

Topology-Optimization-Based Additive Construction

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What is Topology
Optimization (TO)?

Definition
Benefits and Disadvantages
TO and Concrete

Optimization of C-
Only Structures

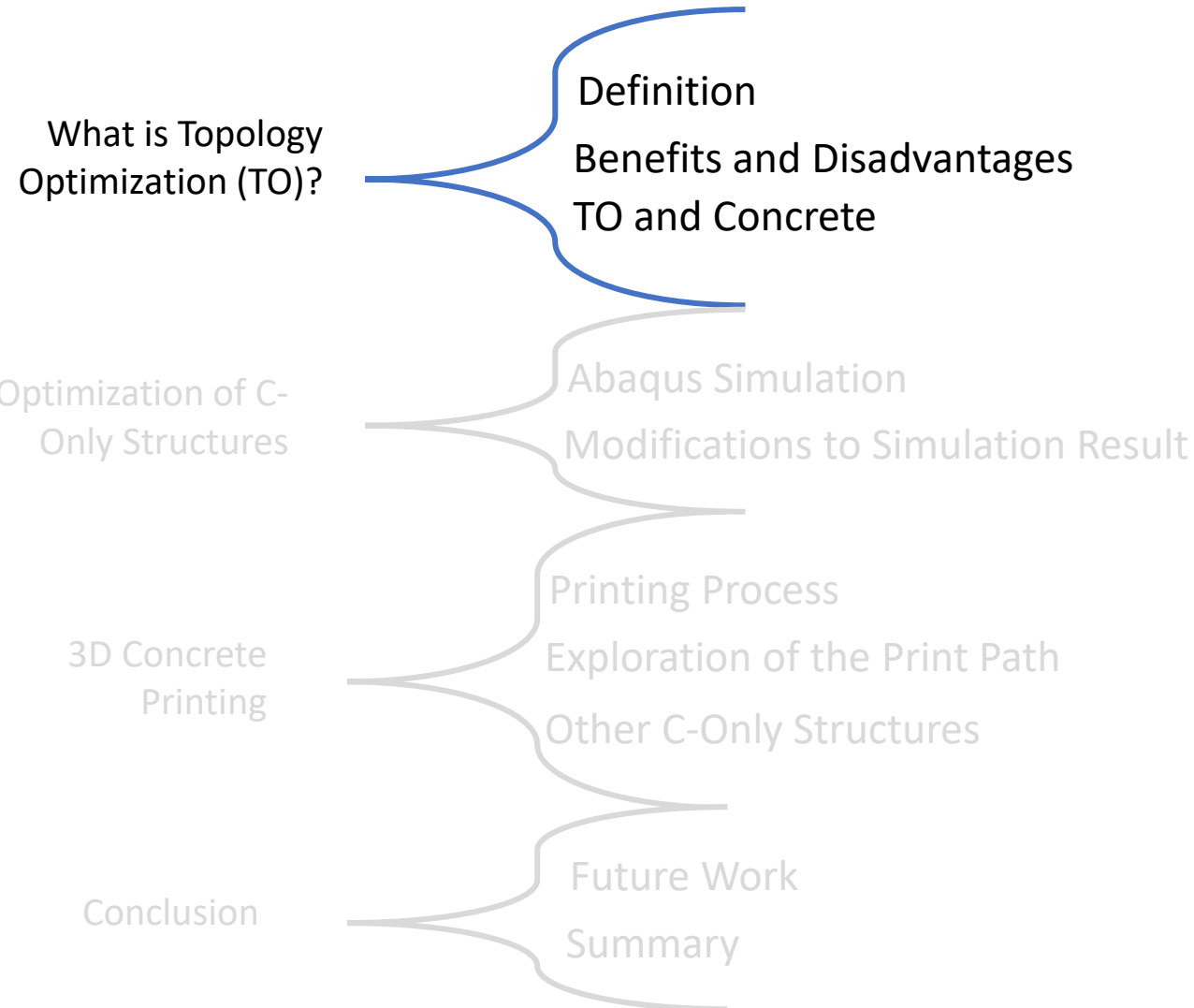
Abaqus Simulation
Modifications to Simulation Result

3D Concrete
Printing

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

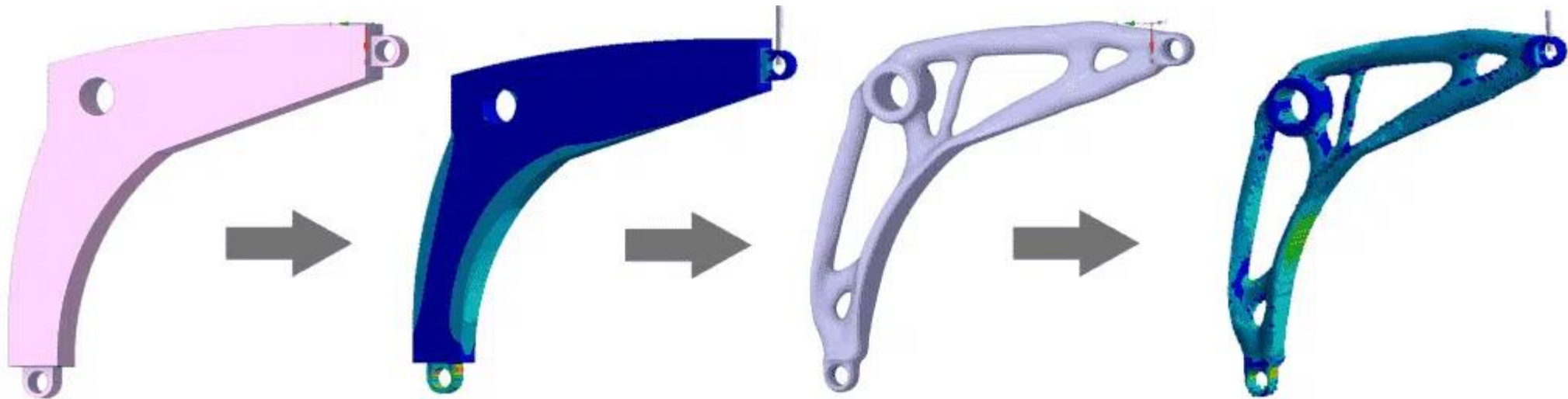
Conclusion

Future Work
Summary



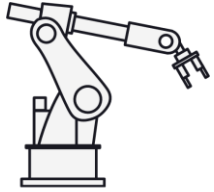
What is Topology Optimization?

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)

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.

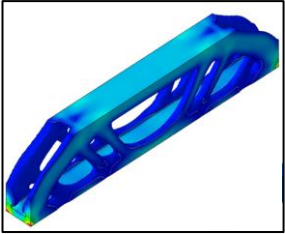


Broadens design creativity

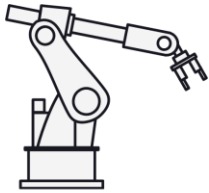


Lighter Structures for structural benefits

Barriers for TO in Additive Construction for Concrete



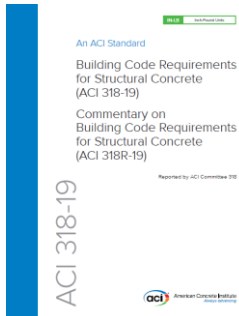
TO is often computationally expensive until achieving the correct model



Expensive Additive Construction Equipment due to large print areas

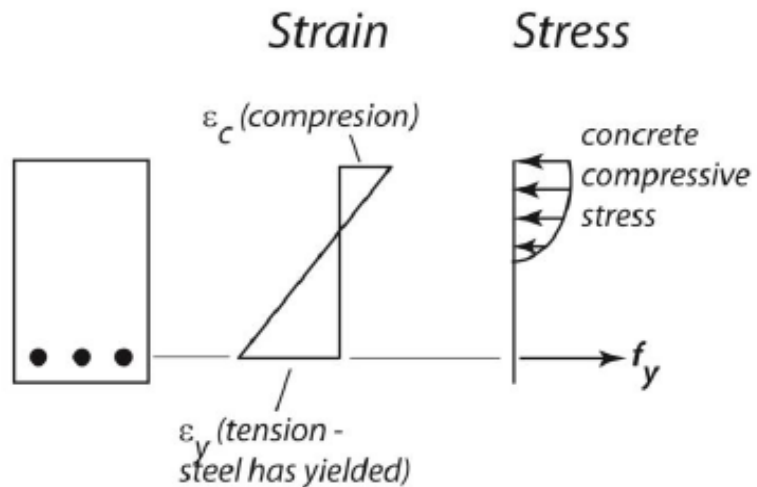
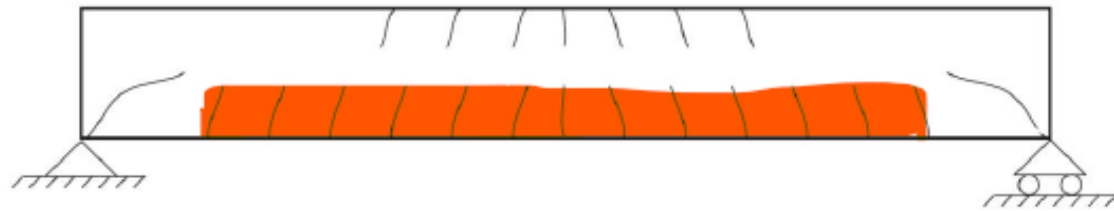


Reinforcement

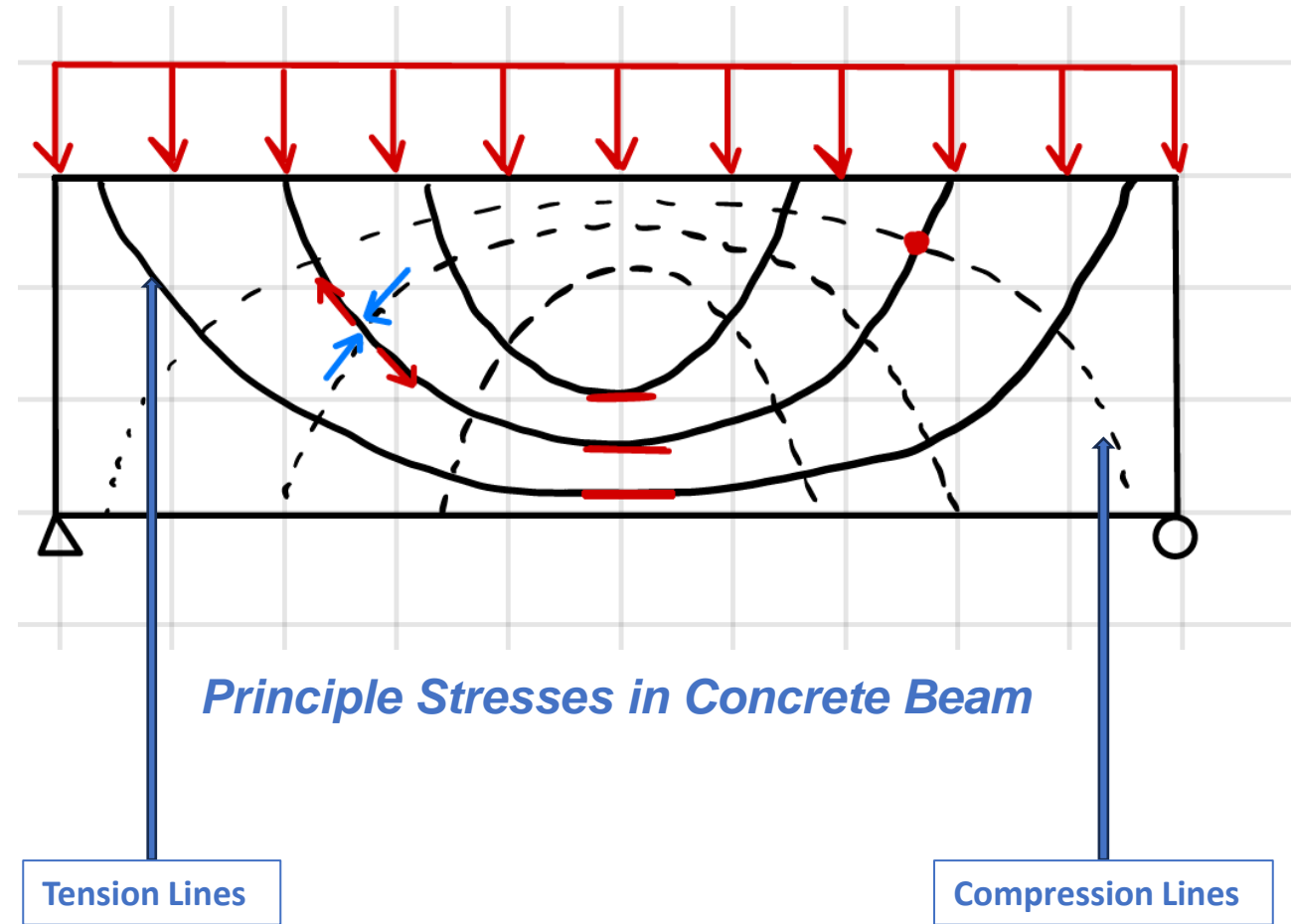


Does not Comply with codes and standards

Is TO suitable for Concrete Structures ?



Concrete Crack in Tension and Compressive Strength Block

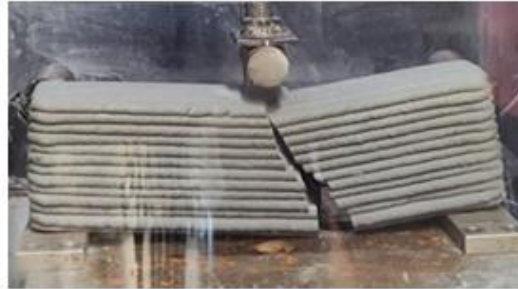


Why Topology Optimization?

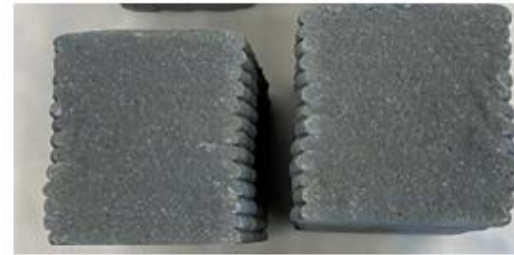
Printing
Path
(Plan)



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?

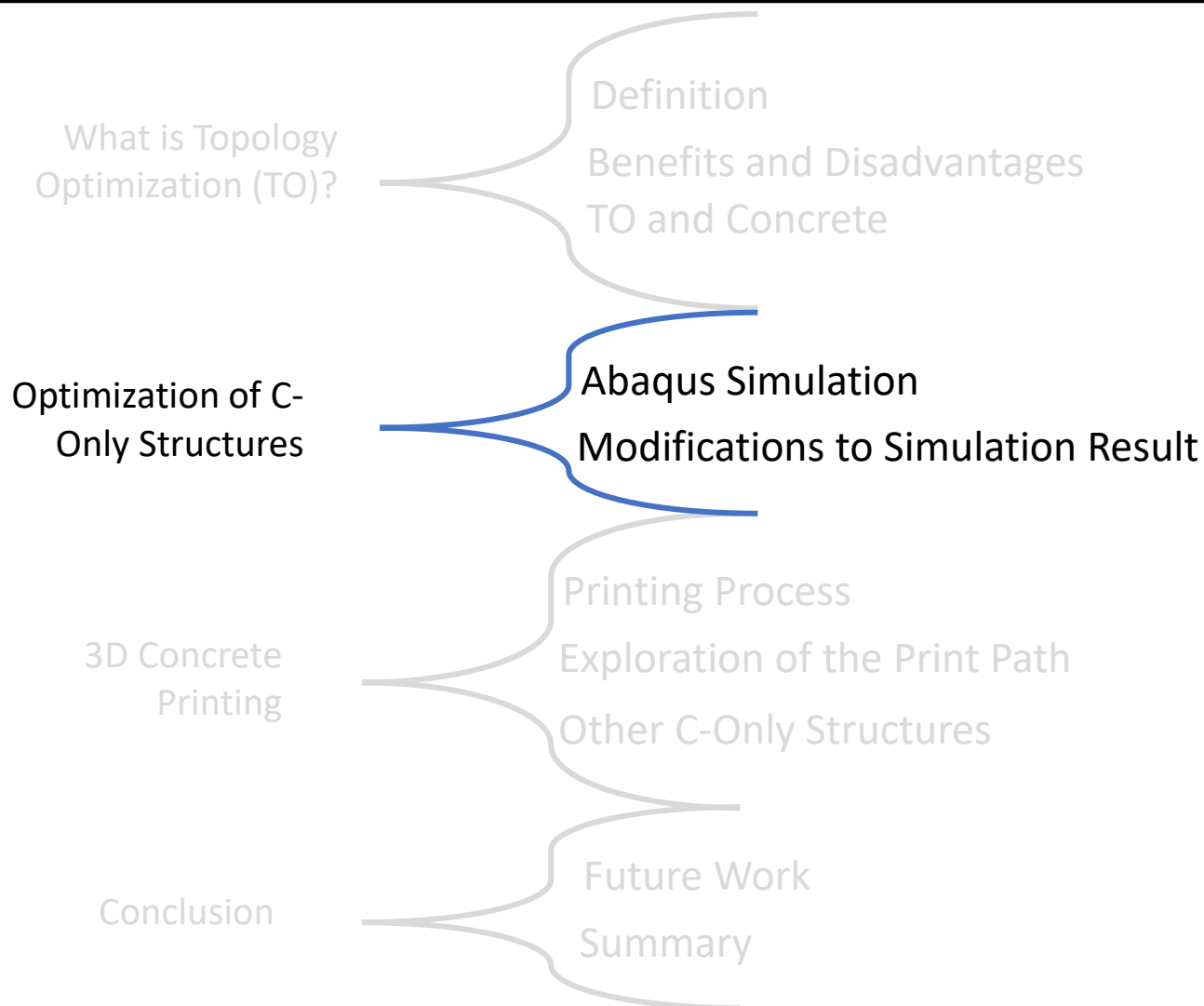
Equivalent Beam



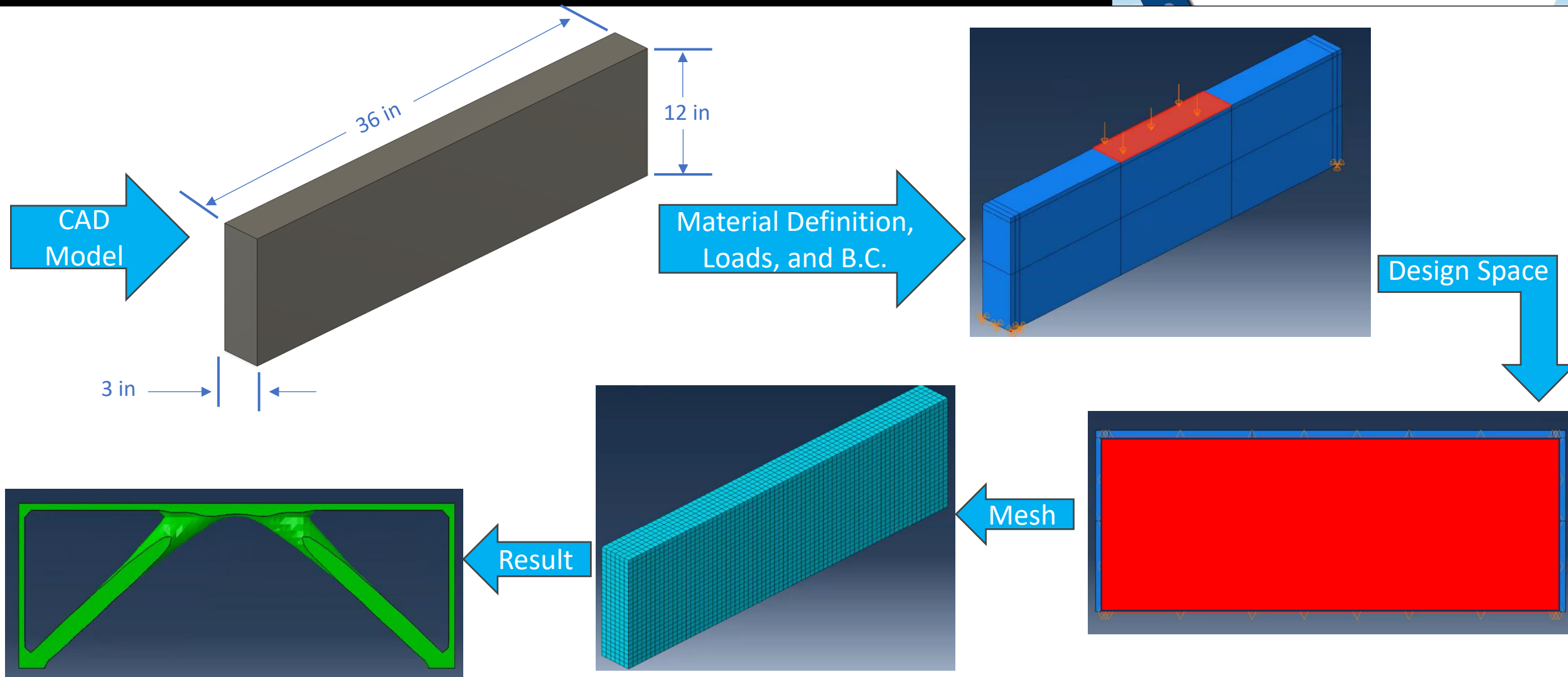
Arch



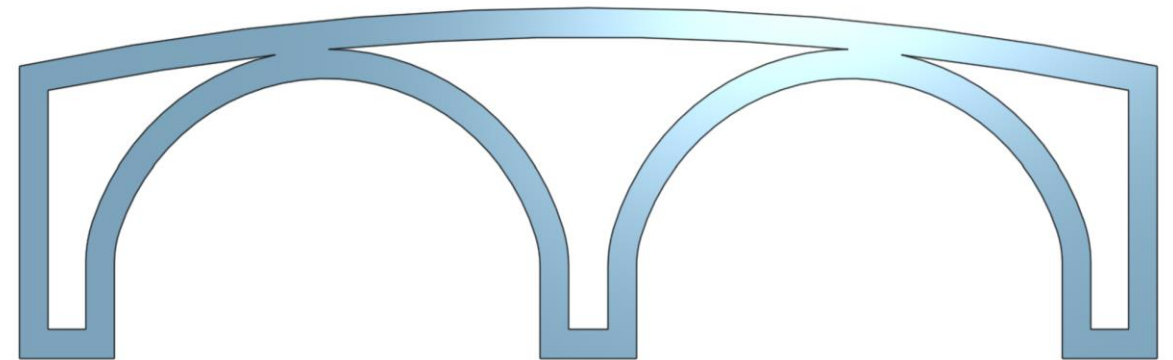
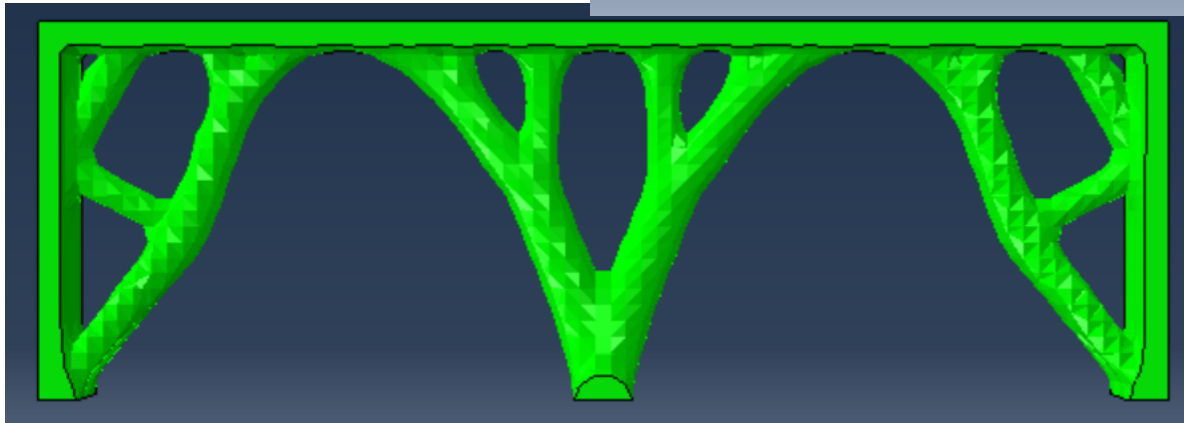
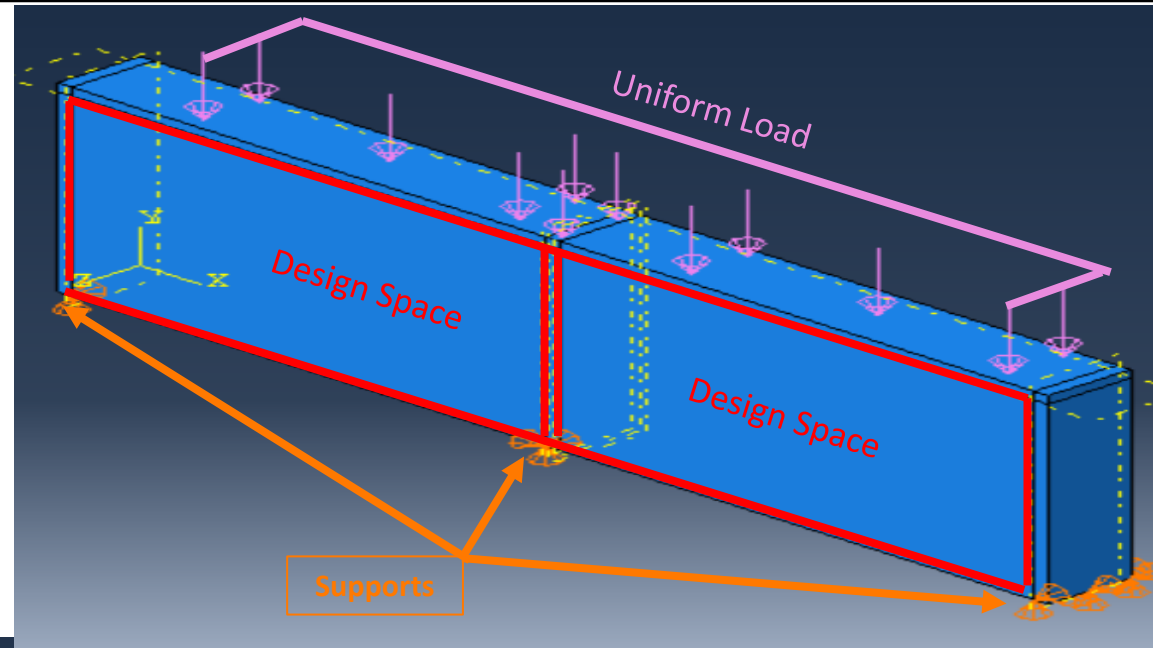
	ID	Force		Span (L)		Depth (d)		Width (b)		Modulus of Rupture (R)	
		(kips)	kN	inch	mm	inch	mm	inch	mm	ksi	mpa
Calculated	Equivelant Beam	0.135	0.602	9.00	228.6	0.75	19.1	3.50	88.9	0.929	6.404
Tested	Arch	1.349	6.000								
	Ratio	10.0	10.0								



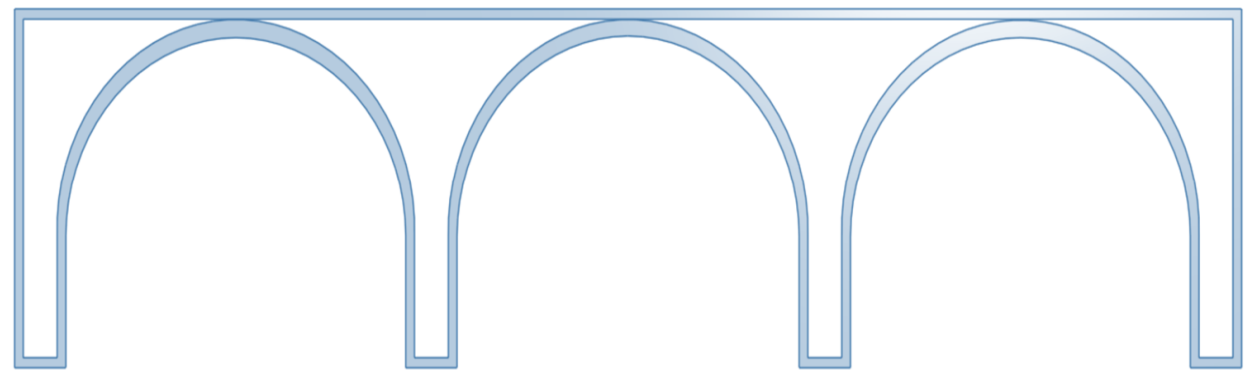
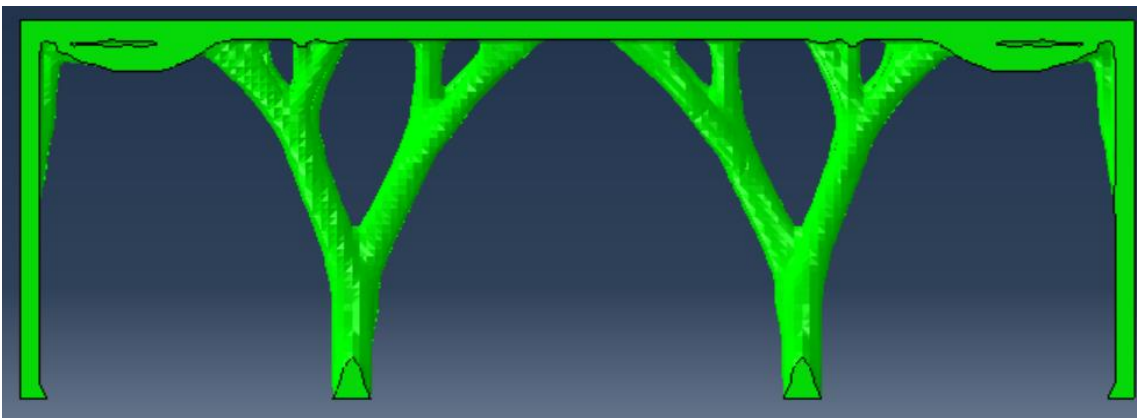
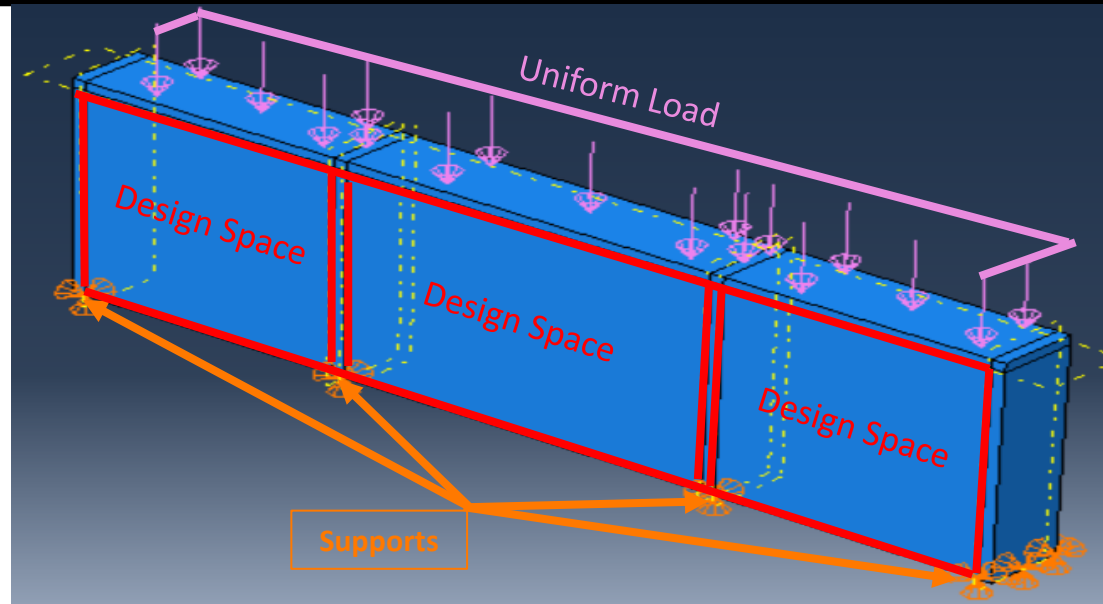
Optimization of C-Only Structures

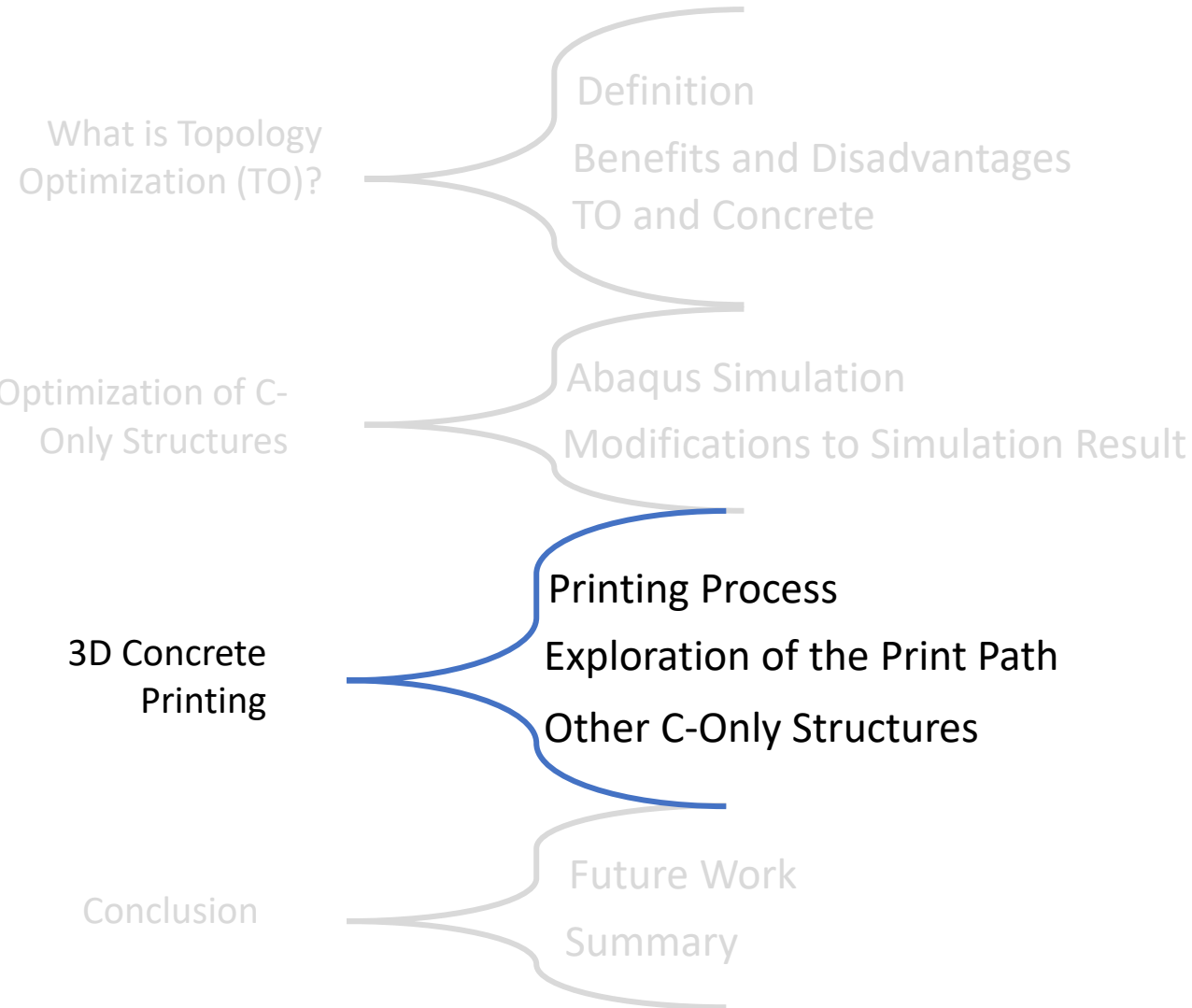


Optimization of C-Only Structures



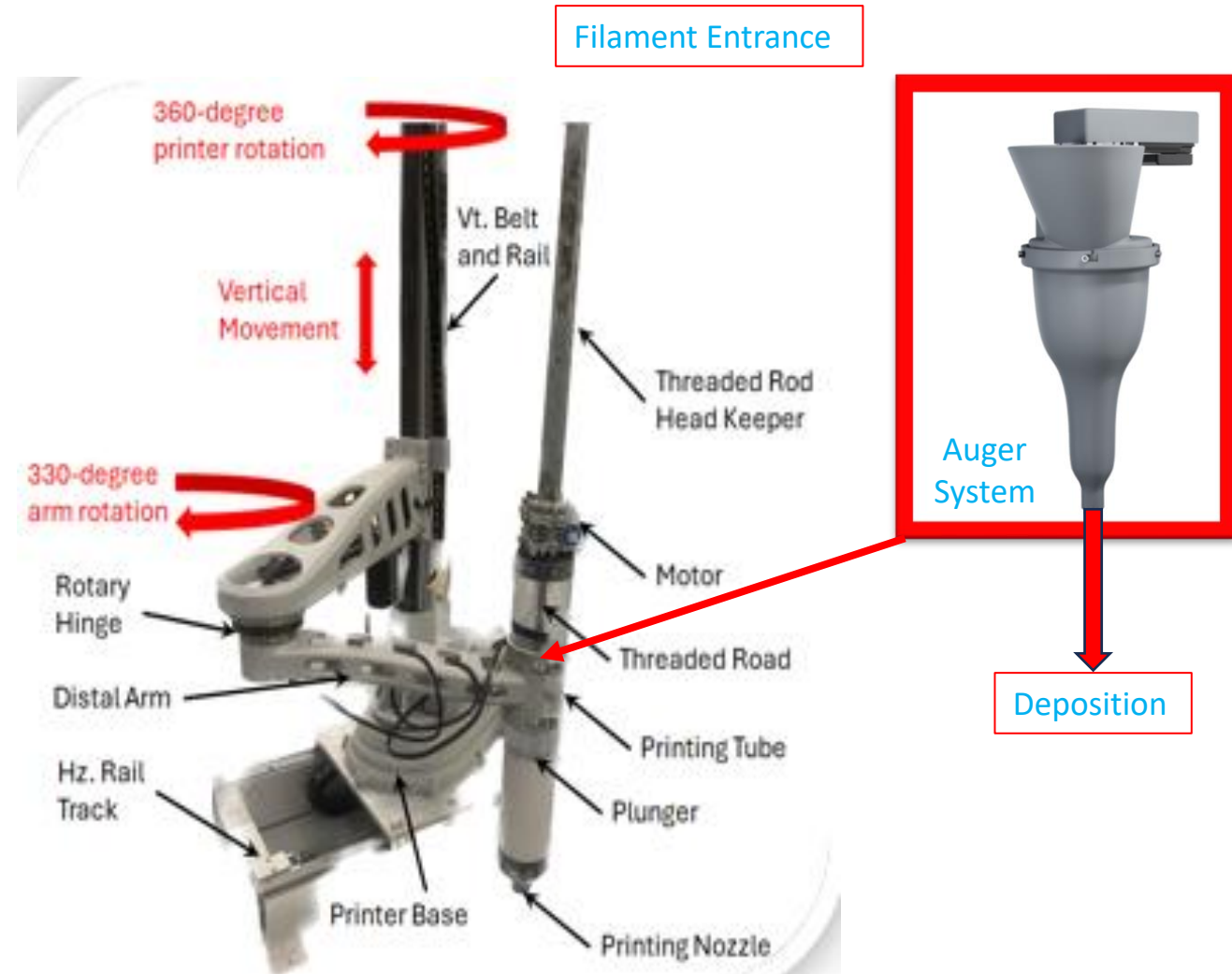
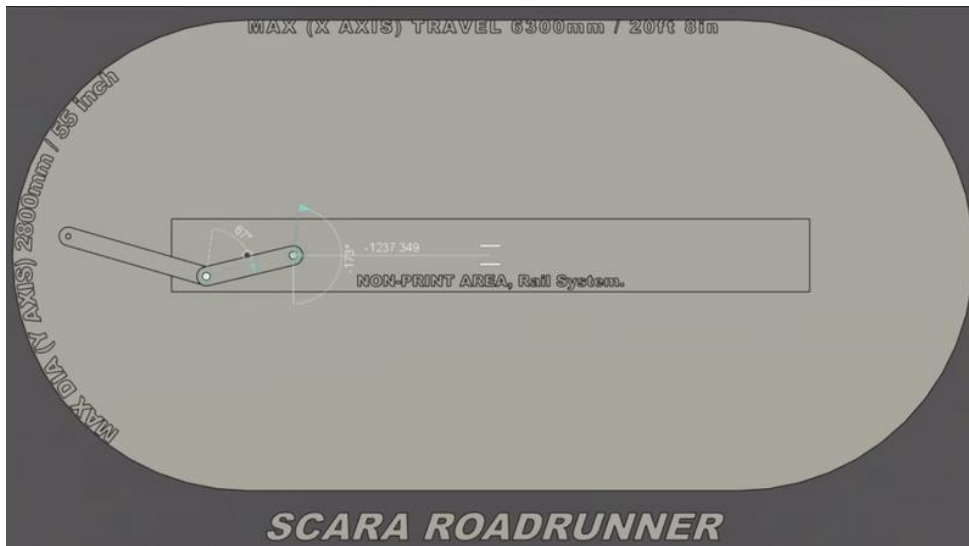
Optimization of C-Only Structures



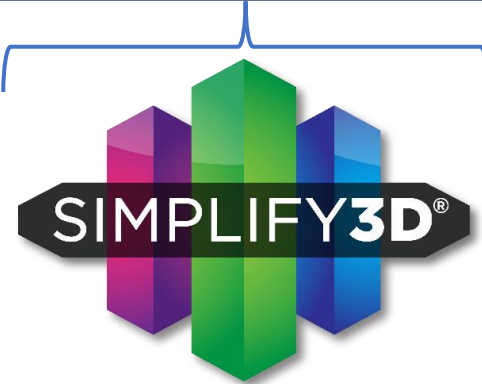
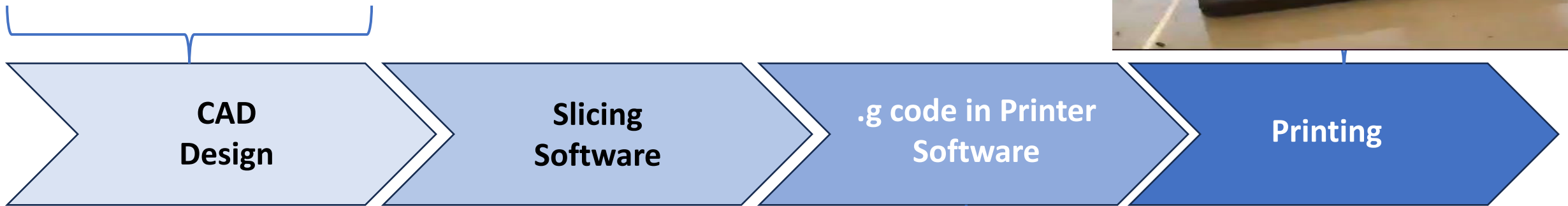


Scara Elite Roadrunner

- 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



Computational Process after Mixing



```
; G-Code generated by Simplify3D(R) Version 5.1.2
; Settings Summary
; processName,Process 1
; autoConfigureMaterial,PLA
; autoConfigureQuality,Fast
; targetModels,Natchez Bridge
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; extruder,Clay
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; extrusionWidth,6.00000
```

Computational Process after Mixing

Layer

Extruder Layer Additions Infill Support Temperature Cooling Speeds Output Scripts Other Advanced

General

Primary Extruder Clay

Layer Height 5.0000 mm

Top Solid Layers 0

Bottom Solid Layers 0

Outline Perimeters 1

☒ Single outline corkscrew printing mode (vase mode)

Adaptive Layer Height

First Layer Settings

First Layer Units Percentage

First Layer Height 100 %

First Layer Width 100 %

First Layer Speed 100 %

Start Point Selection

☐ Randomize start point placement

☒ Optimize start points for fastest printing

Extruder

Process Name Process 1 Find Setting: Search...

Select Profile SCARA V4/ELITE-Clay extruder - 8mm Update Profile Save as New...

Auto-Configure for Material PLA

Auto-Configure for Quality Fast

Extruder Layer Additions Infill Support Temperature Cooling Speeds Output Scripts Other Advanced

Extruder List (click item to edit settings)

Clay

General

Extruder Toolhead Number Tool 0

Nozzle diameter 8.00 mm

Extrusion Multiplier 1.00

Extrusion Width Automatic Manual 9.60 mm

Additions

Extruder Layer Additions Infill Support Temperature Cooling Speeds Output Scripts Other Advanced

Skirt/Brim

☒ Use Skirt/Brim

Skirt Extruder All Extruders

Skirt Layers 1

Skirt Offset 10.00 mm

Skirt Outlines 1

Prime Pillar

☐ Use Prime Pillar

Prime Pillar Extruder All Extruders

Prime Pillar Width 12.00 mm

Prime Pillar Location North-West

Prime Pillar Speed 100 %

Other

Extruder Layer Additions Infill Support Temperature Cooling Speeds Output Scripts Other Advanced

Bridging

☒ Identify Bridging Regions

Unsupported Area Threshold 40.0 mm²

Bridging Infill Extra Expansion 0.00 mm

Bridging Extrusion Modifier 100 %

Bridging Extrusion Modifier 100 %

Filament Properties

Extruder to Edit: Clay

Filament Diameter 1.7500 mm

Filament Price 215.00 price/kg

Filament Density 1.25 grams/cm³

Filament Density 1.25 grams/cm³

Advanced

Extruder Layer Additions Infill Support Temperature Cooling Speeds Output Scripts Other Advanced

Thin Wall Behavior

External Thin Wall Type Perimeters Only

Internal Thin Wall Type Allow Gap Fill

Allowed Perimeter Overlap 10 %

Single Extrusions

Minimum Single Extrusion Length 1.00 mm

Minimum Single Extrusion Width 50 %

Maximum Single Extrusion Width 200 %

Single Extrusion Endpoint Extension 0.20 mm

Ooze Control Behavior

☐ Only retract when crossing open spaces

☐ Force retraction between layers

☐ Force retraction on top layers

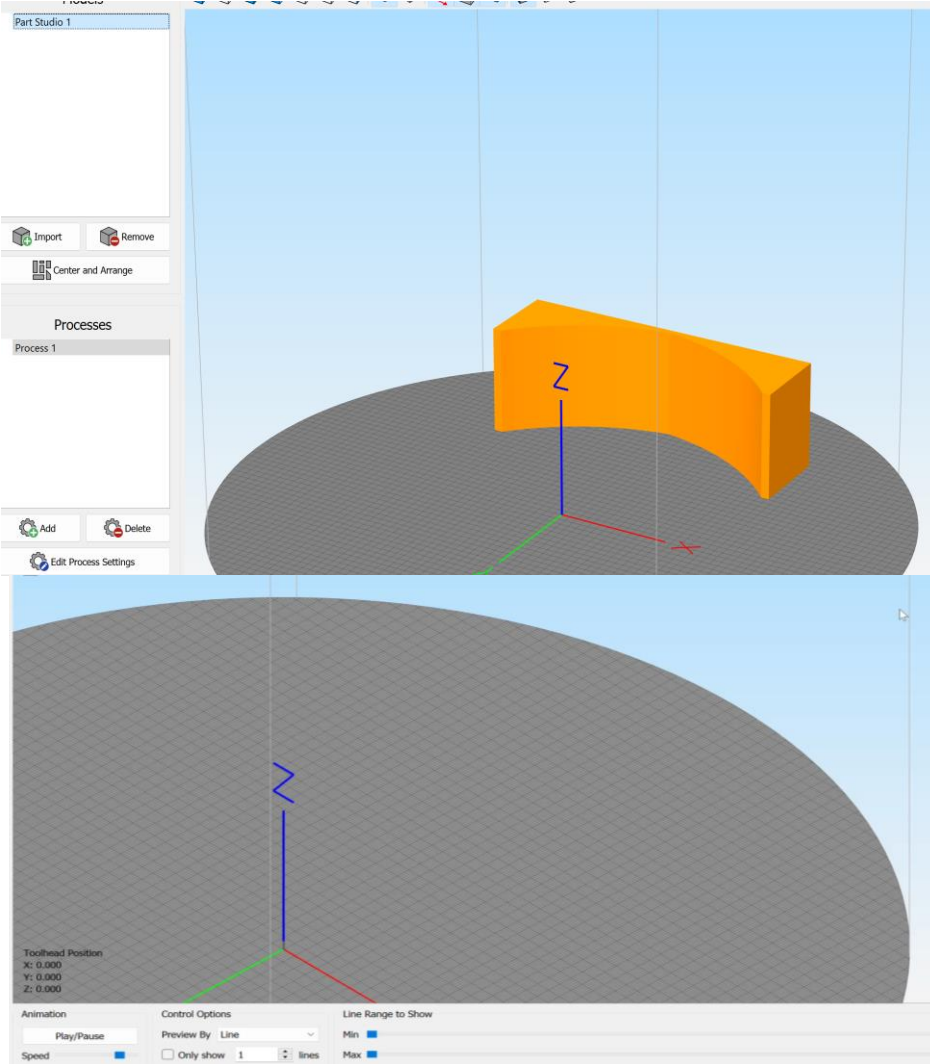
☐ Require minimum travel for retraction 3.00 mm

☐ Require minimum extrusion for retraction 3.00 mm

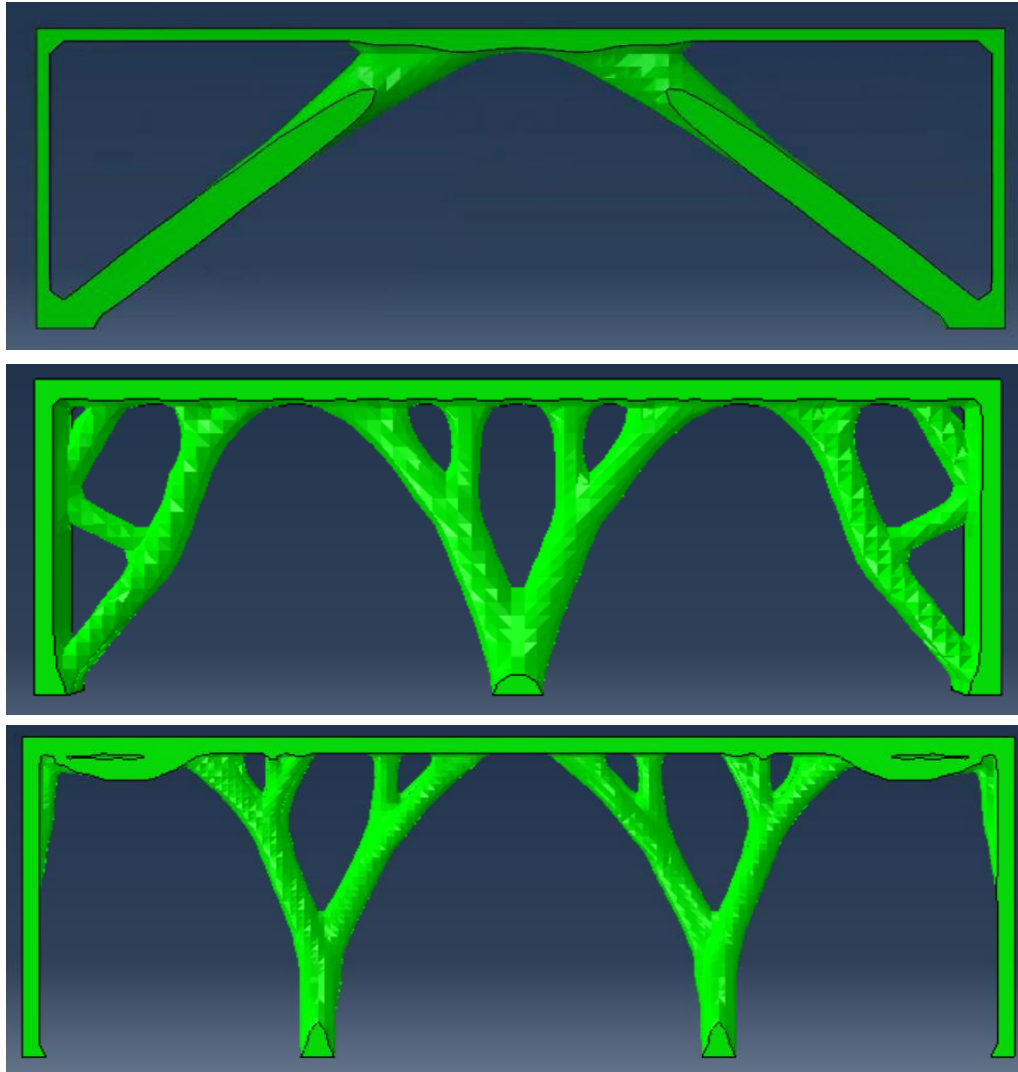
☐ Only vertical lift on top layers

☐ Perform retraction during wipe movement

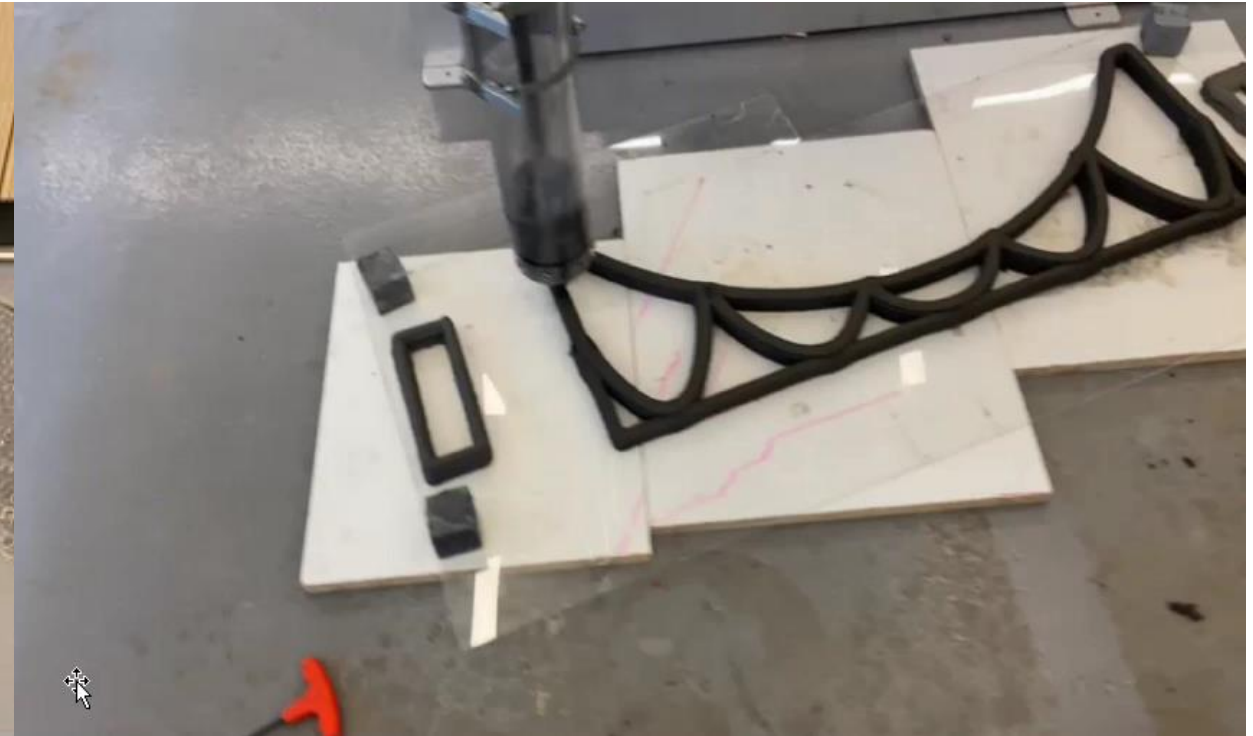
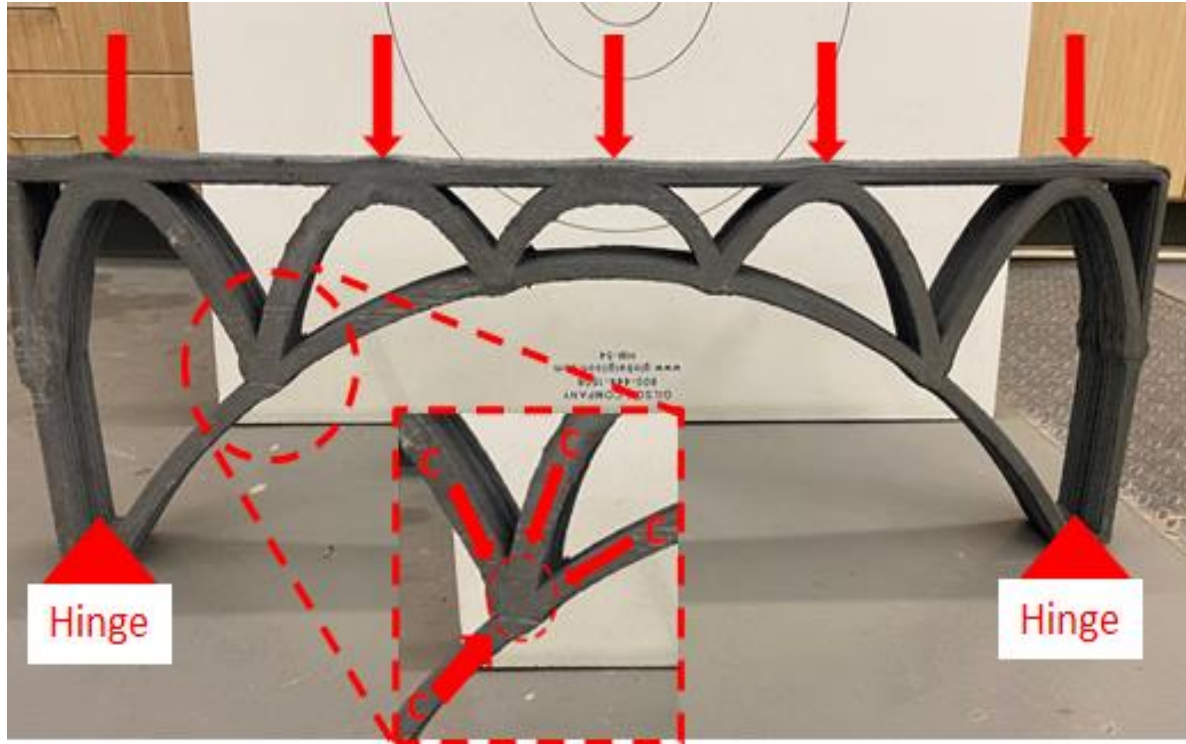
Wiping Mode Wipe All Features

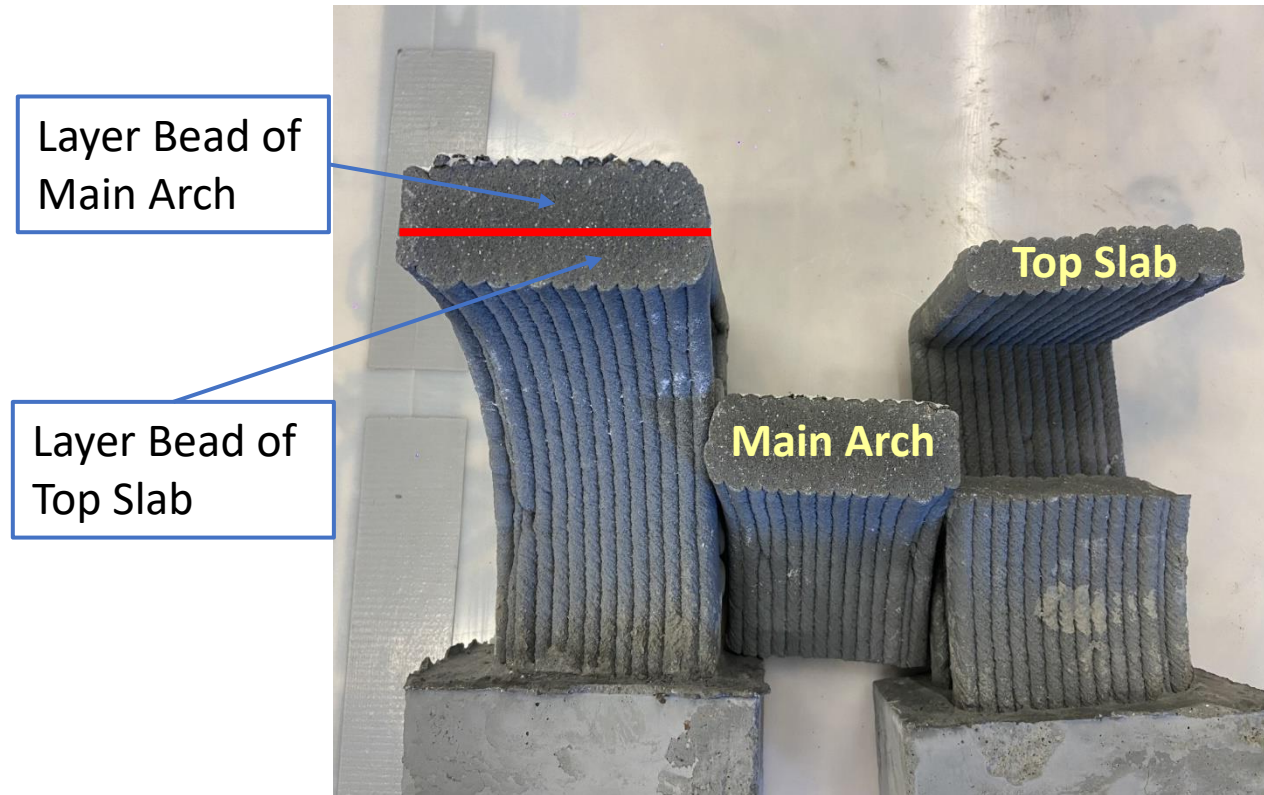


3D Concrete Printing at Rowan University

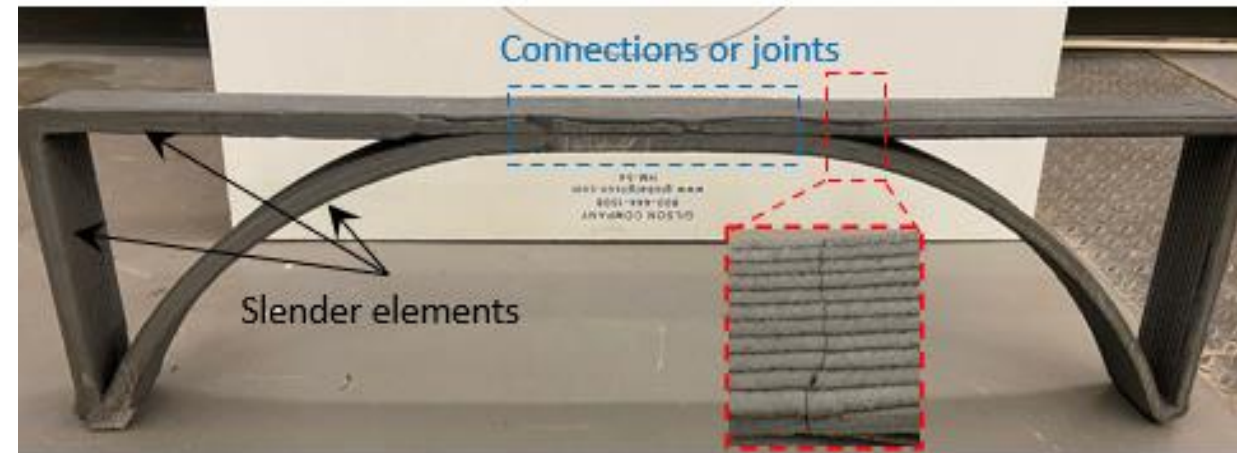


Compression Only Structures

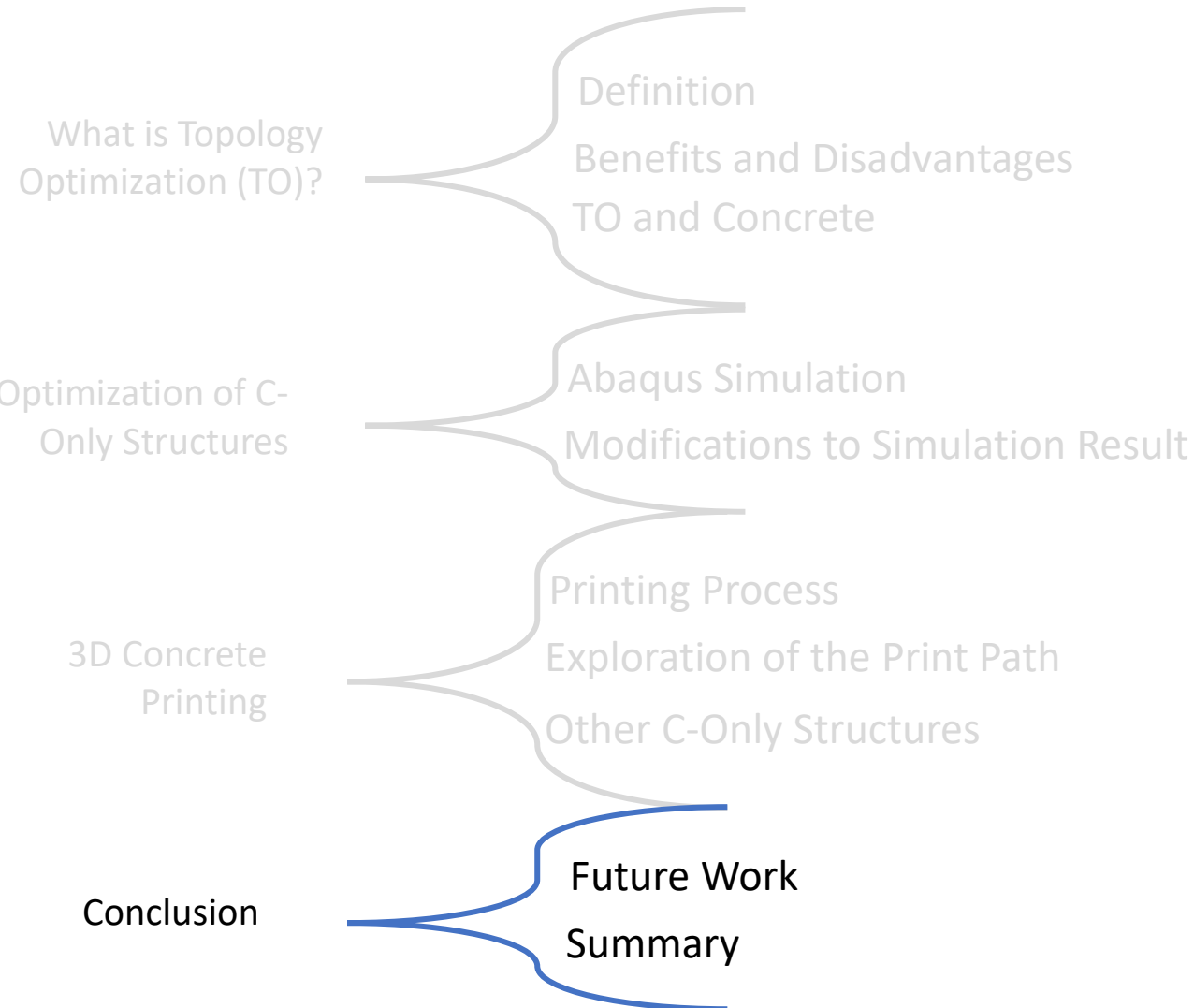




Fused Layers
and Joints

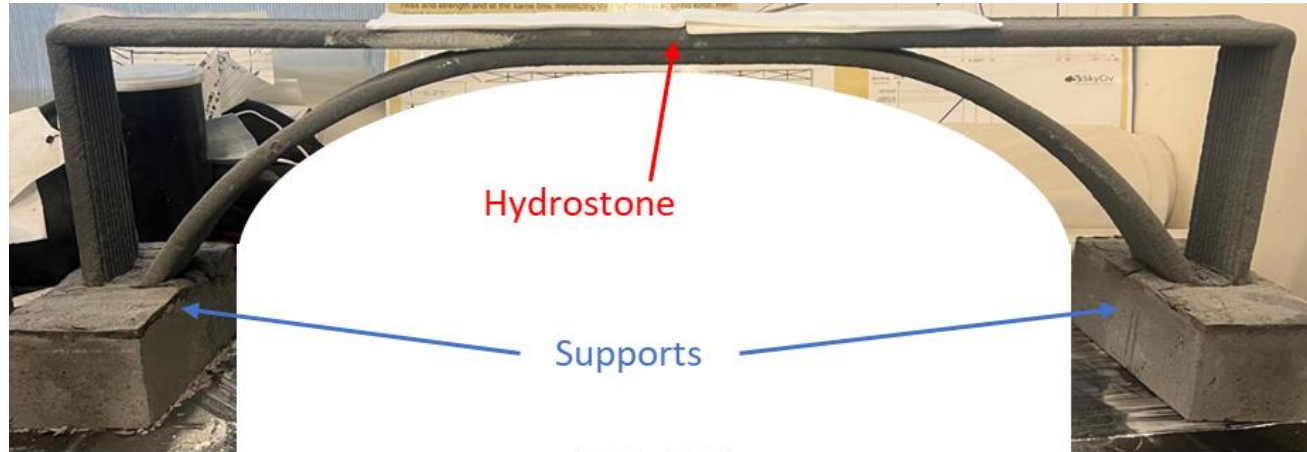


Shrinkage Cracks

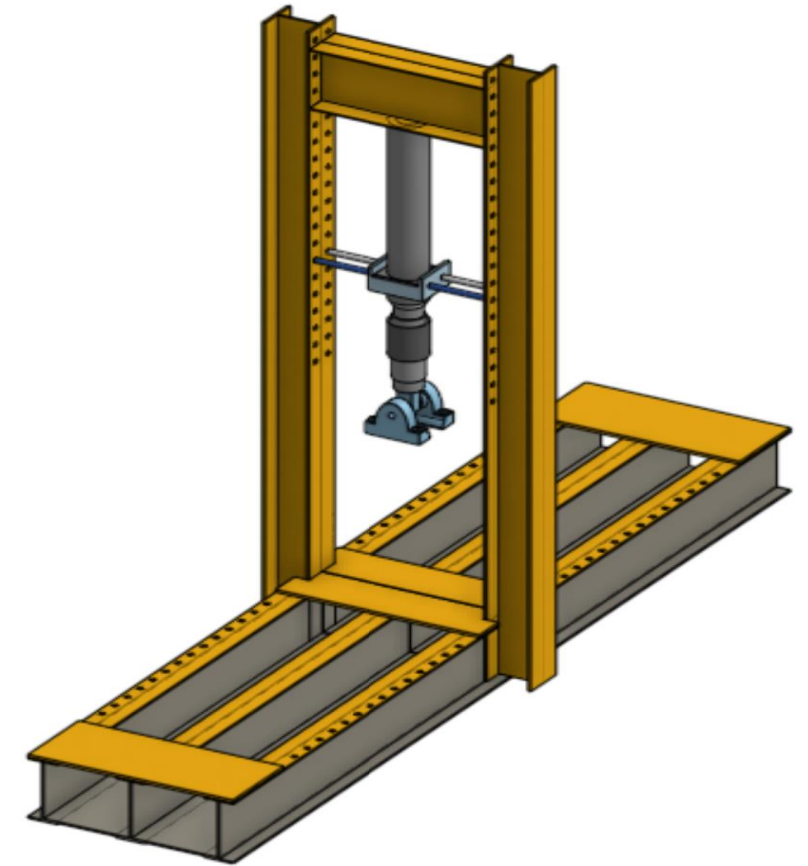
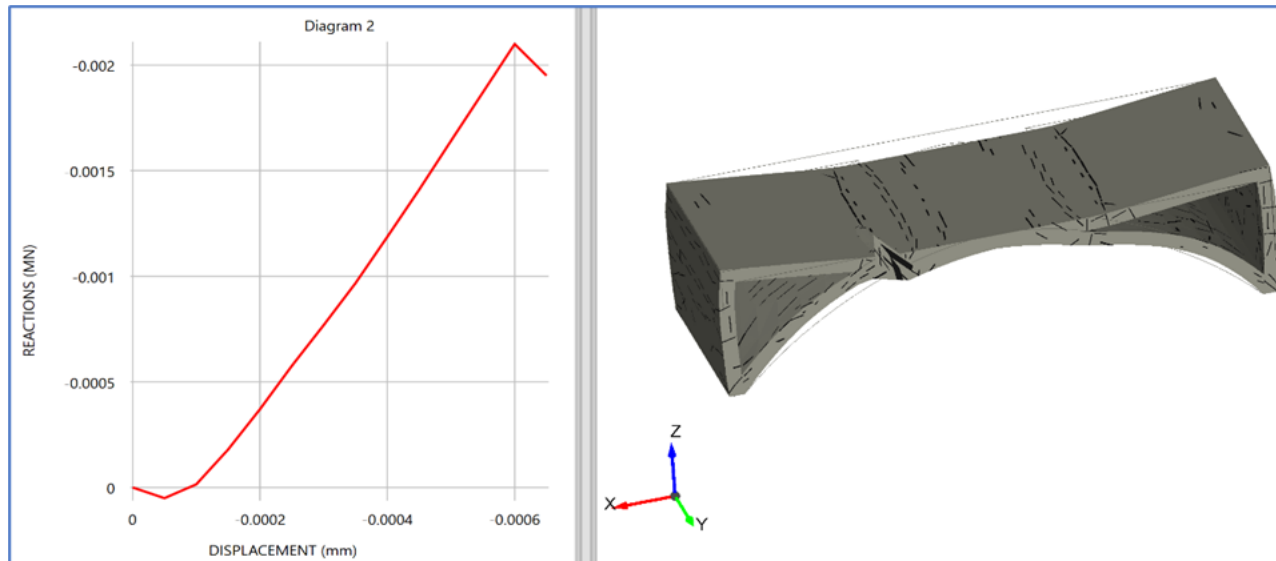


Future Work

Single Arch Bridge
Prepared for Testing



ATENA Analysis of a
Single Arch Bridge



CAD Model of Actuator

Future Work



Topology-Optimization-Based Additive Construction

- 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.

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Thank you.



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