ACI CONCRETE CONVENTION
THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

Rowan University

Topology-Optimization-Based Additive Construction

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Toronto, Ontario, Canada
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Overview

What is Topology Optimization (TO)?
- Definition
- Benefits and Disadvantages
- TO and Concrete

Optimization of C-Only Structures
- Abaqus Simulation
- Modifications to Simulation Result

3D Concrete Printing
- Printing Process
- Exploration of the Print Path
- Other C-Only Structures

Conclusion
- Future Work
- Summary

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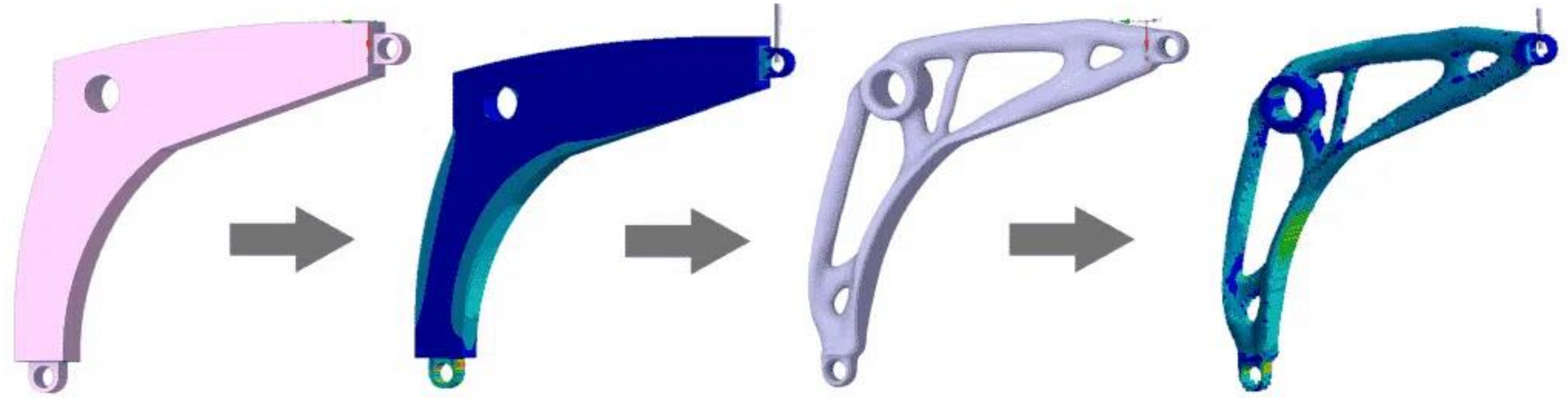
What is Topology Optimization?

Topology optimization (TO) is an **optimization** method that uses algorithmic **models** to optimize **material layout** within a **user-defined space** for a given **set of loads, conditions, and constraints**. TO maximizes the performance and efficiency of the design by removing redundant material from areas that do not need to carry significant loads to reduce weight or solve design challenges like reducing resonance or thermal stress.



Topology Optimization of a Bell Crank (ANSYS Innovation Courses)

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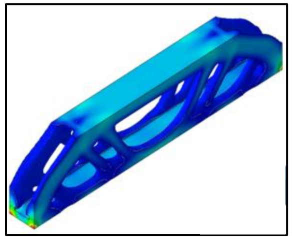
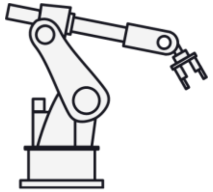
Benefits of TO in Additive Construction for Concrete

- Overcome labor shortage and development of skilled labor.
- Construction time and cost saving.
- Reduction of material wastage.
- Reduction of carbon footprint of construction industry.
- Broadens design creativity
- Lighter Structures for structural benefits

Barriers for TO in Additive Construction for Concrete

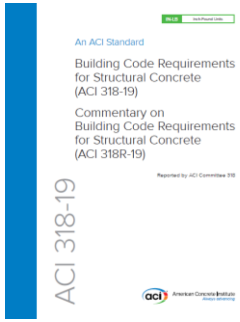


TO is often computationally expensive until achieving the correct model



Expensive Additive Construction Equipment due to large print areas

Reinforcement



An ACI Standard

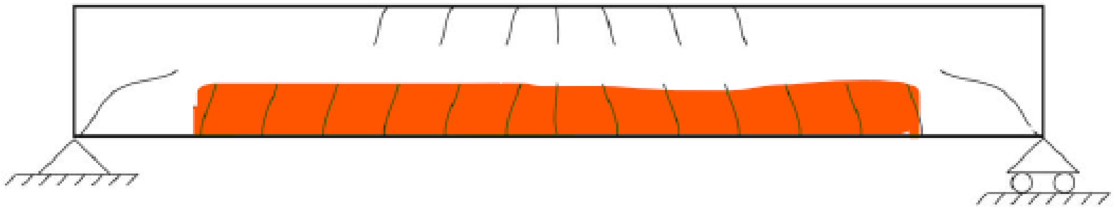
Building Code Requirements for Structural Concrete (ACI 318-19)

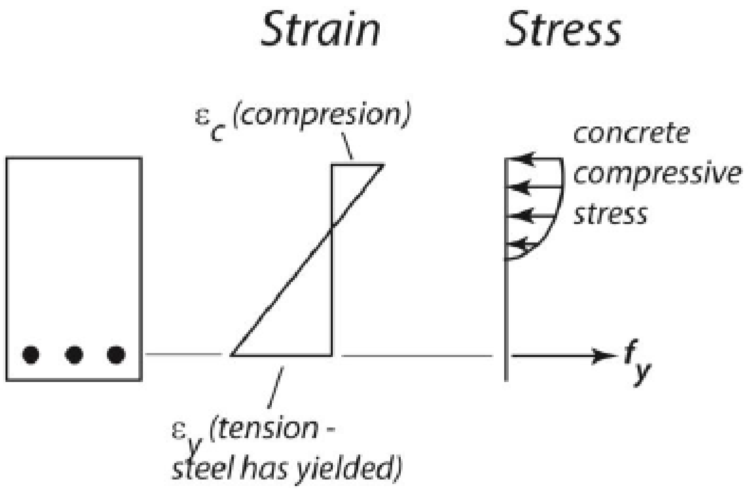
Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19)

ACI 318-19

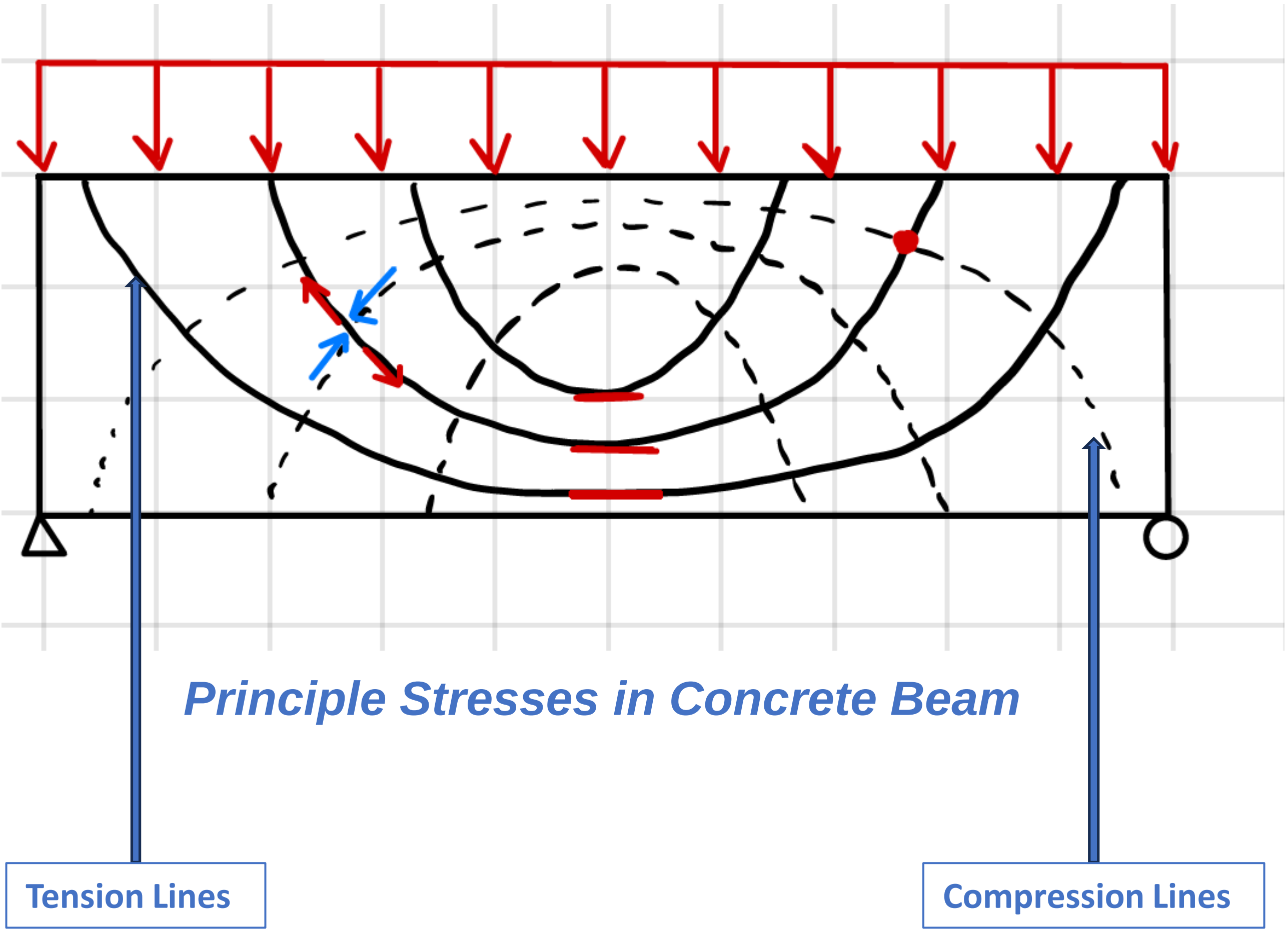
Does not Comply with codes and standards

Is TO suitable for Concrete Structures ?





Concrete Crack in Tension and Compressive Strength Block



Principle Stresses in Concrete Beam

Why Topology Optimization?

Printing Path (Plan)

Testing/ Failure Mode

Interface

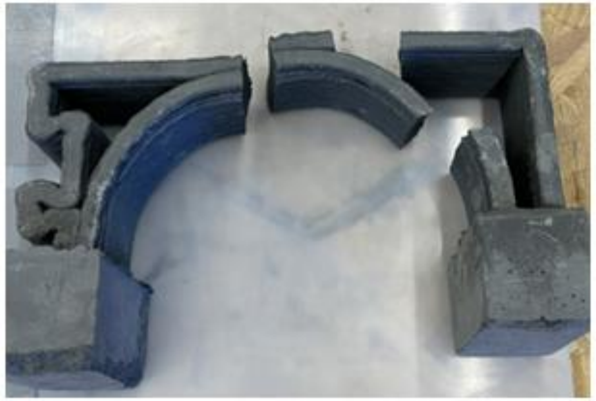
Beam 1 **Beam 2** **Beam 3**

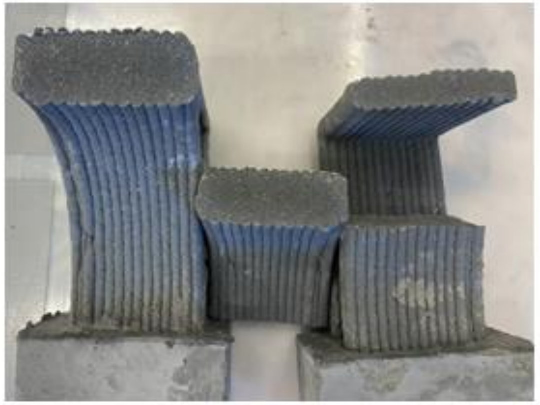
ID	Force		Span (L)		Depth (d)		Width (b)		Modulus of Rupture (R)	
	(kips)	kN	inch	mm	inch	mm	inch	mm	ksi	mpa
Beam 1	2.460	10.943	9.25	235.0	3.50	88.9	3.00	76.2	0.929	6.404
Beam 2	2.000	8.896	9.00	228.6	3.50	88.9	3.25	82.6	0.678	4.676
Beam 3	2.880	12.811	9.13	231.8	3.75	95.3	3.00	76.2	0.934	6.442

Why Topology Optimization?

Equivalent Beam

Arch





	ID	Force		Span (L)		Depth (d)		Width (b)		Modulus of Rupture (R)	
		(kips)	kN	inch	mm	inch	mm	inch	mm	ksi	mpa
Calculated	Equivelant Beam	0.135	0.602	9.00	228.6	0.75	19.1	3.50	88.9	0.929	6.404
Tested	Arch	1.349	6.000								
	Ratio	10.0	10.0								

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Optimization of C-Only Structures

- **Abaqus Simulation**
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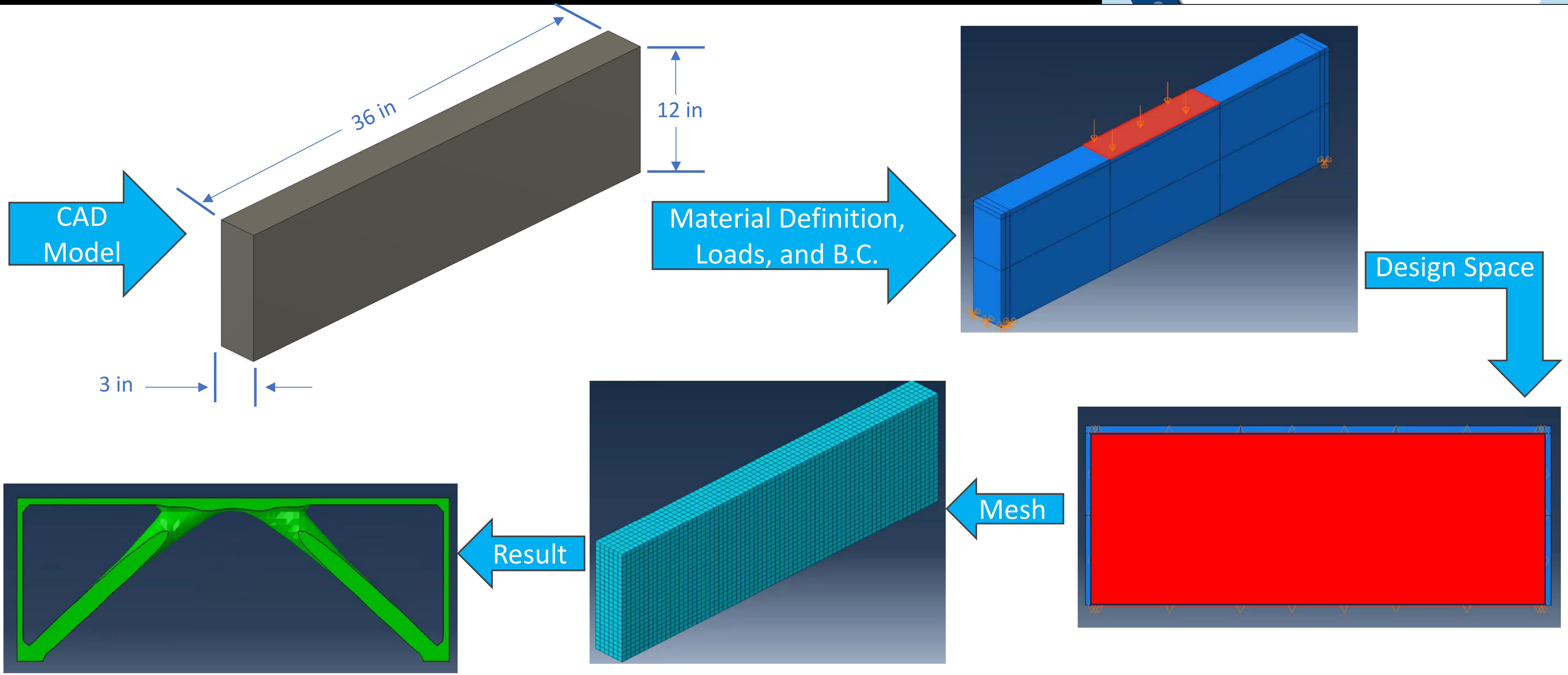

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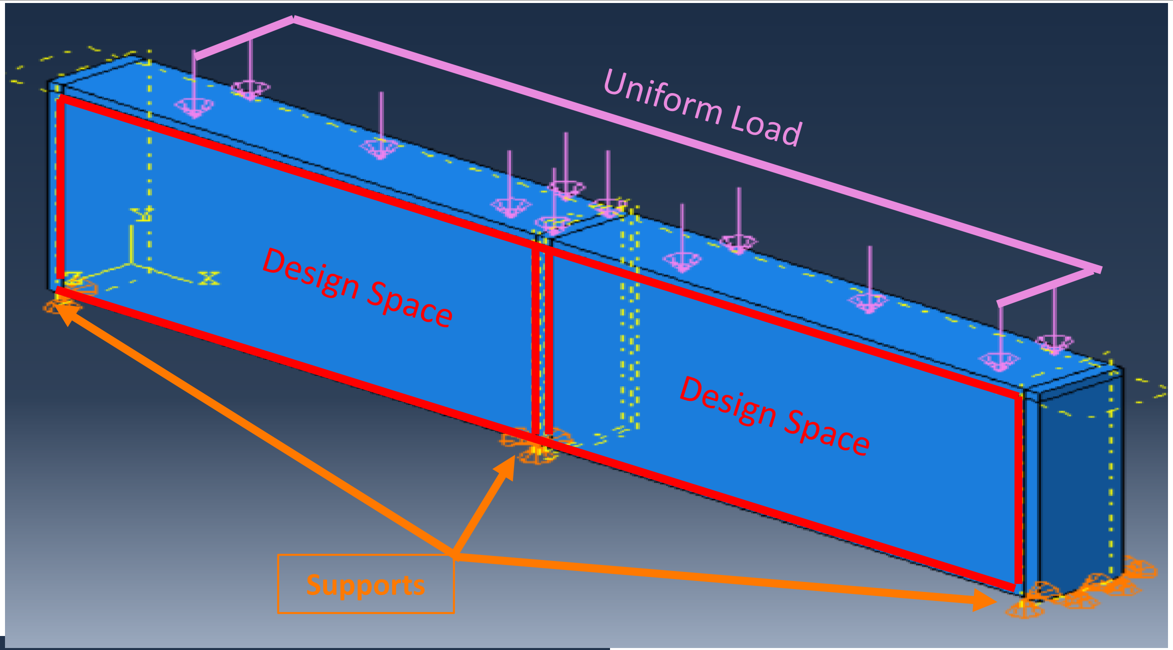

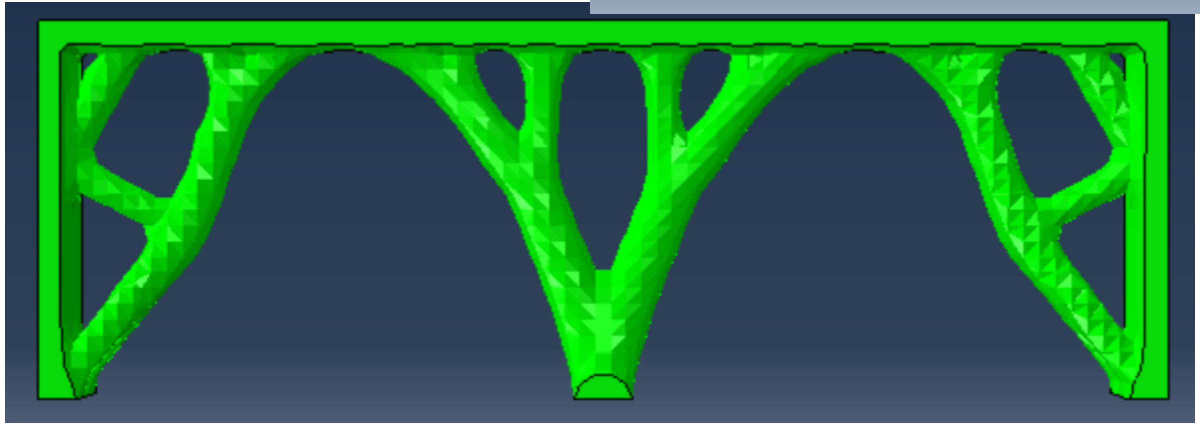

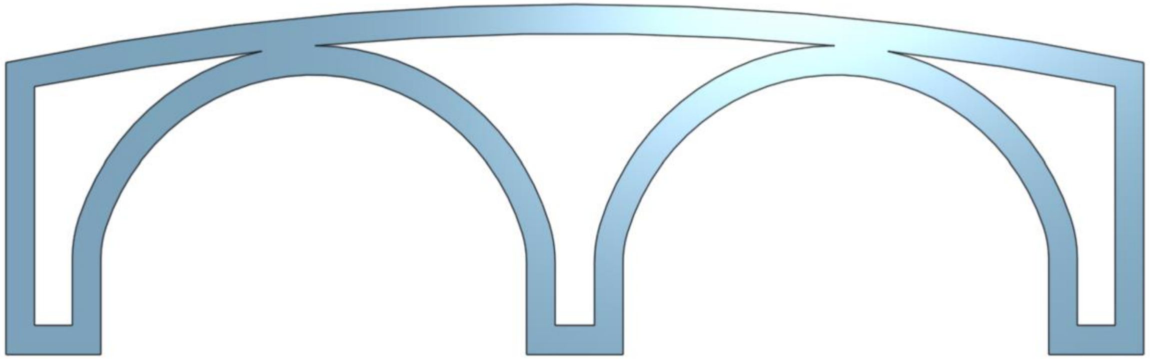

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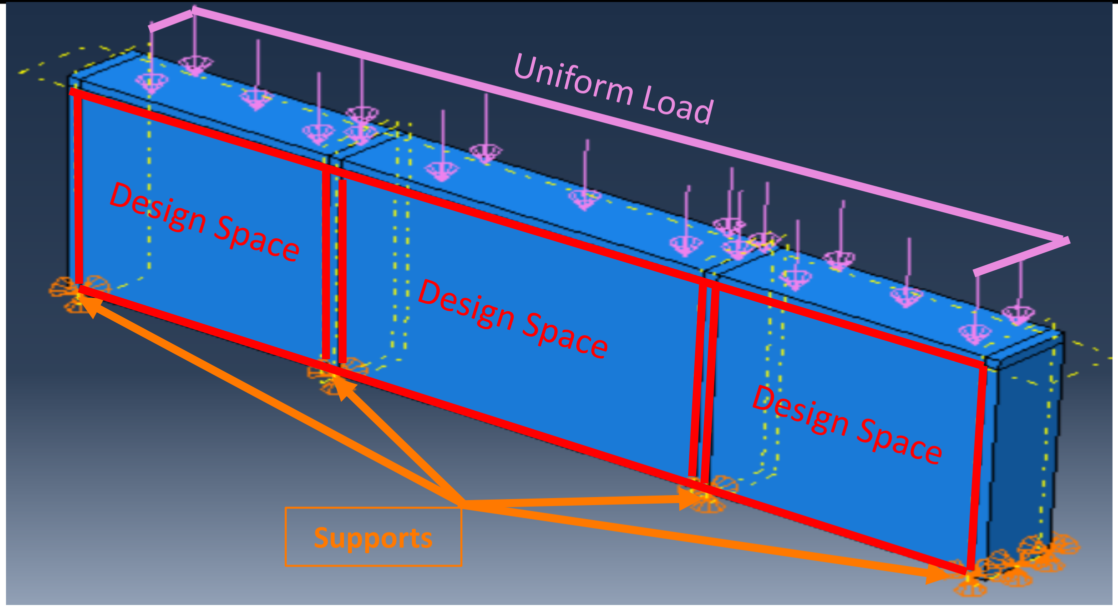

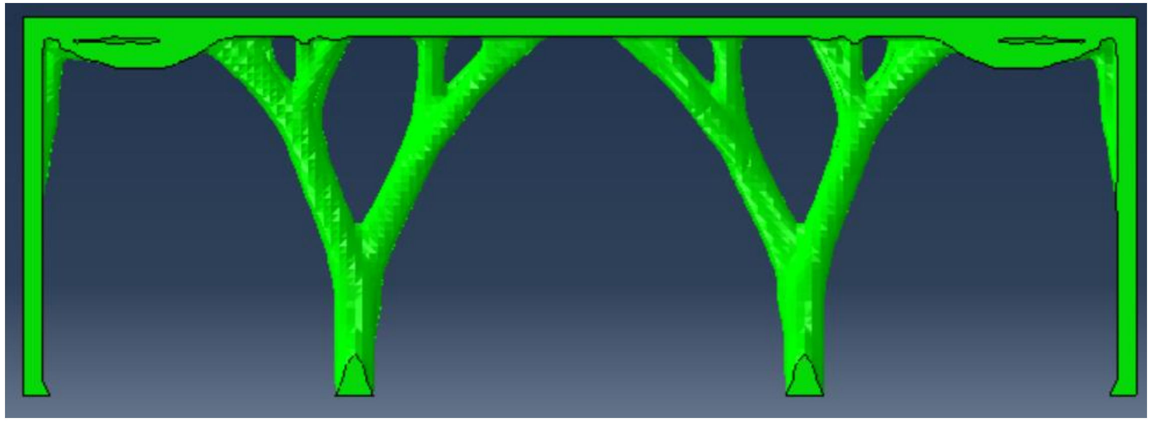

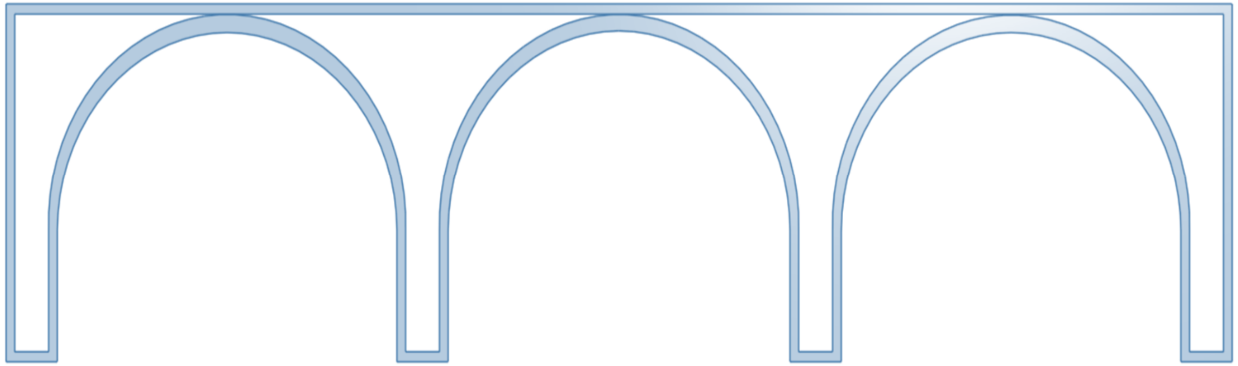

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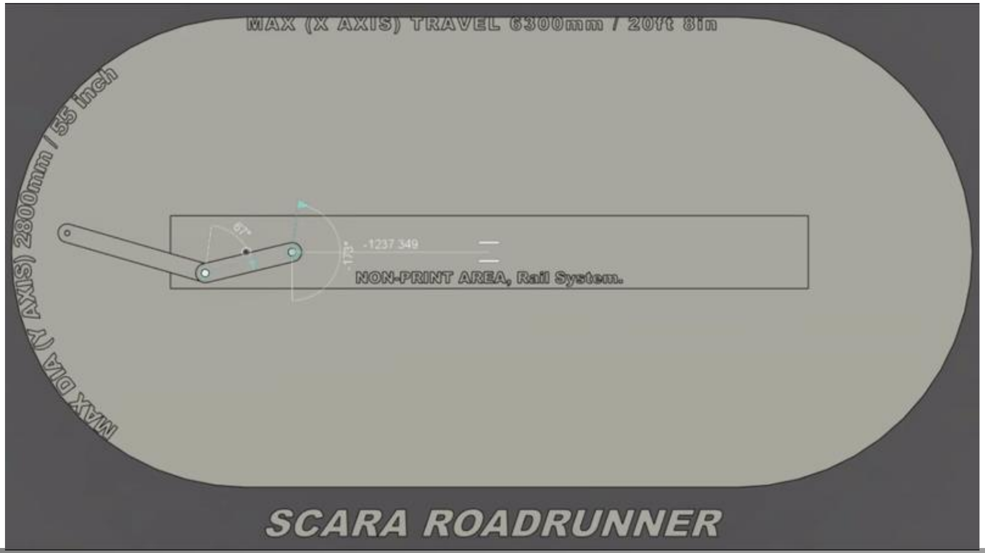
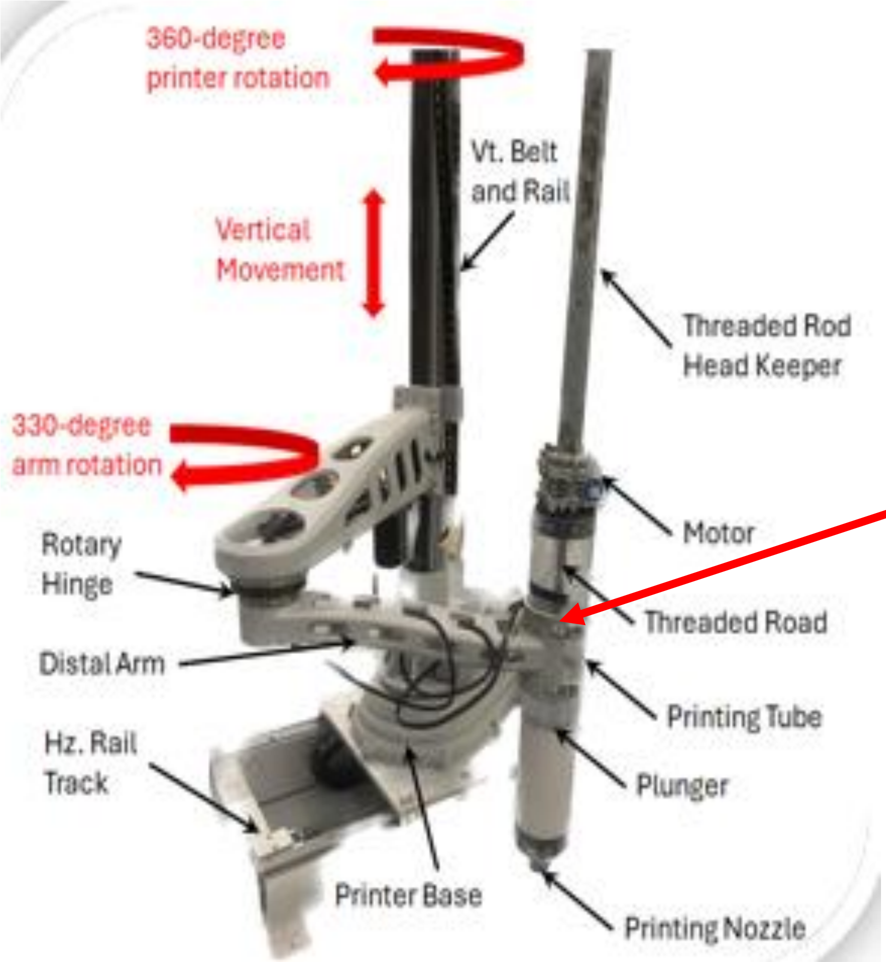
Scara Elite Roadrunner

- Printing specifications
  - Length- 20 ft
  - Width- 14 ft
  - Height- 7 ft
  - Arm length of 7 ft
- Prints 1”-4” per second
- Prints 360° with continuous rotation



Filament Entrance



Deposition

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Computational Process after Mixing

onshape®

AUTODESK Fusion

CAD Design → **Slicing Software** → **.g code in Printer Software** → **Printing**

SIMPLIFY3D®

```
; G-Code generated by Simplify3D(R) Version 5.1.2
; Settings Summary
;   processName,Process 1
;   autoConfigureMaterial,PLA
;   autoConfigureQuality,Fast
;   targetModels,Natchez Bridge
;   profileName,SCARA V4/ELITE-Clay extruder - 8mm
;   profileVersion,2023-02-09 15:00:24
;   app,S3D-Software 5.1.2
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;   extruder,Clay
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;   extrusionWidth,6.00000
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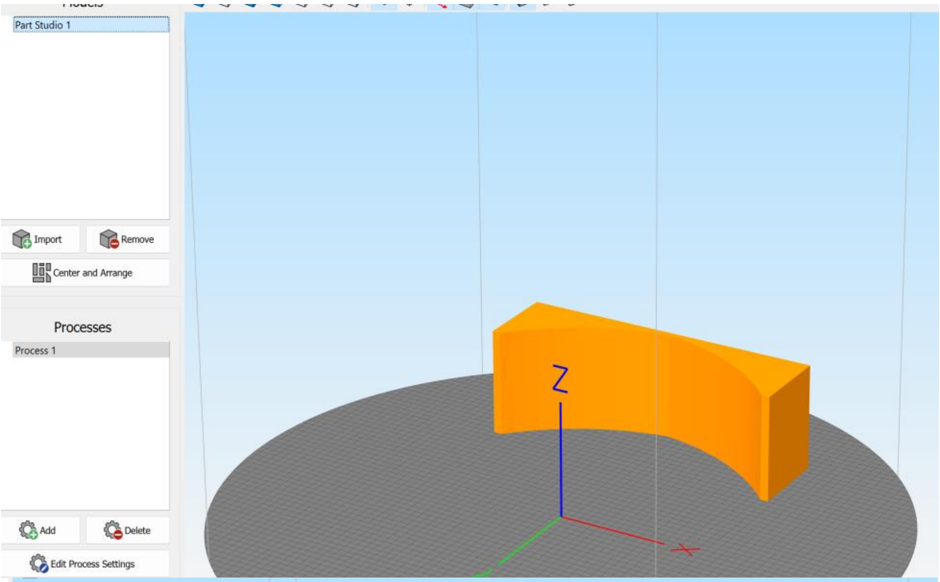
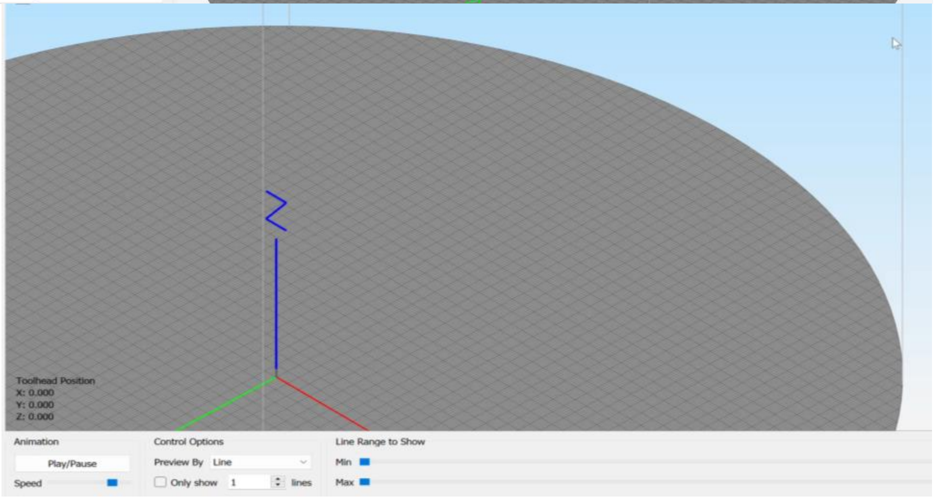
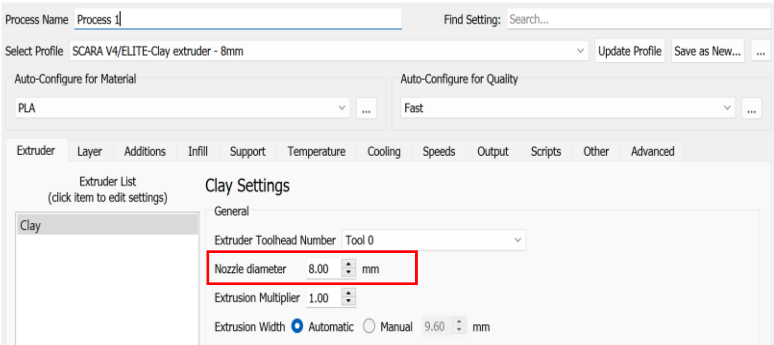
Computational Process after Mixing

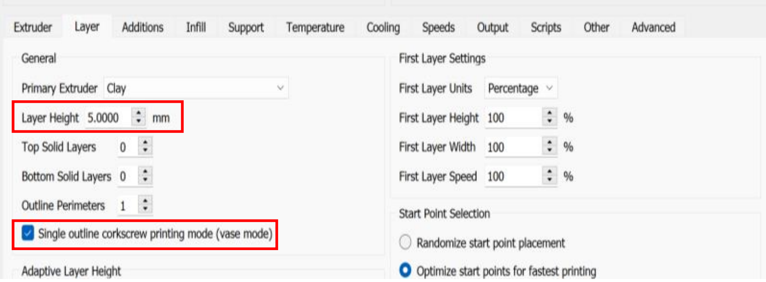




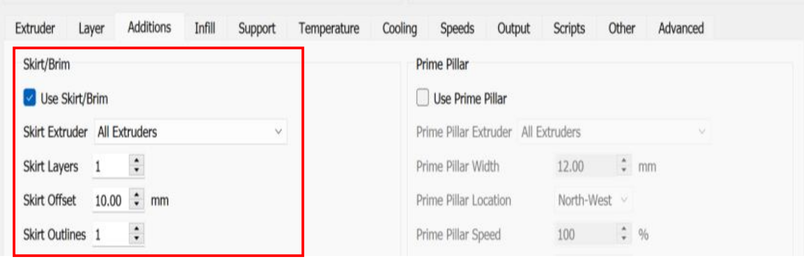
Extruder



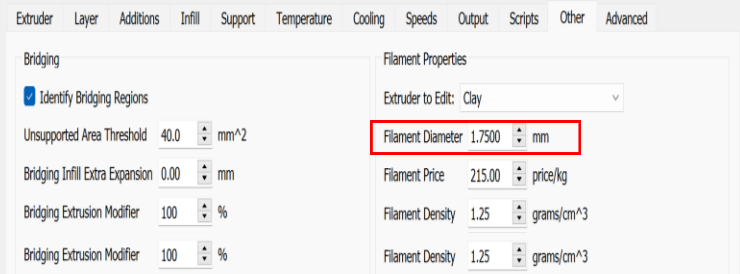
Layer



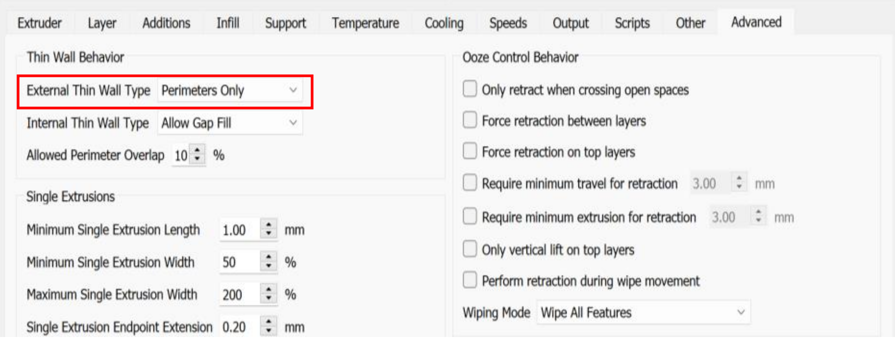
Additions



Other



Advanced



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3D Concrete Printing at Rowan University

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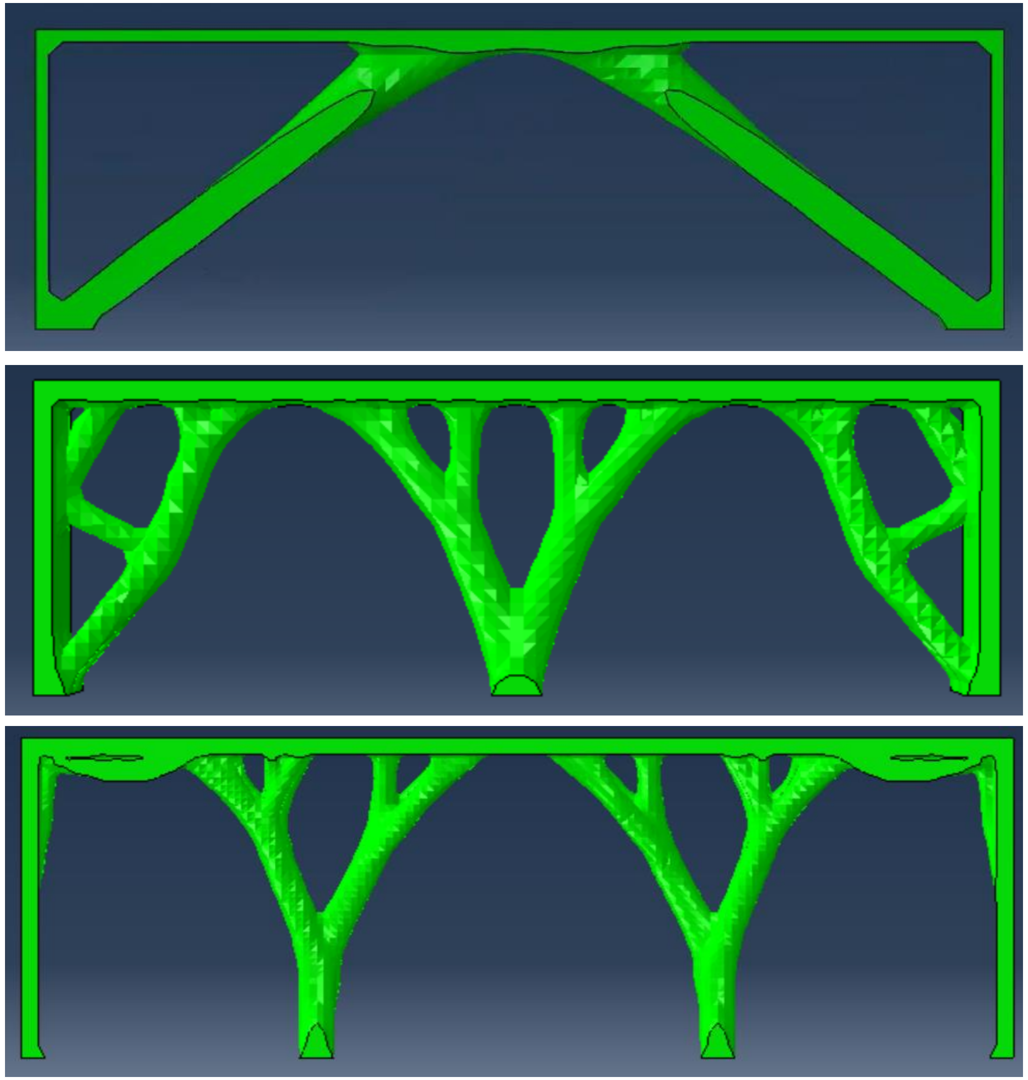
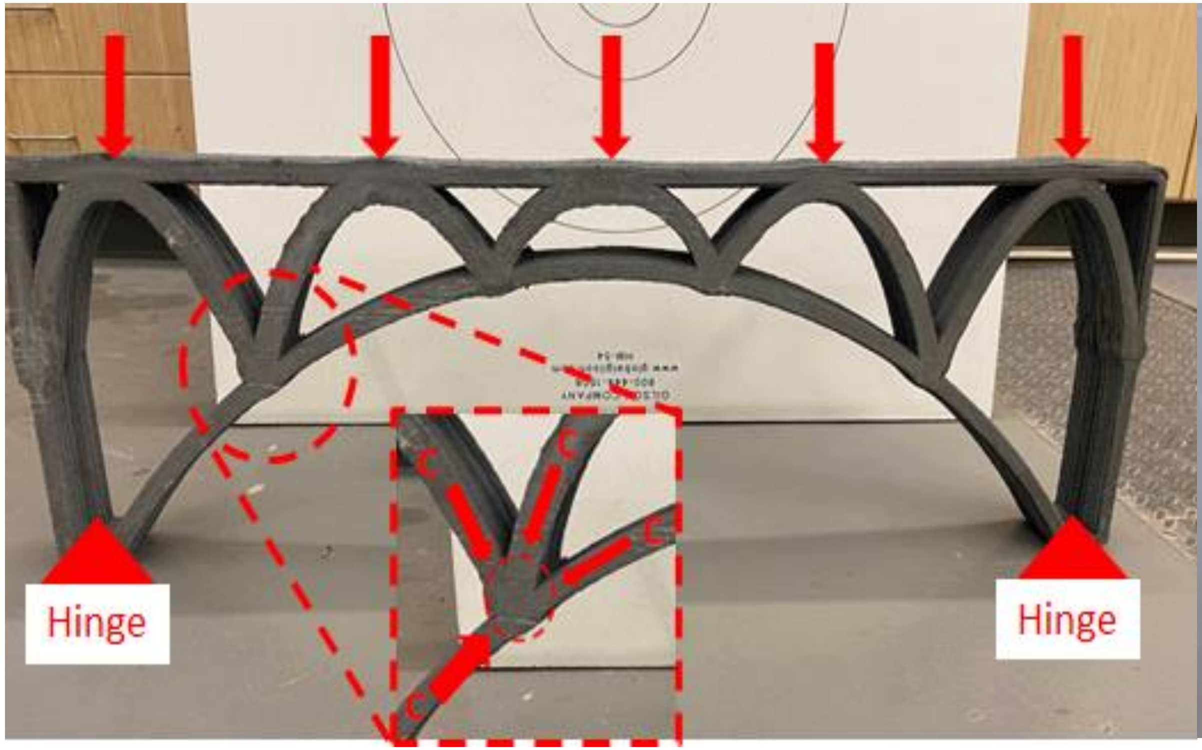
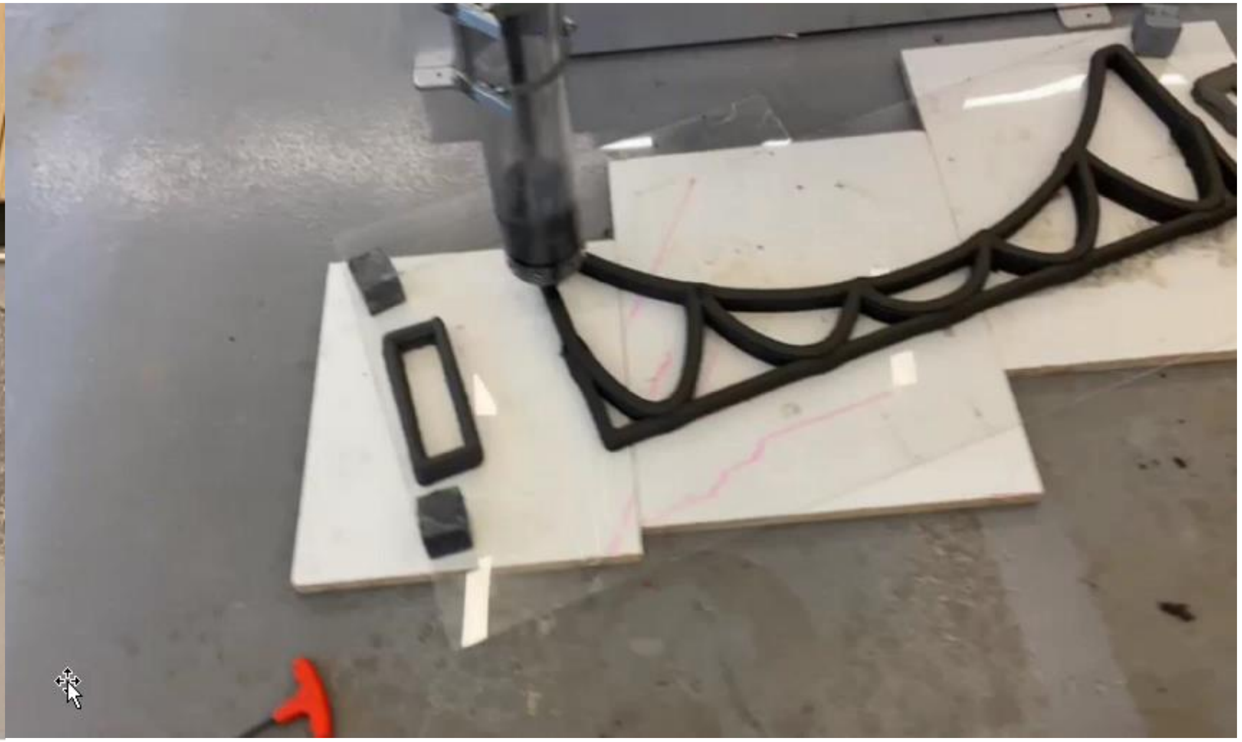


Topology-Optimization-Based Additive Construction

Compression Only Structures





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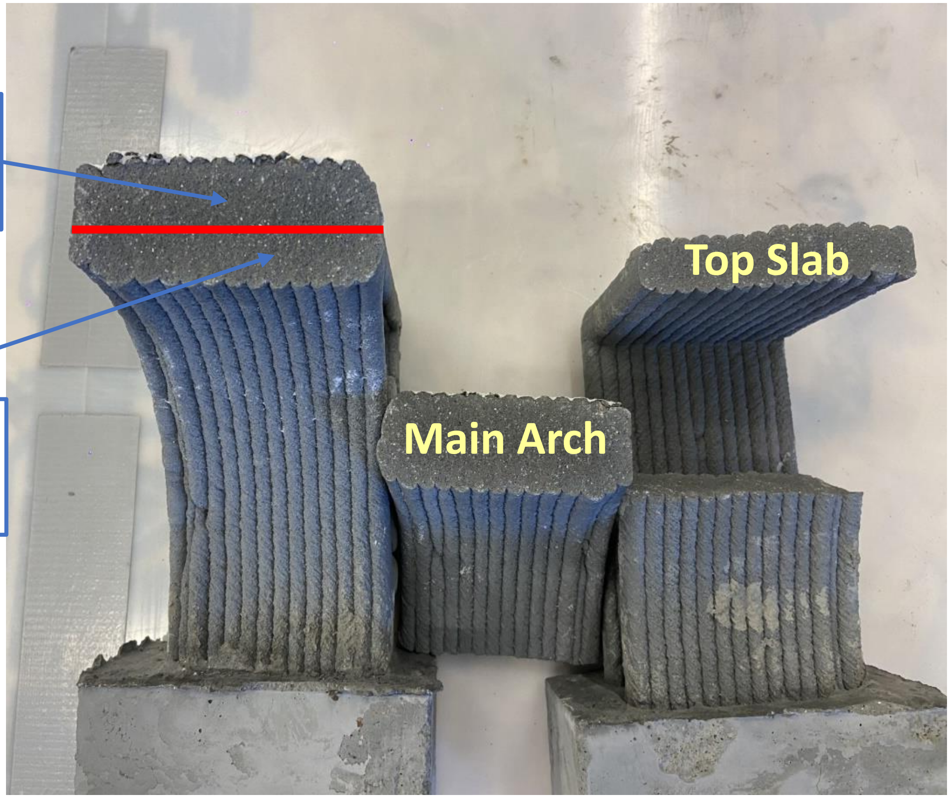
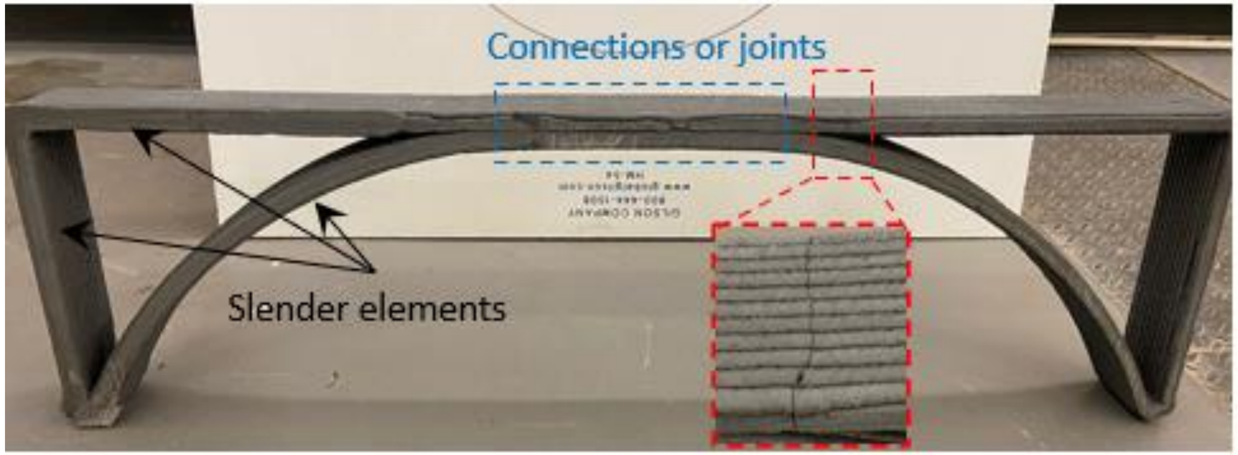
Layer Bead of Main Arch

Layer Bead of Top Slab





Shrinkage Cracks

Fused Layers
and Joints

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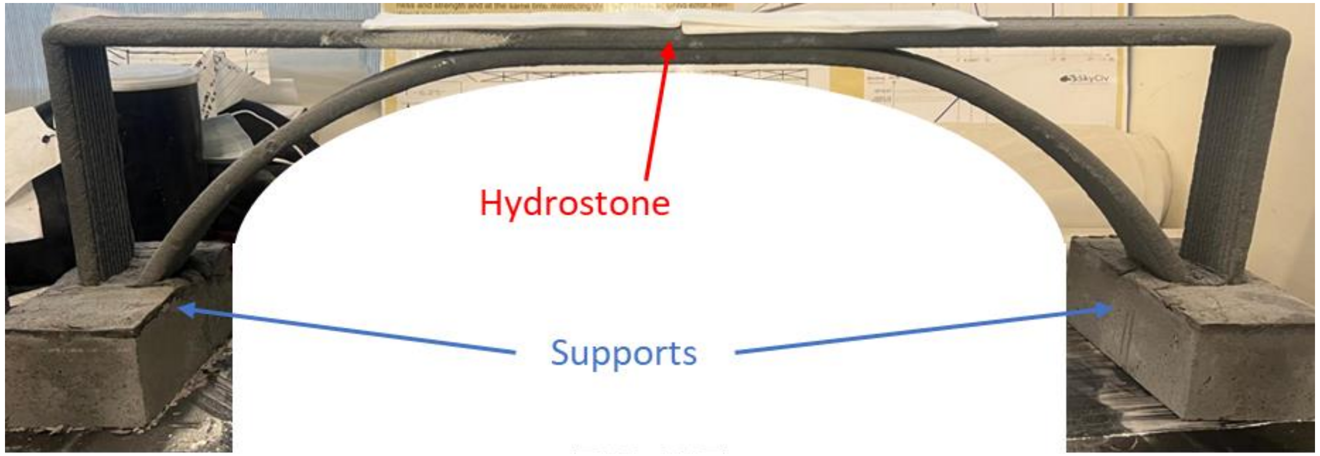
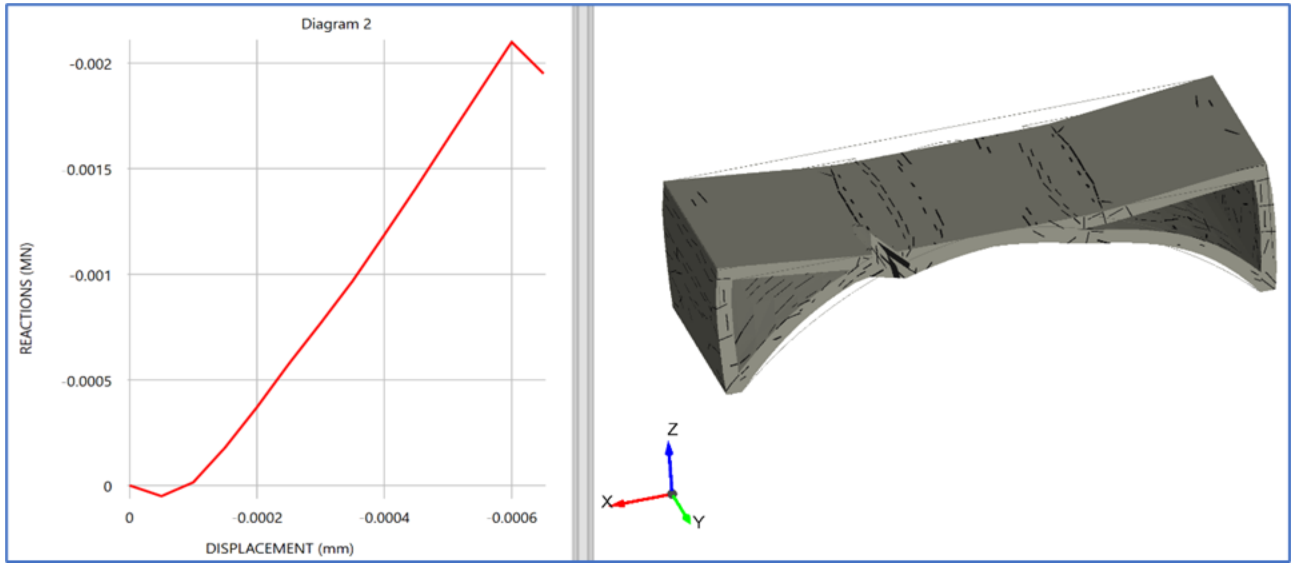
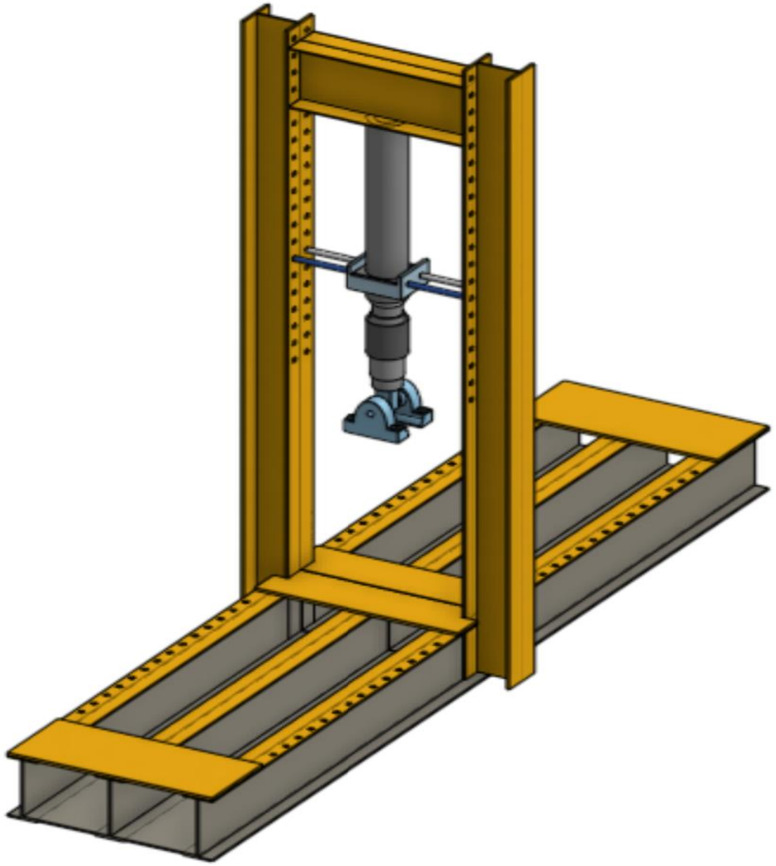
Future Work

Single Arch Bridge Prepared for Testing



ATENA Analysis of a Single Arch Bridge





CAD Model of Actuator

Future Work

Conclusion

– Topology optimization works within a user defined space to create a design that has a **decreased volume** and performs at the same caliber or **greater than the original design**.

– Software such as "Abaqus" allows the user to **define the design space, boundary conditions, loads, and materials to give an optimized shape** which satisfies the prescribed constraints.

– **Slight variation in the printing path of the layer to be circular** to form an arch resulted in a **much higher capacity** if compared to a straight-line printing path for the same amount of material. Therefore, the small arch-like exhibited ten times load carrying capacity compared to an equivalent beam with the same size and volume calculated based on the modulus of rupture.

– Continued analysis through analysis software, such as "ATENA," provide an idea as to the results from testing and validate the values, as well.

– The process of topology optimization can be used in different ways with various types of structures, from simple beams, to complex arches.

Thank you.

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