3D Printing for Technical Theatre

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Theatrical technical directors have long relied on wood and steel for scenery construction. But, the rapidly changing world of plastic manufacturing with fused deposition modeling (FDM) machines, colloquially called 3D printers, opens the doors to this new material. In the high speed world of a theatrical scene shop, the new technology is unlikely to be adopted until several questions have been answered. Are these tools reliable? And can the 3D printed product be trusted to not fail? And on a tool with so many settings and variables, how do we know which ones to use?

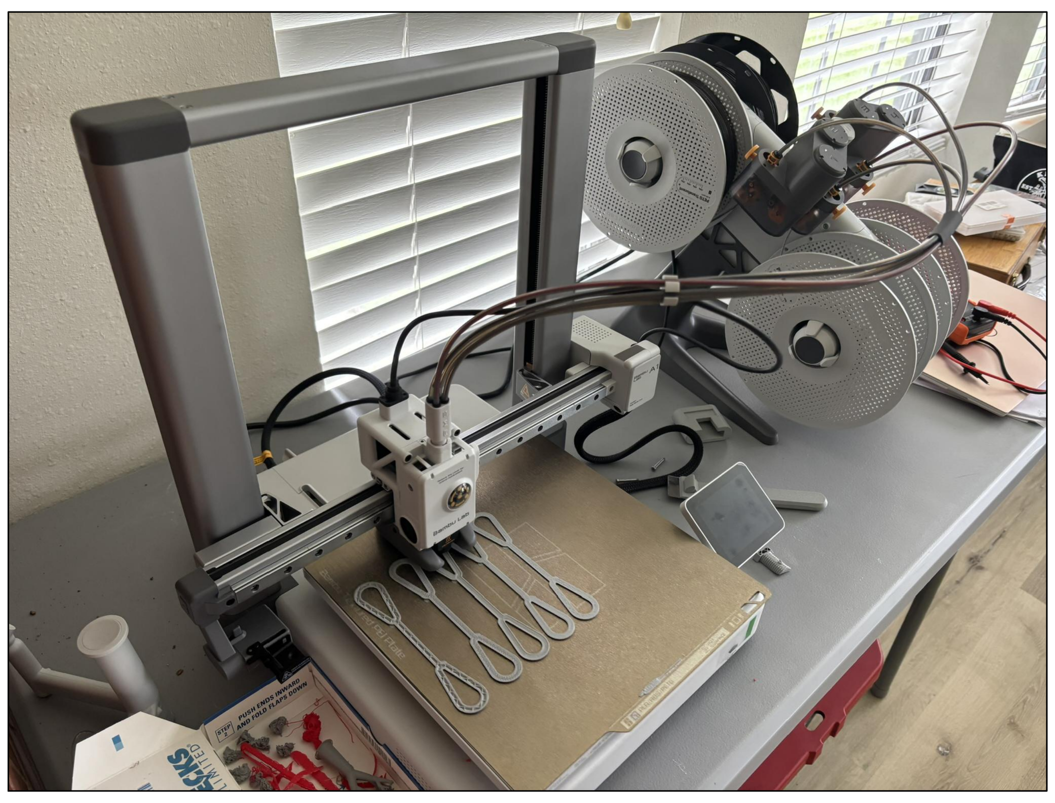
My research attempts to answer these questions through testing the tensile strength of 3D printed materials, infill percentages, and patterns, and explored the challenges involved in printing threads, while also testing the reliability of new printer technology, and observing the frequency and type of print failure rates on various types of prints. This all culminated in a printed turnbuckle capable of holding over 250lbs!

Laura hanging on a 3D printed turnbuckle.
FOR ~~SCIENCE~~ fun.

New Tool of the Trade?

I've observed more than 98% successful prints on the Bambu Lab A1 printer used for this research period. The wasted filament and print time are an insignificant cost on relatively small prints, but could be significant for larger components, or if the user is up against a production deadline. Many factors contribute to failed prints, including ambient temperature and humidity, build plate cleanliness, and the number and complexity of component being printed at a time. A larger survey of users over a greater timespan would be necessary to fully quantify the rate of successful prints.

Relative to the tool itself, 3D printers are complicated machines with hundreds of components, where the failure of one could sideline the machine entirely. During my research period, a faulty power switch put a halt to printing. The manufacturer was helpful and quick to send a replacement part, but the printer was inoperable for a full week while the part was delivered. Replacing it took me, a novice tinkerer equipped with the necessary tools, more than 2 hours to replace. A component buried deeper in the workings of the machine could take significantly more time, potentially an issue for a busy shop in a time crunch. Even simple maintenance, like cleaning the heated nozzle, can take hours to complete and test. This could be an issue in the lead-up to load-in and technical rehearsals.



The Bambu Lab A1 3D printer with automatic material system (AMS).

Beyond the small hiccup with the power switch, the Bambu Lab A1 seems to live up to the manufacturer's promise of fully automated calibration and automatic bed-leveling. A few taps on the built-in touch screen starts the calibration sequence, and the bed can be auto-leveled at the beginning of each print to ensure optimal performance. Many manufacturers boast similar capabilities.

A 3D printed turnbuckle capable of holding 250lbs+.

Can You Trust It?

The use of any new material demands caution. The manufacturer's published mechanical properties serves as a reasonable starting point, but can it be trusted? And what about the seemingly endless variables offered in the slicing software, like infill percentage, infill pattern, number of wall loops, infill/wall overlap? In the last 10 years, the scientific community has carried out a significant amount of research that can offer guidance on these topics. The findings sometimes contradict one another, but a few consistent findings emerged and were supported by my own testing:

1) The printed part is strongest when the load is parallel to the fibers. [1]
2) Infill pattern makes a difference. A 45°/45° rectilinear infill is reliably strong regardless of direction of load at all infill percentages. A 0°/90° rectilinear pattern is even stronger when aligned with the direction of the load at all infill percentages. At 100% infill, the Hilbert Curve infill pattern resulted in the greatest strength of all printed parts but was weaker than the rectilinear pattern at all other infill percentages. [2, 3]
3) Weight of a printed component relative to the weight calculated by the slicing software correlates to the strength, suggesting that one can simply weigh a component to assess the quality of the print. [4]

My testing indicated that, when using 100% infill with the Hilbert Curve or rectilinear patterns, the tensile strength in the x-y axis of the printed parts broke at the low end of the manufacturer's published range.

Even with all of this data supporting its worthiness, 3D printing has a few unavoidable drawbacks. First, 3D printed components appear identical once finished. A part with 25% infill is visually identical to one with 100% infill. This can be problematic if multiple versions are printed, or if someone forgets to change the settings in the slicing program. Second, the strength of the most commonly used materials, PLA and PETG, can vary based on the humidity during printing, and while the material is in service. Like all other plastics, they are susceptible to UV and heat damage. Printed parts left in the sun or a hot car will have unquantifiable mechanical properties. These factors suggest that technical directors should include significant safety factors, carefully control 3D printed component inventory, and be willing to treat those components as consumables.

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3. Aloyaydi, Bandar, Subbarayan Sivasankaran, and Ammar Mustafa. 2020. "Investigation of Infill-Patterns on Mechanical Response of 3D Printed Poly-Lactic-Acid." Polymer Testing 87 (July): 106557. https://doi.org/10.1016/j.polymertesting.2020.106557.
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