# Designing for Strength: Maximizing the Integrity of a 3D Printed Object

Jason Bertrand, Kylie Caprini, John Field, Alma Francois-Pijuan, Olivia Heng, Sarah Hilburgh, James McFarland, Jordan Molina, Isaiah Rohrs, & Justin Otelo

Joint Science and Technology Institute, Virtual 2021

## Introduction

Designing for Strength includes designing and determining the maximum load a 3D-printed object can uphold without failure. Understanding the science of resilient 3D objects is necessary for its safe incorporation into load-bearing structure design. There is currently little information on this topic and a strong understanding of the special considerations that need to be given to 3D-printed parts will become crucial as 3D printers are utilized in more industries. Our research on 3D-printed parts' inherent weaknesses will aid engineers to create stronger prints.

Figure 1: Prusa MK3 #D Printer with complete model of Nefertiti on the steel plate.

## Background

3D printers are devices that allow engineers to create and alter 3D objects through online computer-aided design (CAD) programs. Prints are able to be modified in a slicer program and then printed from the 3D printer via the extruder. There are a variety of filament material, such as plastics, metals, and composites - thus illustrating the endless opportunities of 3D printing.

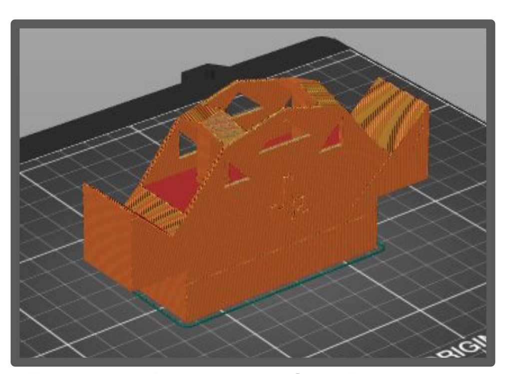

Figure 2: A picture of a 3D model being displayed in Prusa Slicer

## Materials and Methods

Materials: Computer, 3D Printer, PLA (Polylactic Acid) Filament, Testing Set-Up (Dake 10 ton hydraulic press, CALT DY220 load cell indicator, CALT DYLY-101-5000 kg. load cell).

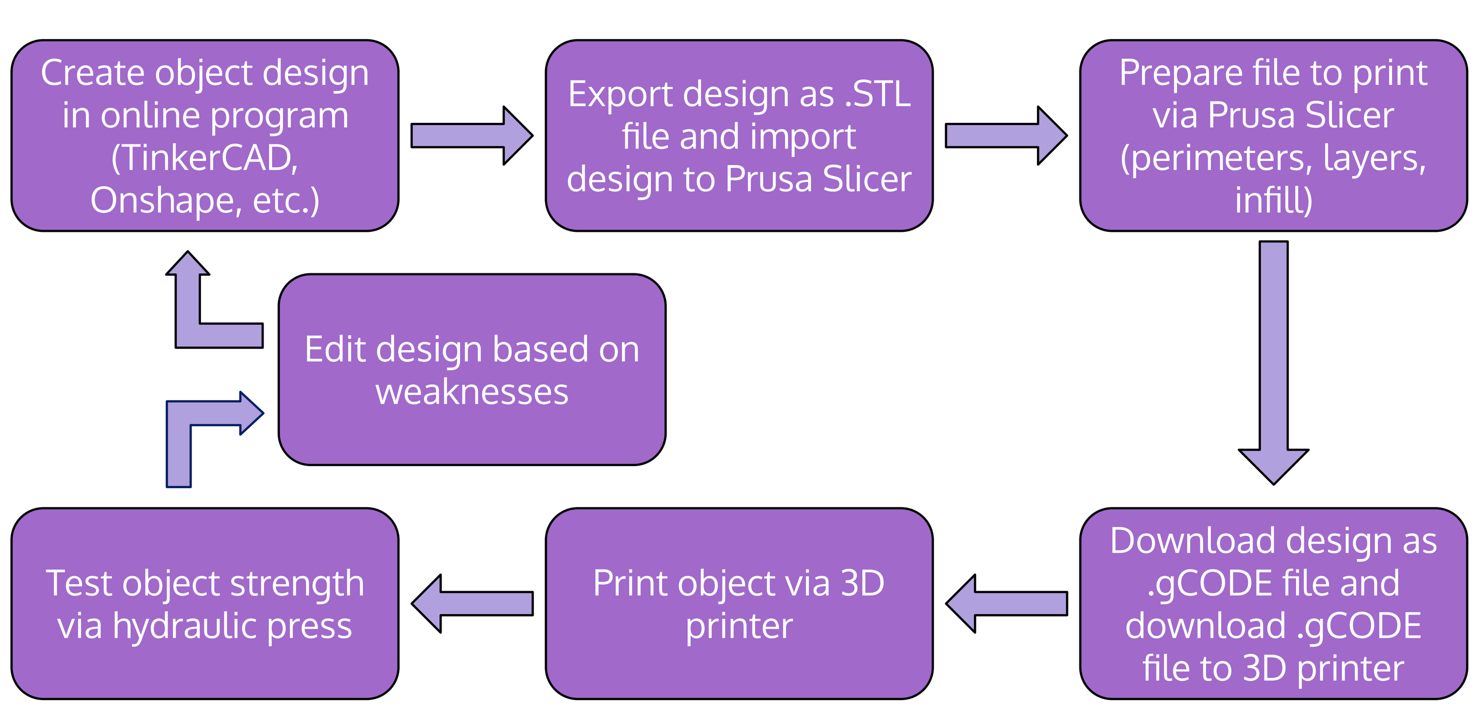


Figure 3: Flow chart depicting the process and methods used to design, print, and test 3D printed objects. The chart follows what is known as 'the Engineering Design Process.'

## Results

- The difference between the bridges is what face they were printed on.
  - Bridges A was printed on its side and Bridge B on its back.
  - Bridge C was printed standing on its end.
- Bridges A and B performed marginally better than C.
  - Bridges A and B print orientation being at a right angle to the external force increases maximum load
  - Bridge C being printed from its end allows it to be easily punctured in the testing process

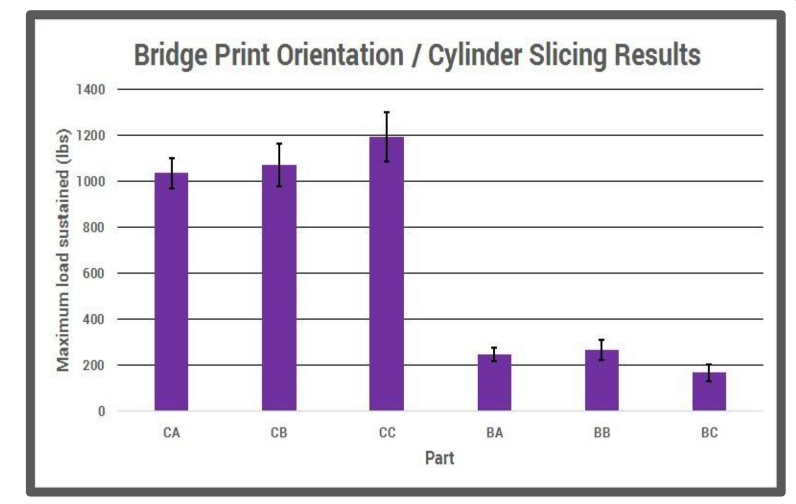


Figure 4: A bar graph depicting the maximum load of various objects, with CA, CB, and CC being cylinders and BA, BB, and BC being bridges.

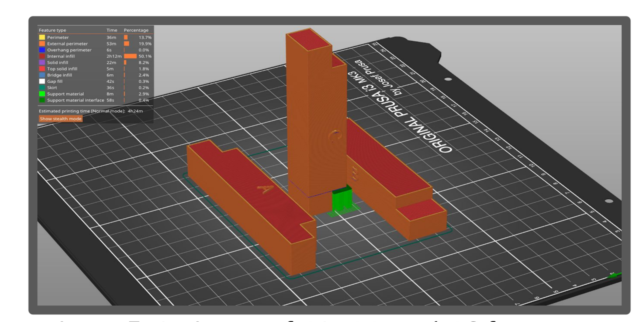

Figure 5: A picture of BA, BB, and BC from Figure 4 in Prusa Slicer.

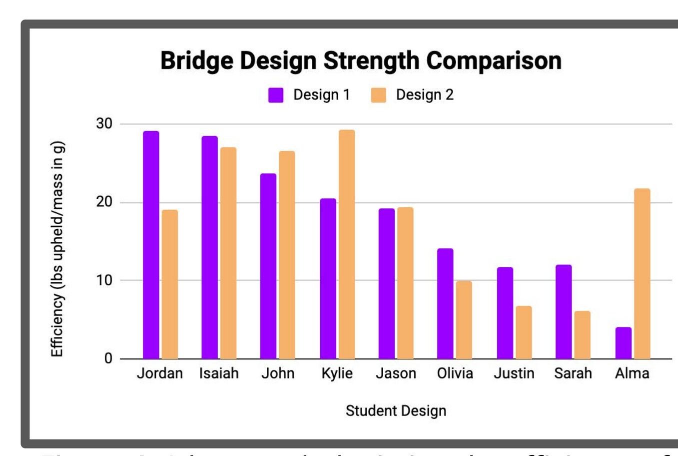


Figure 6: A bar graph depicting the efficiency of bridge designs 1 and 2 for each designer.

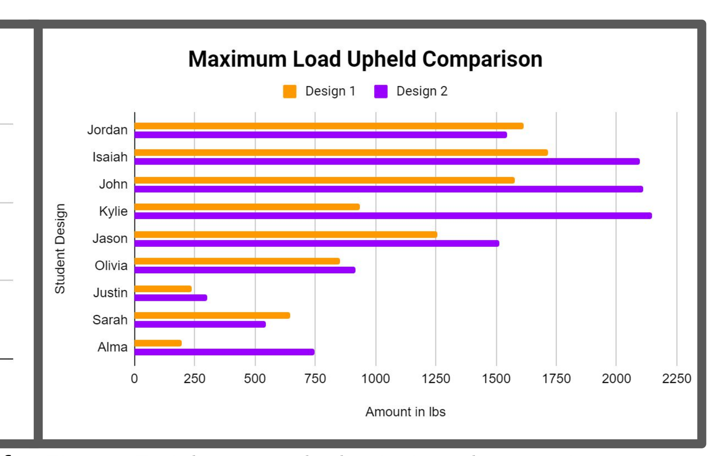


Figure 7: A bar graph depicting the maximum load of bridge designs 1 and 2 for each designer.

- The overall load the bridges could handle increased from Design 1 to Design 2 for most of the students.
- The majority of designs did not increase in their efficiency from Design 1 to Design 2. The additional loads are attributed more to increased design mass than improved geometry.
- There were two instances where the maximum load of Design 2 were less than those of Design 1.
- Out of the top five of the bridges that had the highest maximum load, majority of them were from Design 2.

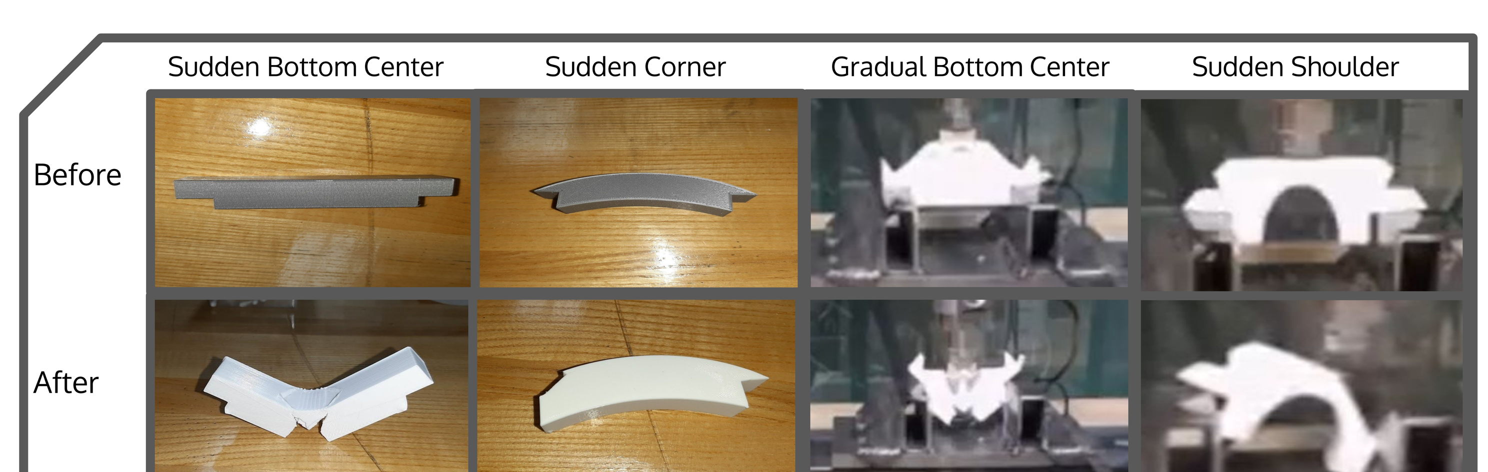


Figure 8: Side-by-side comparisons of four bridges before and after testing. The most common bridge failures were sudden corner failures; however, the percentage of these failures decreased between designs 1 and 2, thus increasing the percentage of gradual failures.

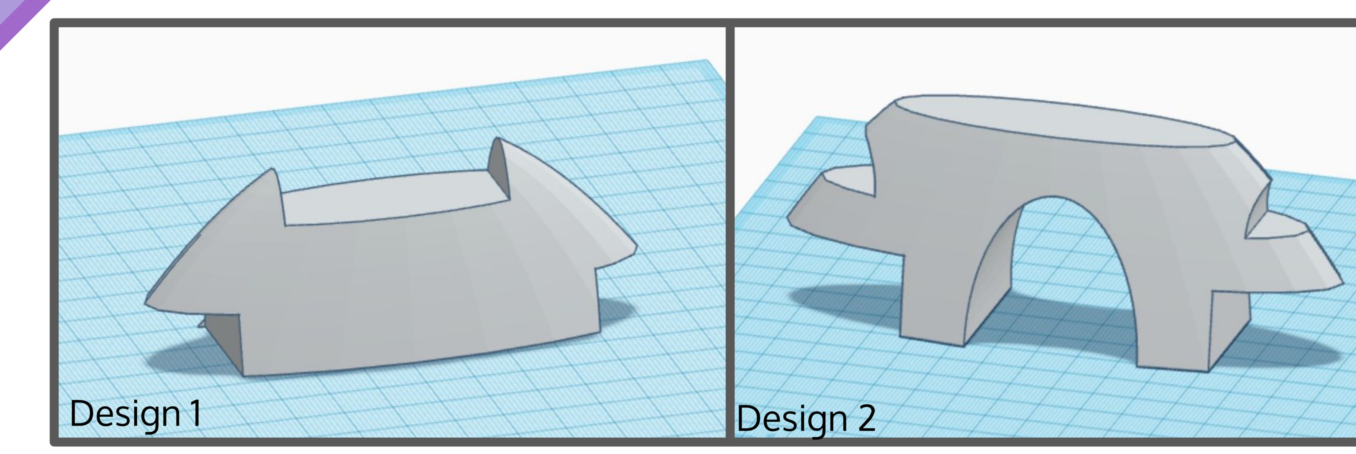


Figure 9: A side-by-side comparison of bridge designs 1 and 2 as created by Kylie Caprini

Many designs were changed greatly from Design 1 to Design 2 including:

- Better design mass distribution
- Improved load distribution
  - Achieved by increasing the bridge's width and height
  - Achieved by curving sharp edges so the force path was longer and minimized stress points
- Increased prominence of shoulders (the area in contact with the test stand)
  - Achieved by increasing width and thickness in corner areas (stress points) to increase corner strength
  - Mass reduction at the bottom of the bridge as a result

## Conclusions

During the testing and development phases, multiple discoveries were made regarding the efficiency of bridge design, such as:

- Geometry was the largest factor that determined the strength of the bridges.
  - Triangles and arches increased the strength of the bridges.
  - Straight lines or 90° angles weakened the bridges.
- 3D print orientation was another factor in bridge strength.
- The 3D printed bridges had a multitude of options to choose from when they were being sliced in Prusa Slicer.
  - A higher infill percentage leads to stronger bridges.
  - A larger amount of exterior perimeters leads to stronger bridges.
  - Different infill patterns (gyroid, honeycomb, etc.) lead to stronger or weaker bridges.


Figure 10: A picture of the testing set-up/load-testing apparatus.

## Acknowledgements

Thank you to our mentors Jacob Yoder, Amanda Farnsworth, Conrad Farnsworth, and Remington Bullis for mentoring and aiding us through the entirety of this program. We appreciate the opportunity provided to us by the Los Alamos National Laboratory, Oak Ridge Institute for Science and Education, and the Defense Threat Reduction Agency's Joint Science and Technology Office for Chemical and Biological Defense. Thank you to our IT Terri Reeves for constantly being available to aid us and provide priceless feedback in our JSTI journey.