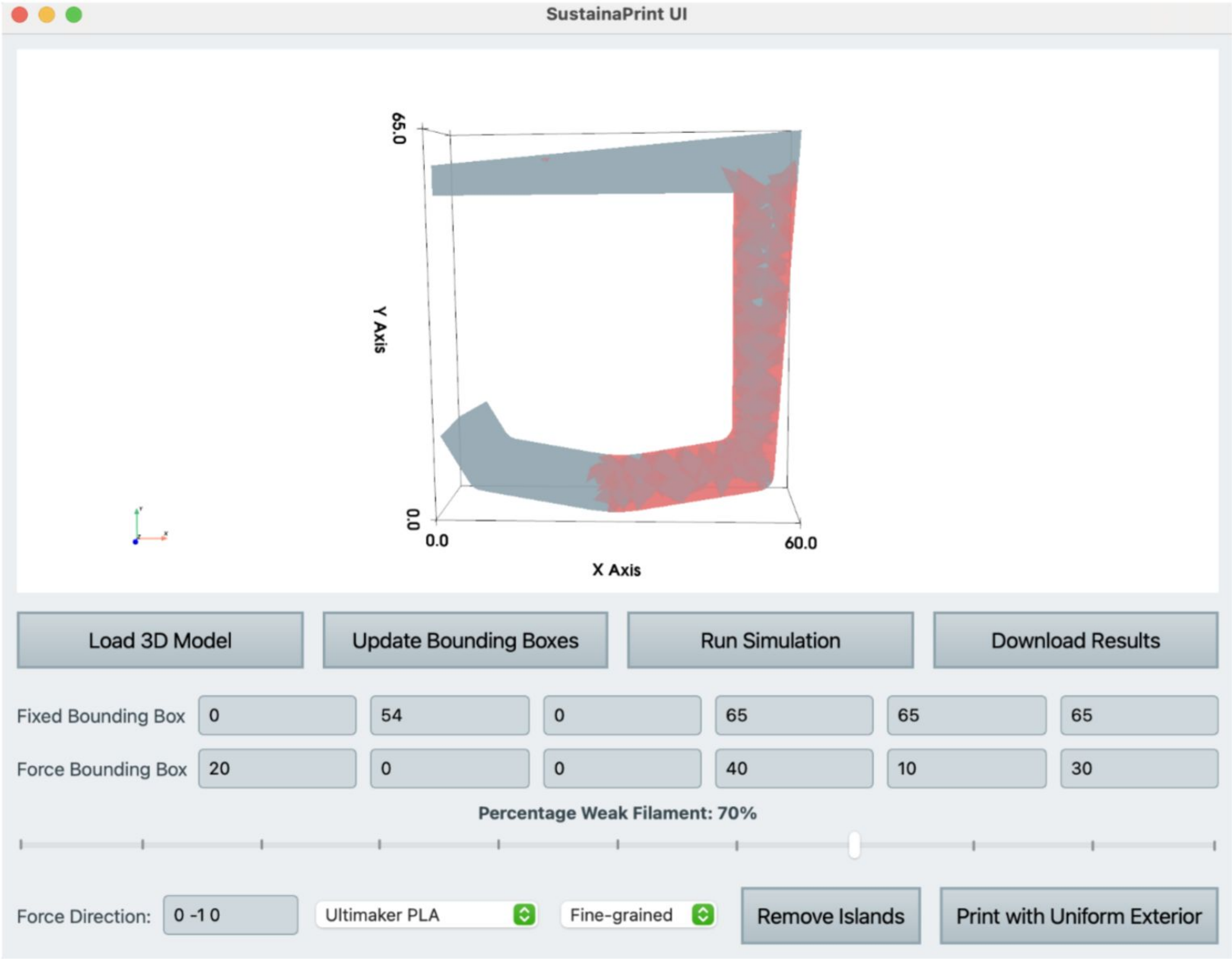
SustainaPrint User Interface



Model and Force Inputs

- Users load their 3D model and specify filaments by inputting material properties or selecting presets.
- The UI allows marking fixed regions and applying forces with visual guidance, including default presets for novices.



Segment & Export

- Users select segmentation modes with previews, adjust eco-friendly material percentage, and apply heuristics.
- Final multi-material print files are exported for dual-extruder printing.

Applications of SustainaPrint

Reinforced Hook

Wall and table-mounted hooks are reinforced at mounting points and hanging edges to support heavy loads while minimizing virgin plastic usage.

Standing Plant Pot

Plant pots with tripod bases are reinforced at the legs and base junctions to withstand soil and water weight, while walls use eco-friendly filament.

Bottle Opener

Bottle openers experience torque at prying edges. SustainaPrint simulates these loads and assigns strong material to high-stress regions.

Stands for Devices

Phone and headphone stands are reinforced at vertical supports and cantilevered hooks to maintain balance and durability with minimal virgin filament.

Evaluation Methodology

SustainaPrint's evaluation includes testing on functional and primitive geometries with controlled print parameters and mechanical testing to validate strength and durability improvements.

Evaluation Methodology - Primitives

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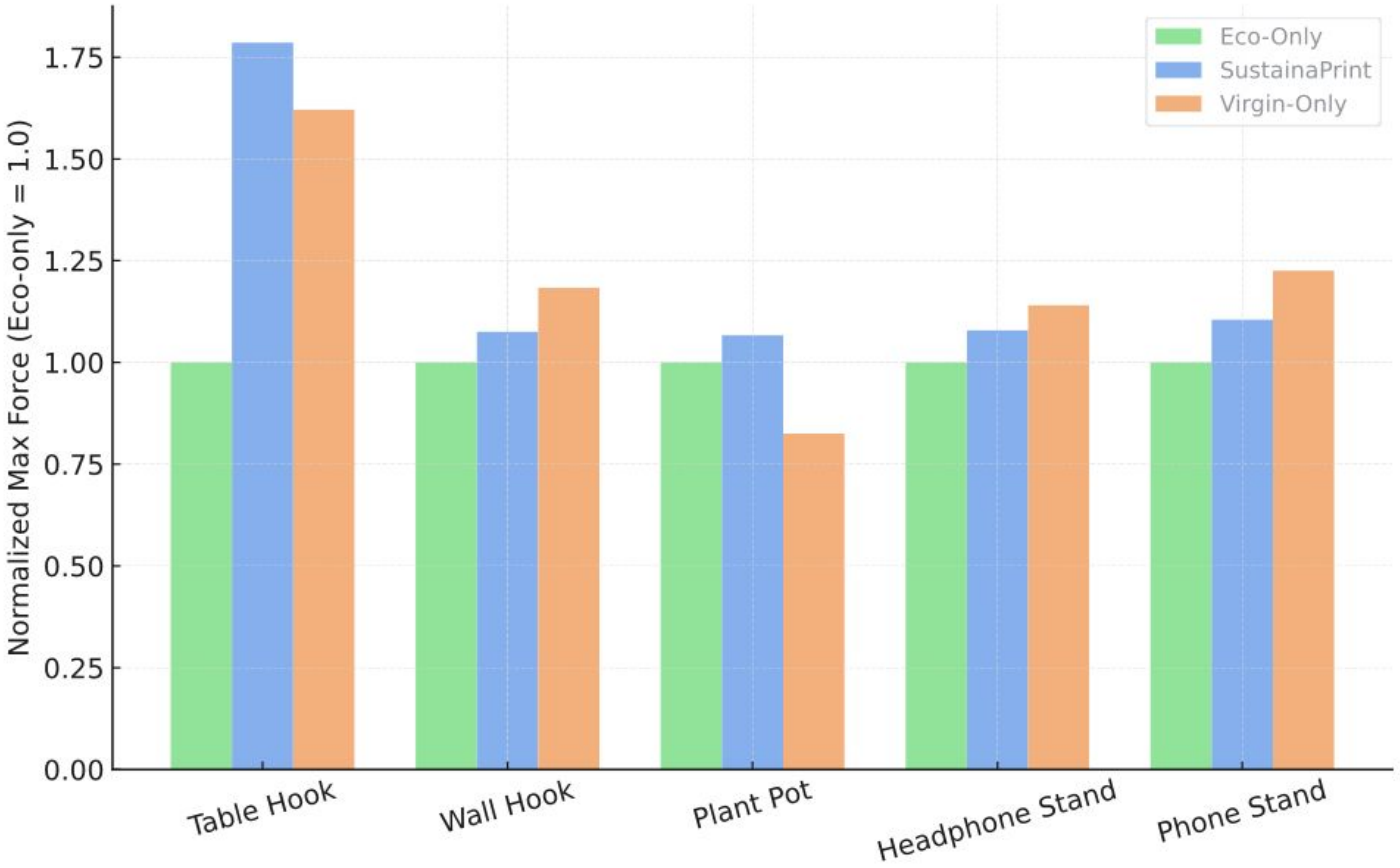
Mechanical Performance Results - Functional Objects

Max Force of Functional Objects by Material

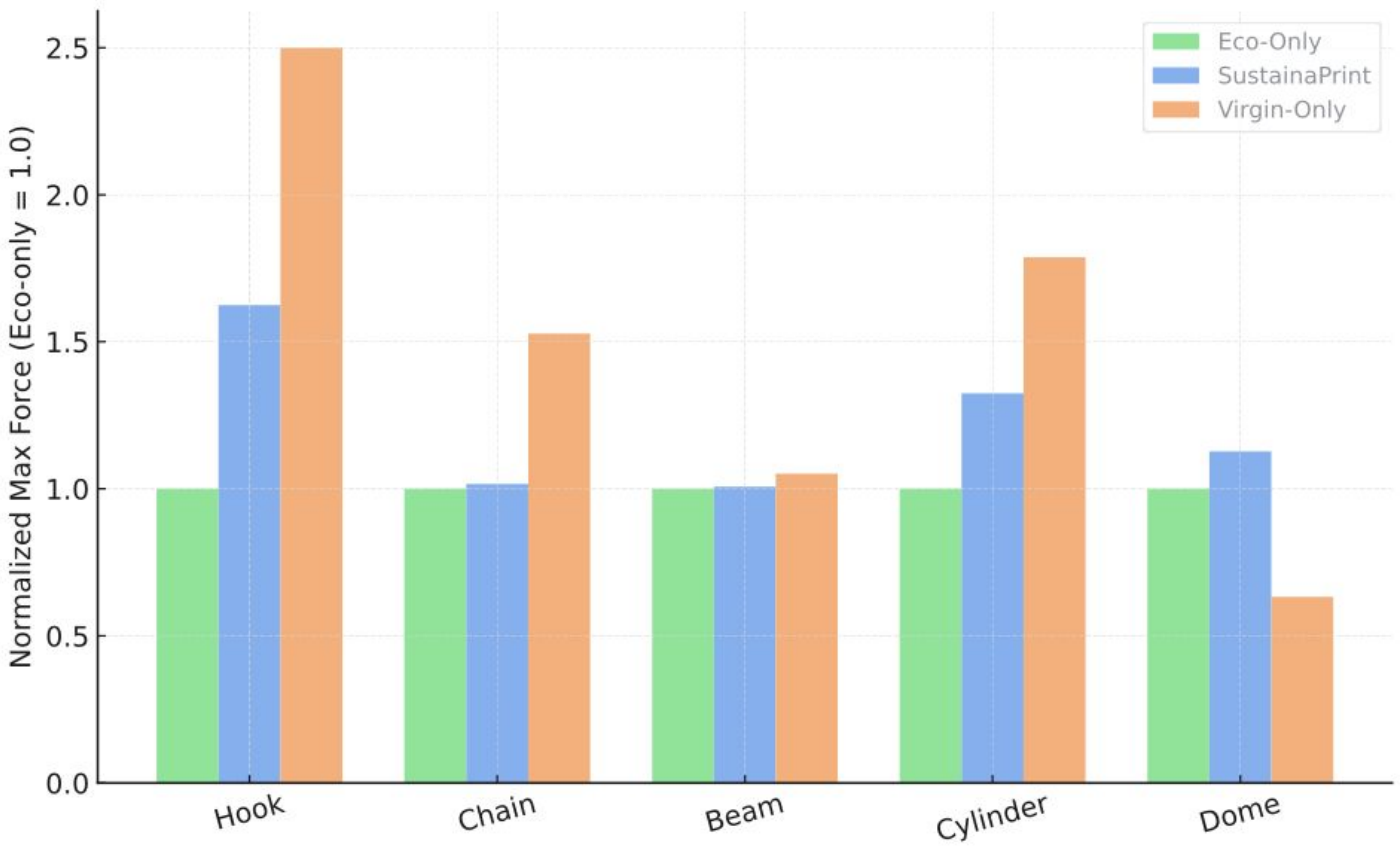


- SustainaPrint improves max force by up to 78.5% (table hook) over eco-only filament, averaging 22.2% improvement.
- Elongation at yield averages 4.0 mm with SustainaPrint, versus 3.7 mm eco-only and 4.4 mm virgin filament.
- Toughness rises 18.5% on average; headphone stand shows a 76.1% increase.
- Stiffness varies by geometry, reflecting trade-offs. Overall change averages -2.0% vs. eco-only filament.

SustainaPrint boosts max load by ~22% over eco-friendly filament using only 20% virgin material.

Mechanical Performance Results - Primitive Objects

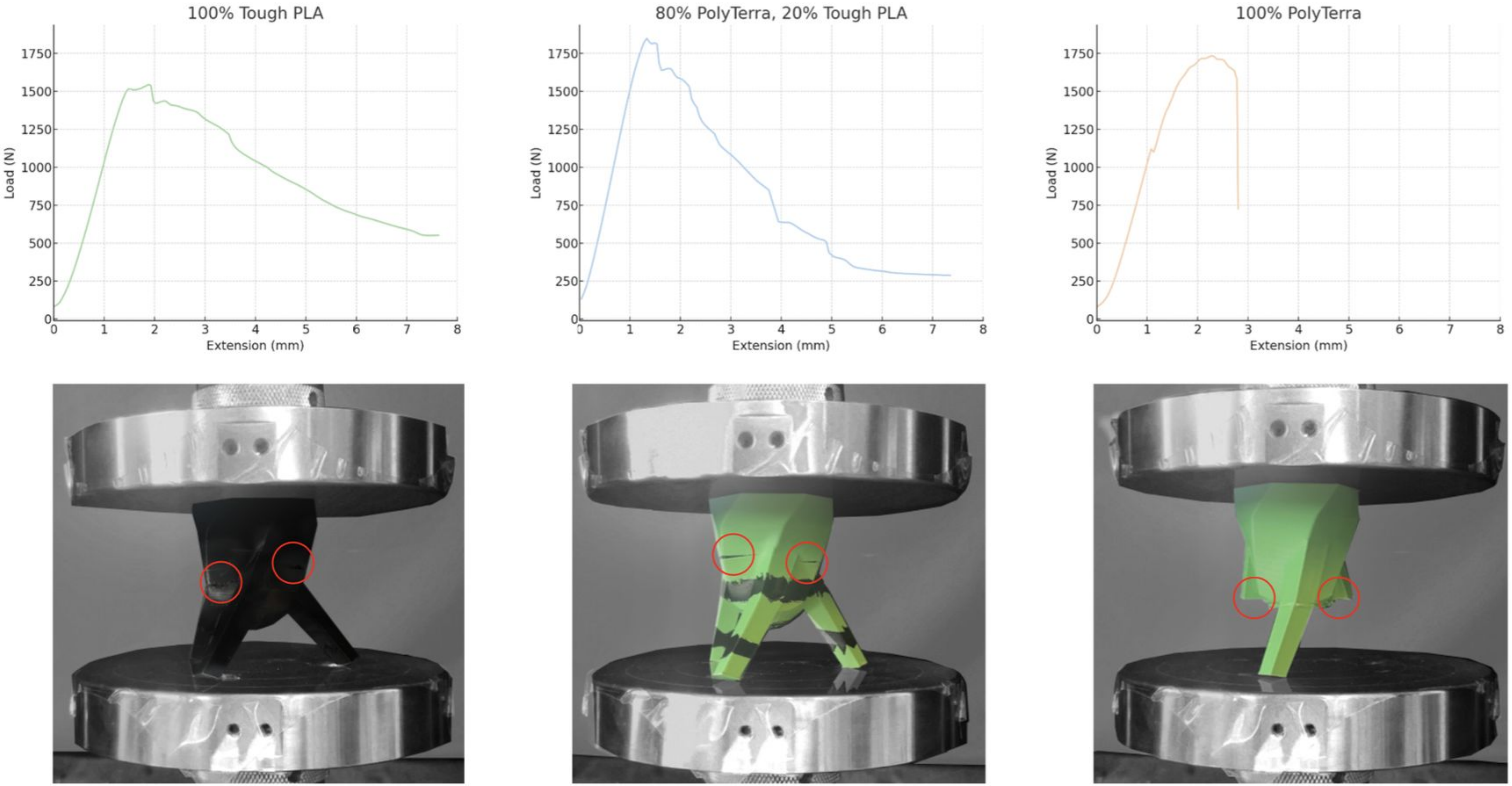
Max Force of Primitive Objects by Material



- Maximum force improved across all geometries with SustainaPrint using 20% virgin and 80% eco-friendly filament.
- In the dome geometry, SustainaPrint surpassed virgin Tough PLA in strength and toughness due to reduced brittleness.
- Selective reinforcement recovers much mechanical performance lost in eco-friendly filaments alone.

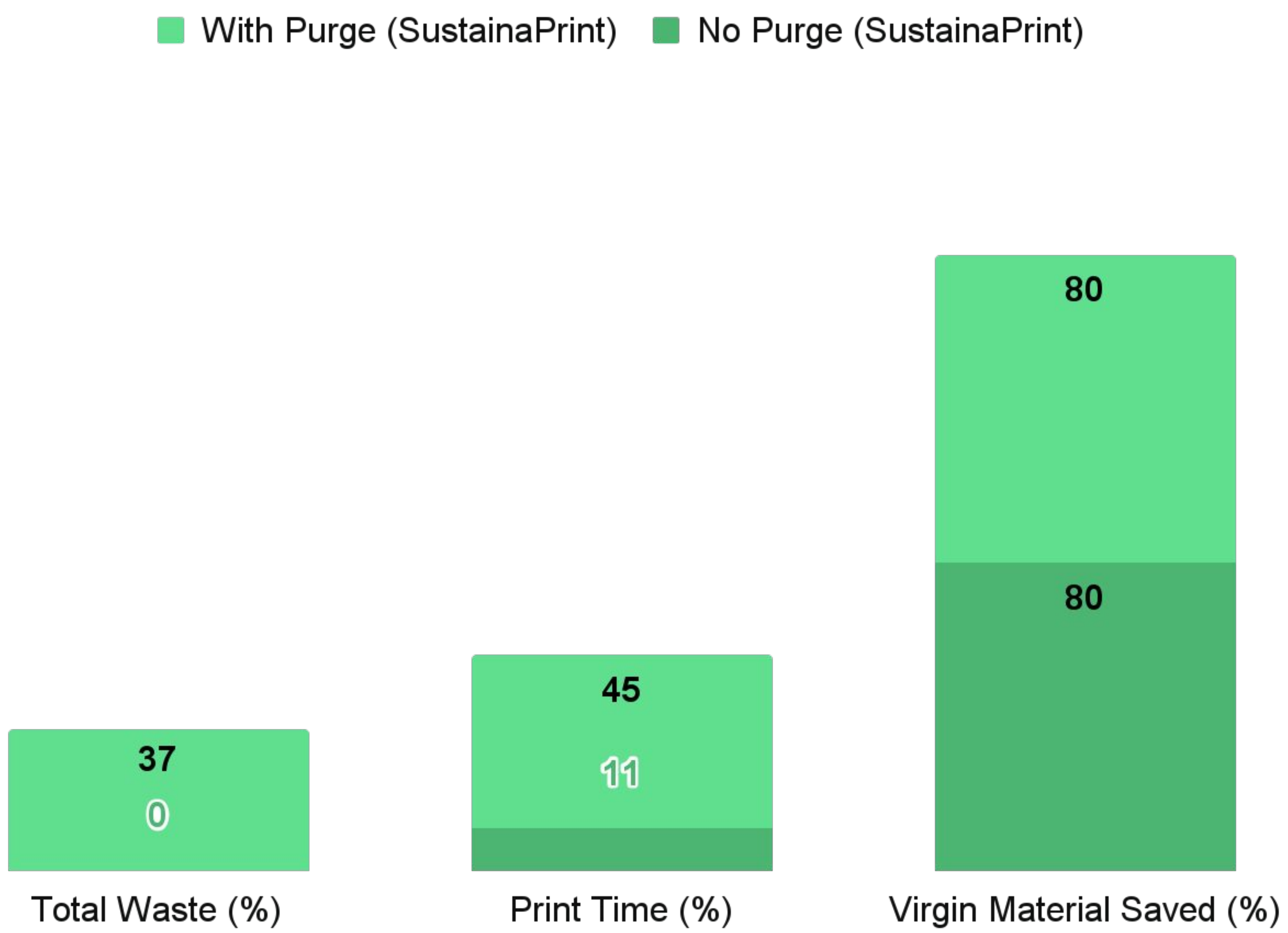
SustainaPrint boosts max load by ~22% over eco-friendly filament using only 20% virgin material.

Case Study: Tripod Plant Pot



Trade-offs in Dual-Material Printing

Waste and Time Increase over Single-Material Prints



Trade-offs

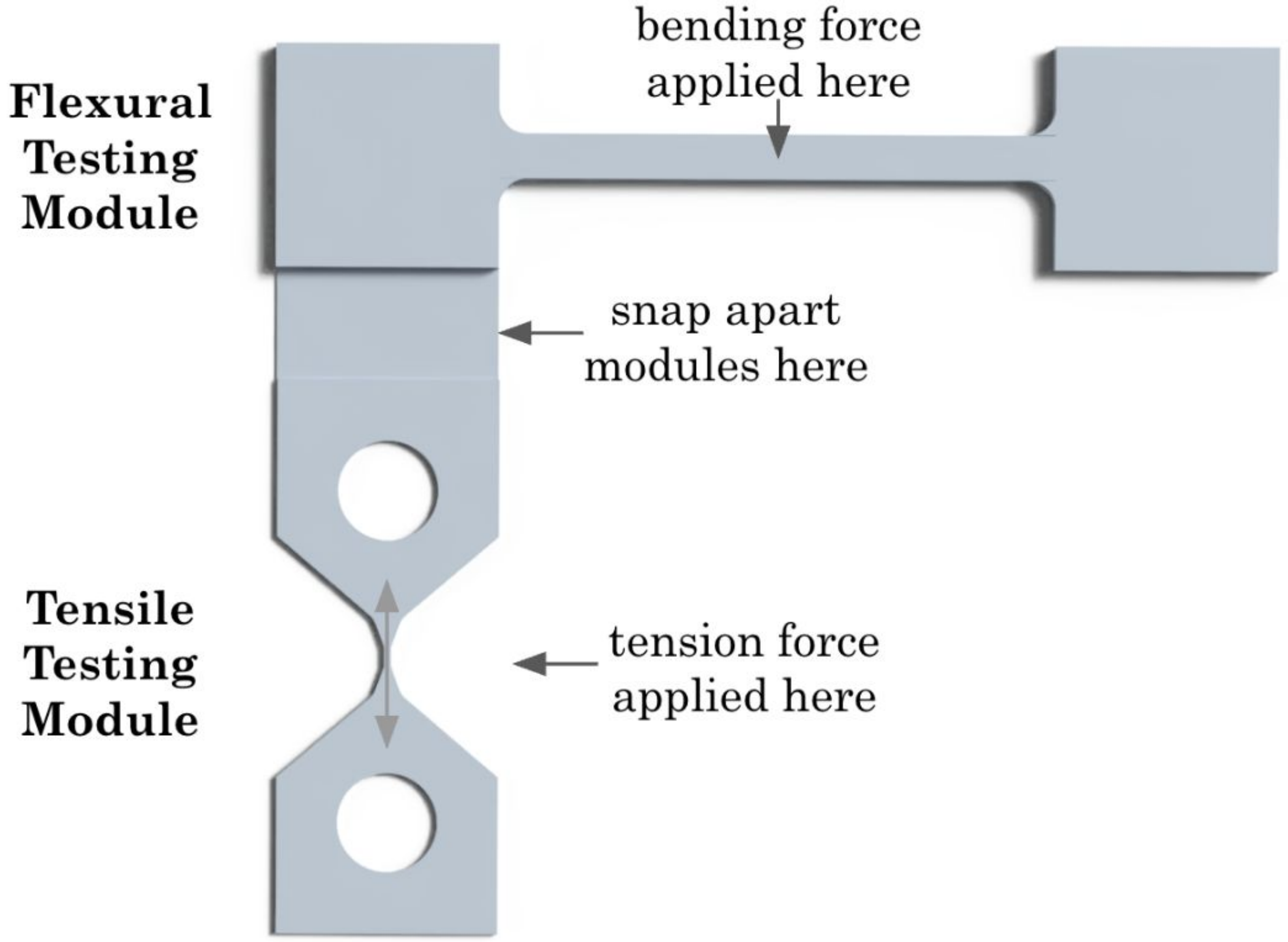
- SustainaPrint prints reduce virgin plastic use by up to 80%, supporting sustainability goals.
- Without purge towers, SustainaPrint adds no additional waste and keeps print time steady.
- With purge towers, waste increases by 37% and print time by 45%, reflecting material switching overhead.

Mechanical Testing Toolkit Introduction

At-Home Filament Quality Assessment

Low-cost solution for basic mechanical evaluations, including uniaxial load and flexural testing.

Testing Types: Tensile and Flexural

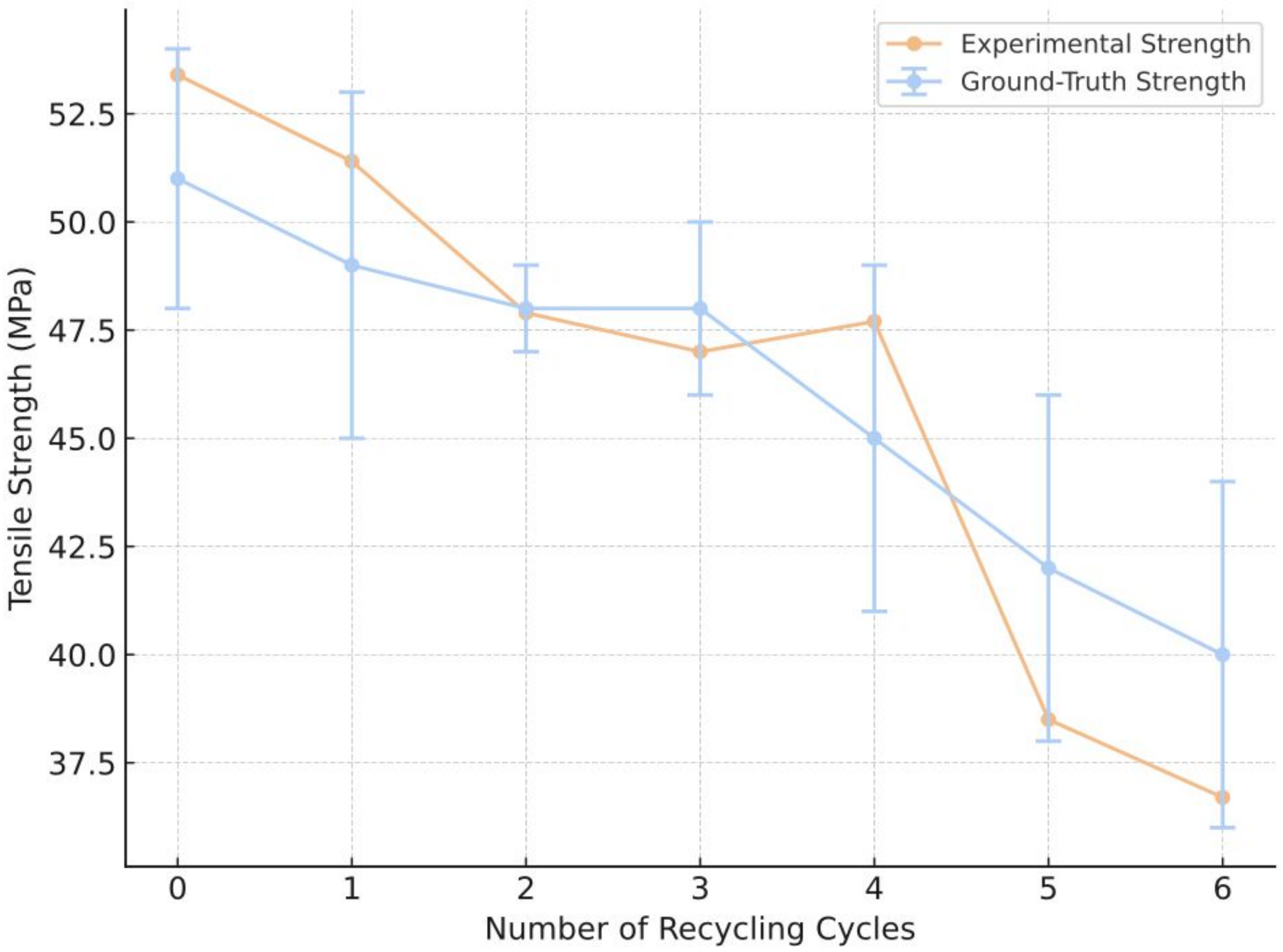


Tensile testing measures maximum force until specimen failure, flexural testing evaluates bending strength.

- A low-cost, 3D-printable mechanical testing toolkit enables makers to assess their filament's tensile and flexural strength at home, providing critical data for sustainable printing decisions.

Testing Results and Validation

Comparison of Experimental and Ground-Truth Tensile & Flexural Strength for PLA Filaments



- Toolkit measures tensile & flexural strength for four commercial PLA filaments, matching datasheet values closely.
- Tensile strength values fall within one standard deviation of ground-truth datasheets, showing accuracy.

Tensile strength measurements stay within one standard deviation of datasheets for all tests.

Limitations and Future Work

SustainaPrint currently requires dual-extrusion printers and user-specified boundary conditions. Future work aims to expand compatibility, automate input, improve slicer integration, and address recyclability challenges to further enhance sustainable 3D printing workflows.

Limitations

- Requires access to dual-extrusion 3D printers, which may not be available to all users.
- Mixed-material outputs complicate recycling due to material separation issues.
- Increased print time and energy consumption compared to single-material prints.

Next Steps

- Incorporate computational design methods for improved recyclability, such as targeted dissolution techniques for material separation.
- Expand support to experimental and novel eco-friendly materials like coffee grounds or clay composites.

Thank you for listening!

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