Computing Interior Support-free Structure via Hollow-to-Fill Construction

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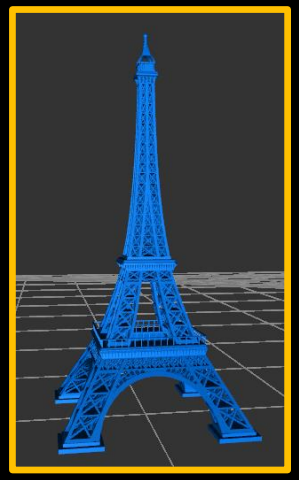
3D Printing



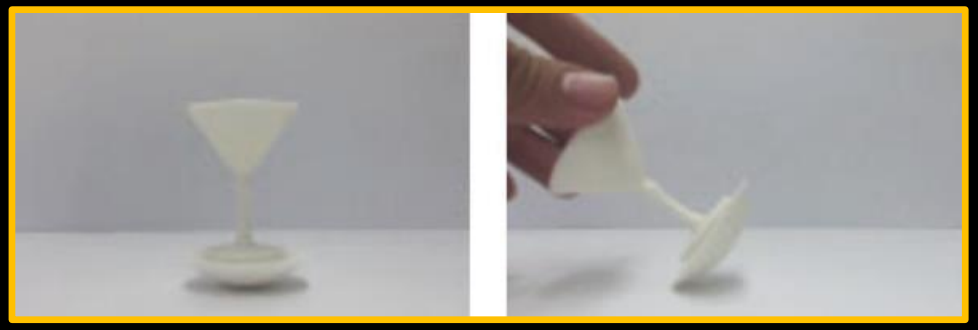
Shape optimization

Prior work – shape optimization

[Prévost et al. 2013]

[Bächer et al. 2014]

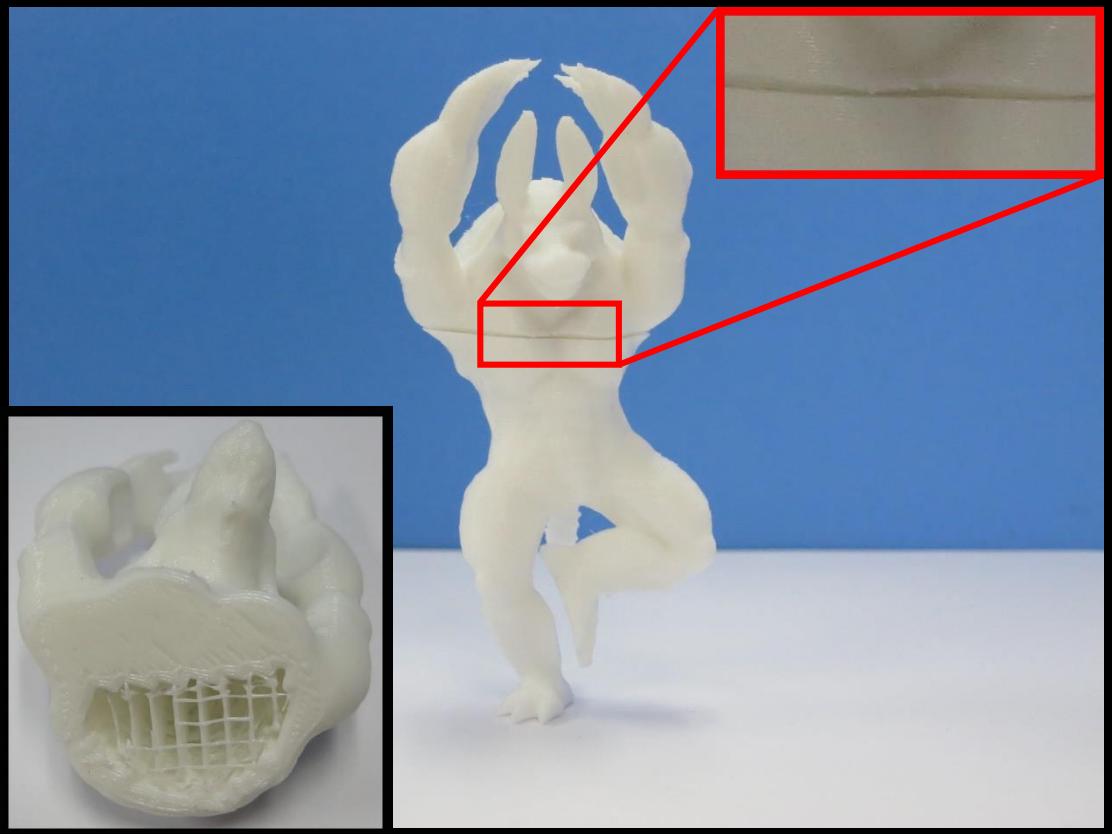
[Wang et al. 2016]



[Zhao et al. 2016]

[Prévost et al. 2016]

Motivation I



The printed Armadillo has a seam.
[Prévost et al. 2013]

Limitation:

1. The additional interior support structures should be removed.
2. The seam affects the visual beauty.

Prior work – support structures

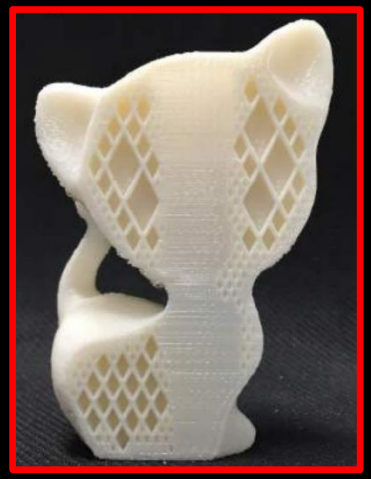
[Chen et al. 2013]

[Vanek et al. 2014]

[Dumas et al. 2014]

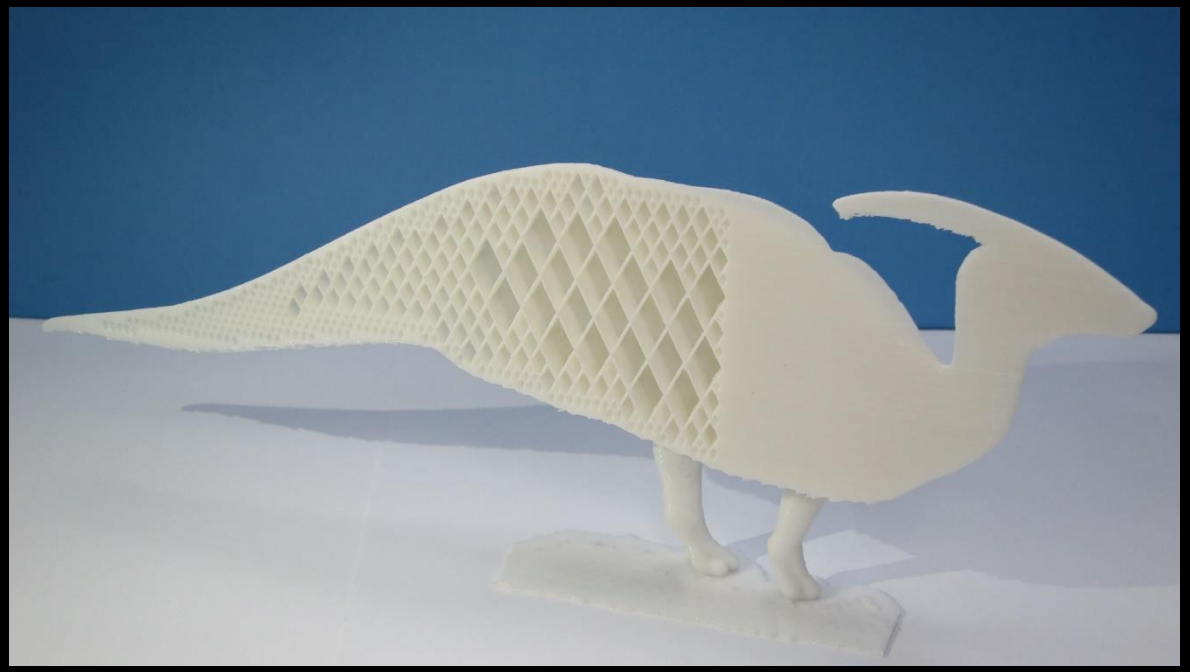
[Hu et al. 2015]

[Hu et al. 2015]



[Wu et al. 2016]

Motivation II



The printed cross section of the Dilo model [Wu et al. 2016]

Limitation:
The limited rhombic space may lead to more redundant material.

Goal

Output: Objects have support-free inner surfaces and meet the design requirements

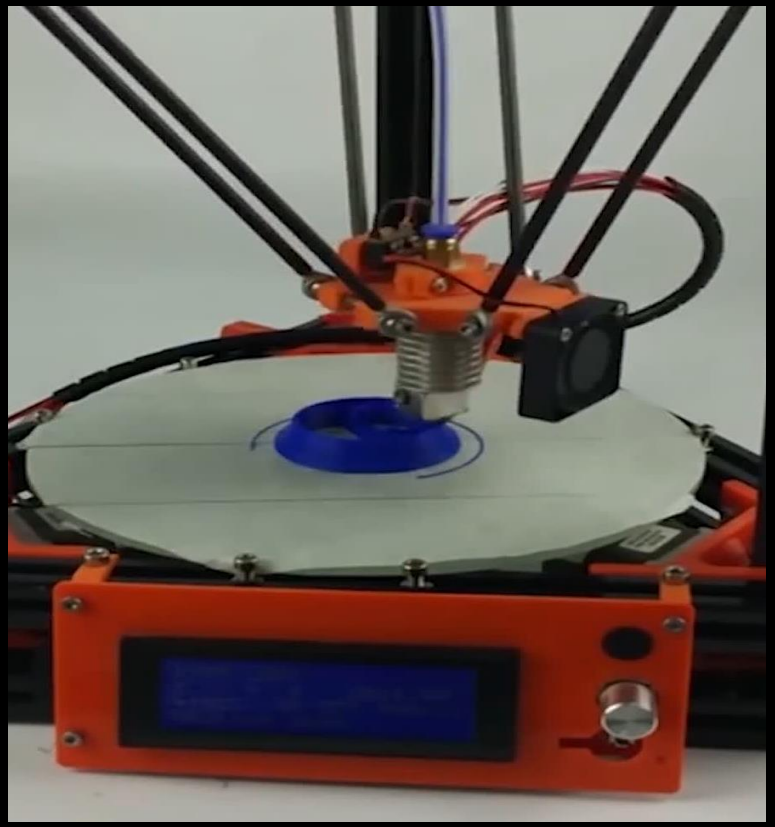
Input: 3D model

Outer surface $\mathcal{M}_O$

Inner surface $\mathcal{M}_I$

Our Approach

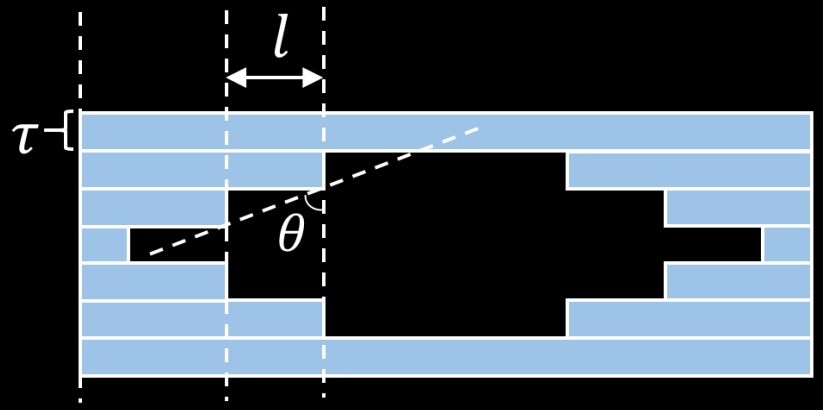
Fused Deposition Modeling (FDM)



1. Layer by layer.
2. The upper layer should be supported by the lower layer.

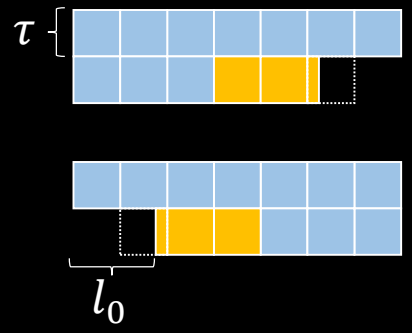
Support-free condition

- Overhang-angle condition
  - The overhang angle $\theta \leq \theta_0$
    - θ_0, the maximal overhang-angle
  - The overhang length $l \leq l_0$
    - l_0, the maximal overhang-length

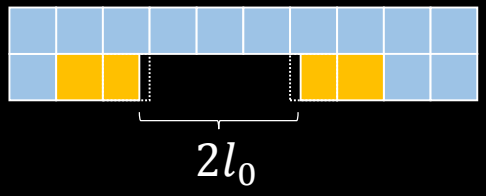


Types of support-free structures

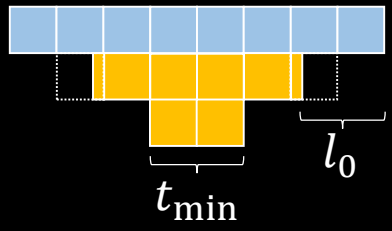
- Three types of support-free structures and the corresponding filling strategy



Type I

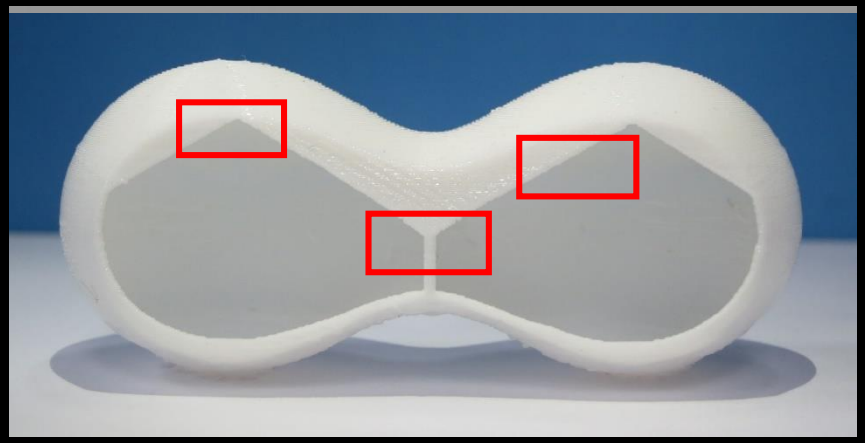


Type II



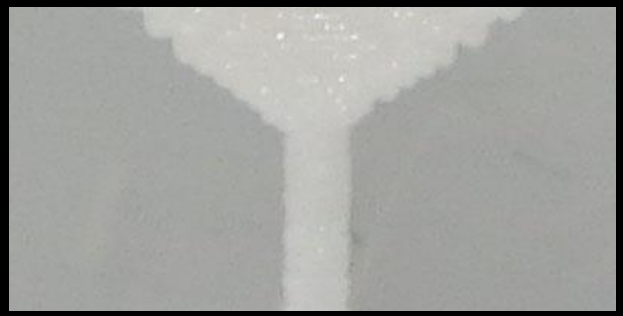
Type III

Printed support-free structures



Type I

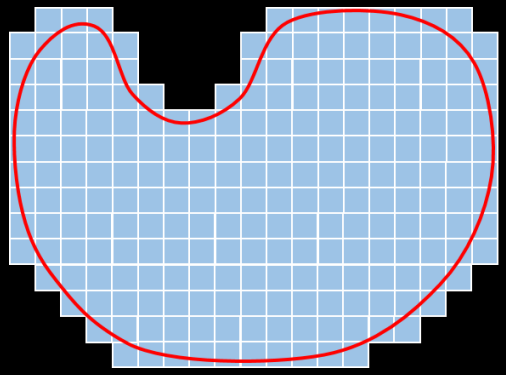
Type II



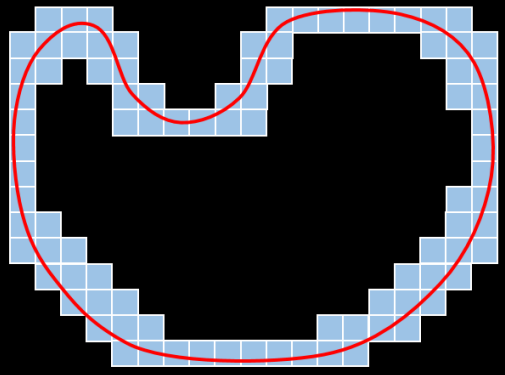
Type III

Interior support-free structure generation

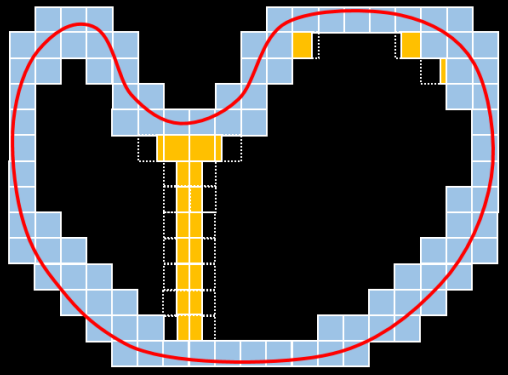
- Hollow-to-fill strategy



A voxelized model



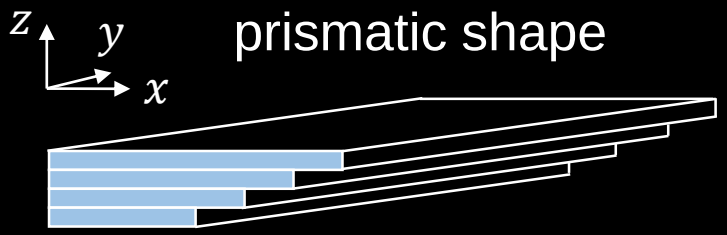
Hollowing



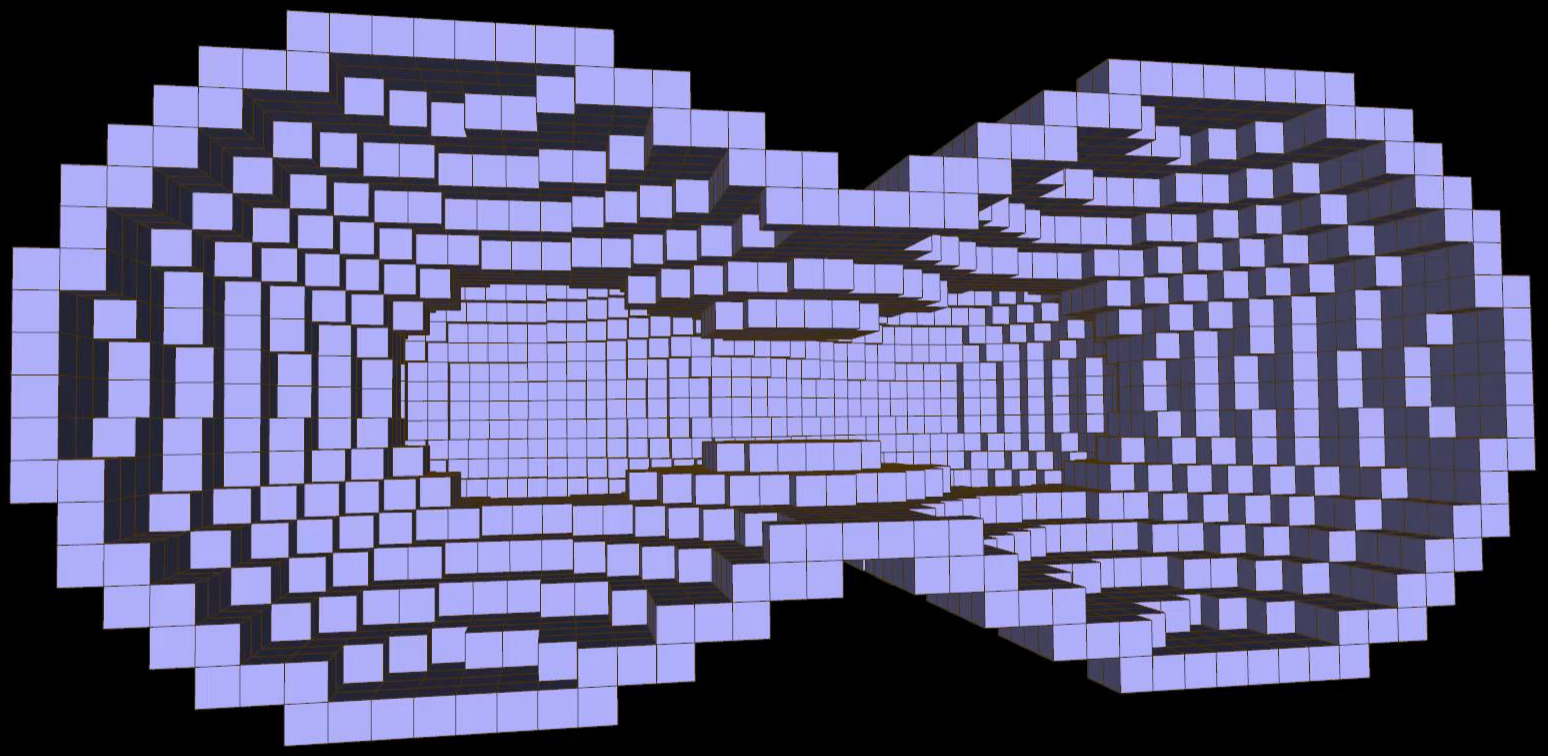
Adding voxels

- Greedy voxel-filling strategy
  - Layer by layer
  - From top to bottom

upside down prismatic shape



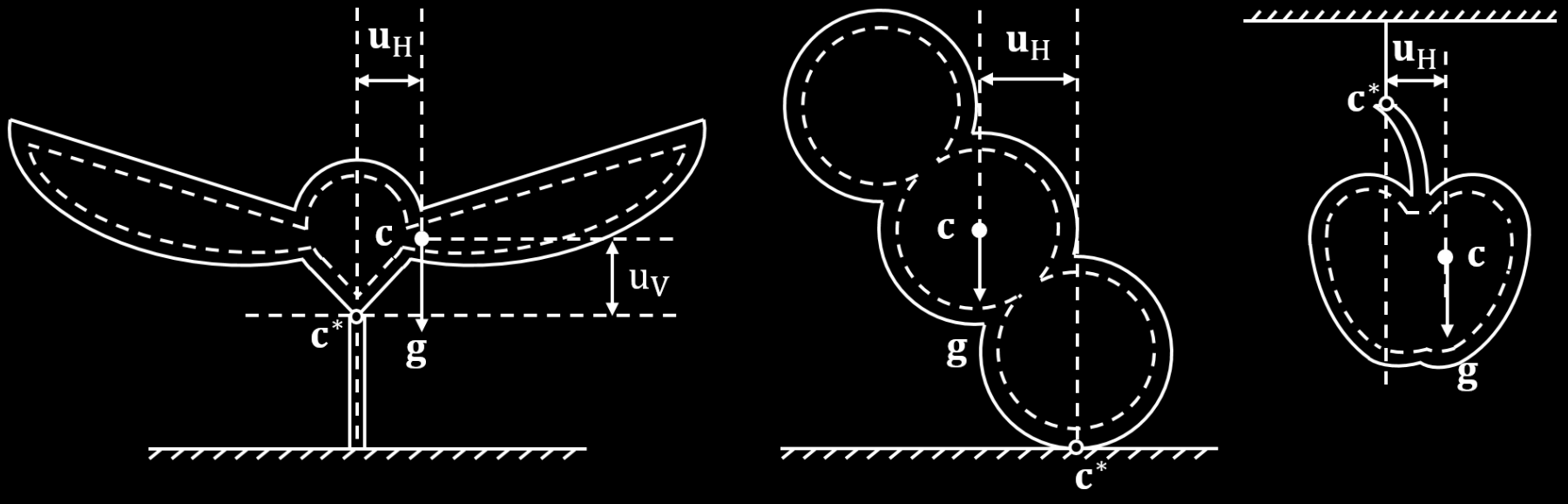
Interior support-free structure generation



Applications

Balanced object design

- Three modes of balancing



Standing on a pivot point Standing on the plane Suspended

Problem formulation

$$\min_{\mathcal{M}_O, \mathcal{M}_I} \|\mathbf{u}_{\mathrm{H}}(\mathcal{M}_O, \mathcal{M}_I)\|^2 + \alpha E_d(\mathcal{M}_O) + \beta E_s(\mathcal{M}_O, \mathcal{M}_I)$$

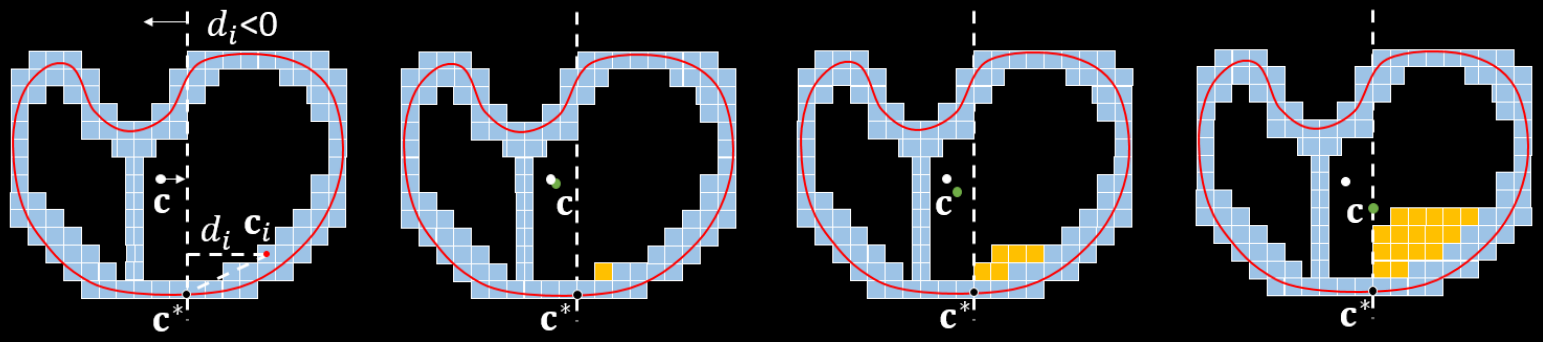
Does it balance?

Does it look like the initial shape?

Penalize the negative $\mathrm{u_V}$ for the first mode of balancing.

Optimization method

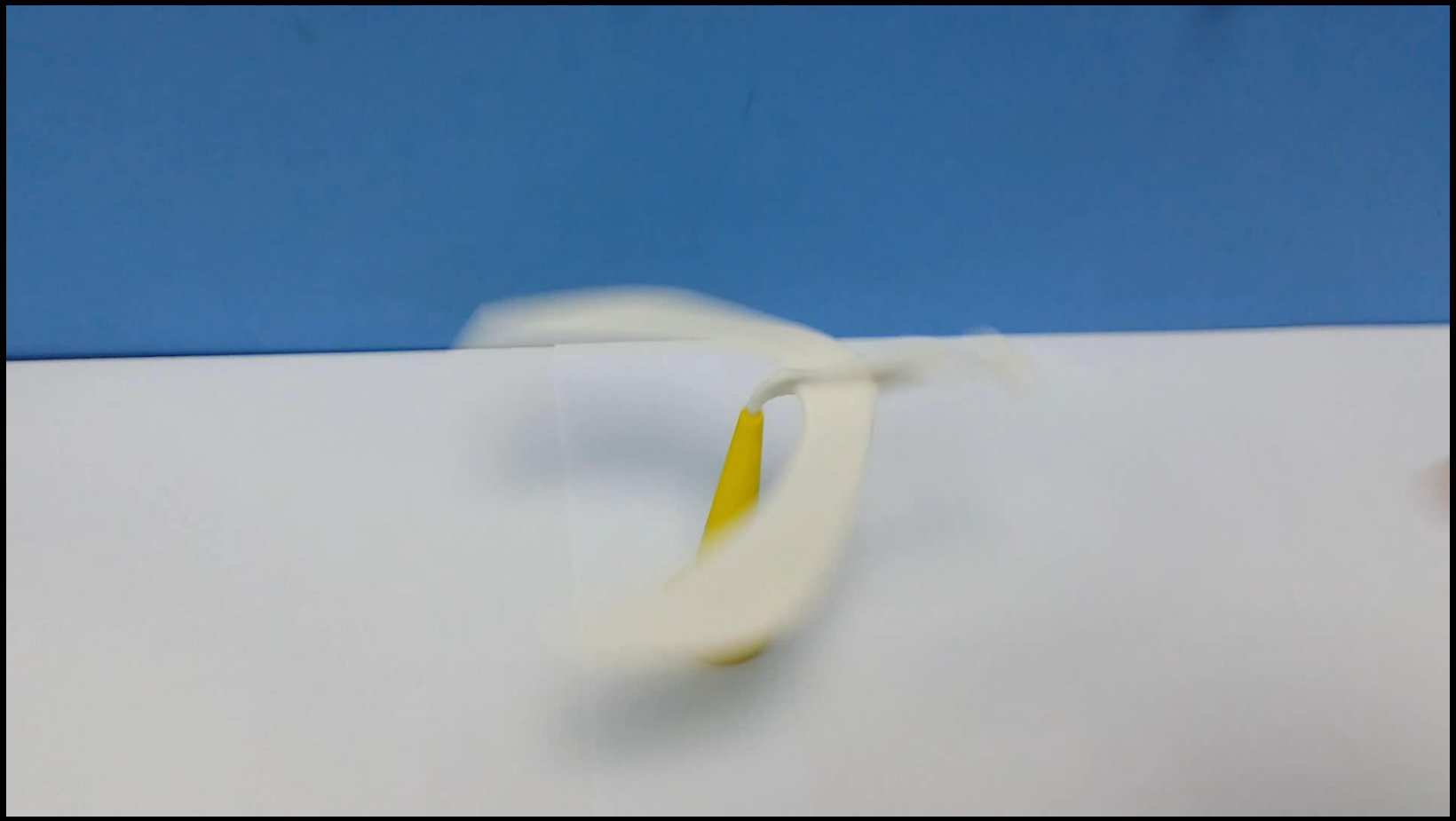
- Voxel filling



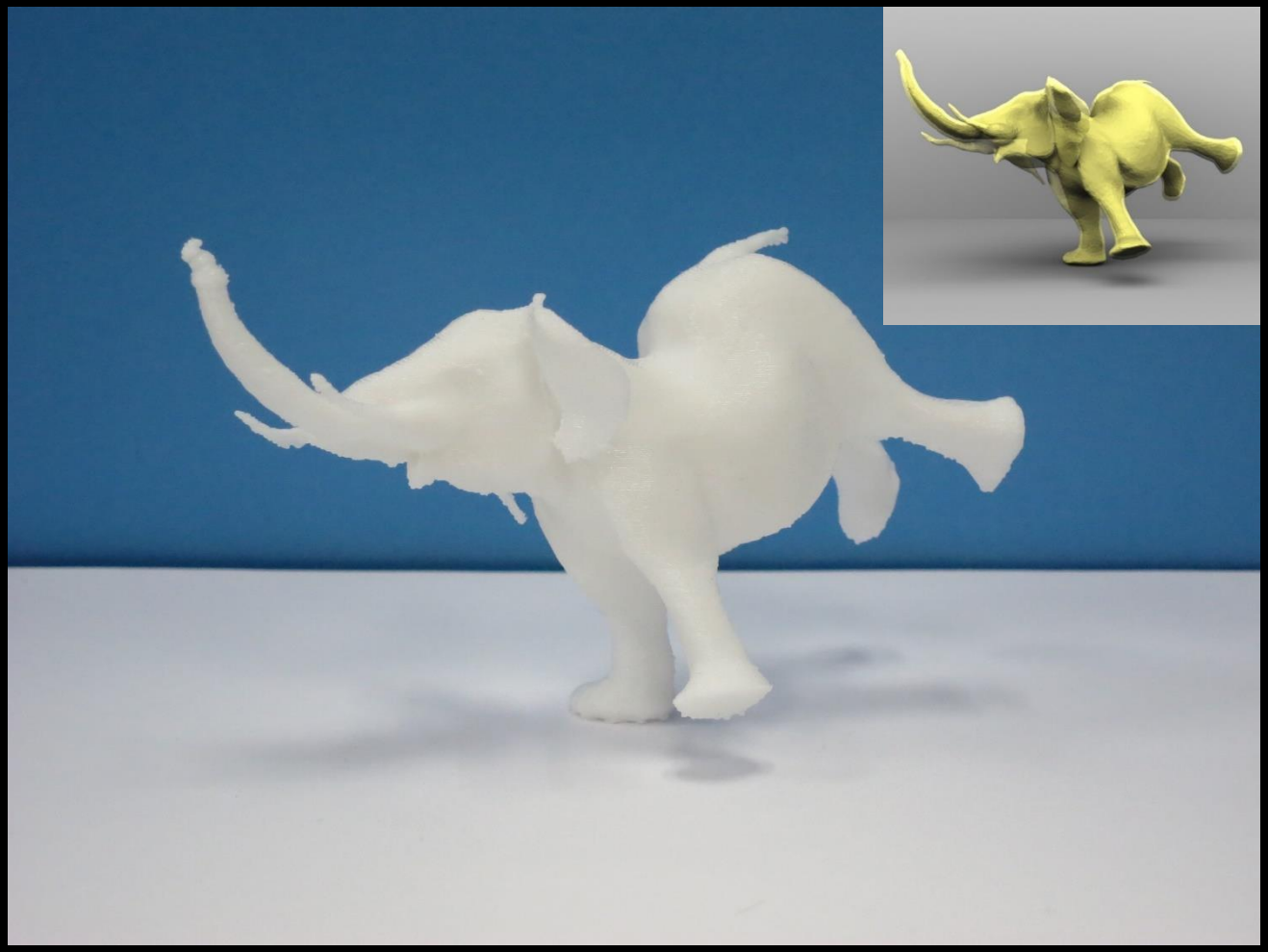
- Model deformation [Prévost et al. 2013]
- Extra weights

Results

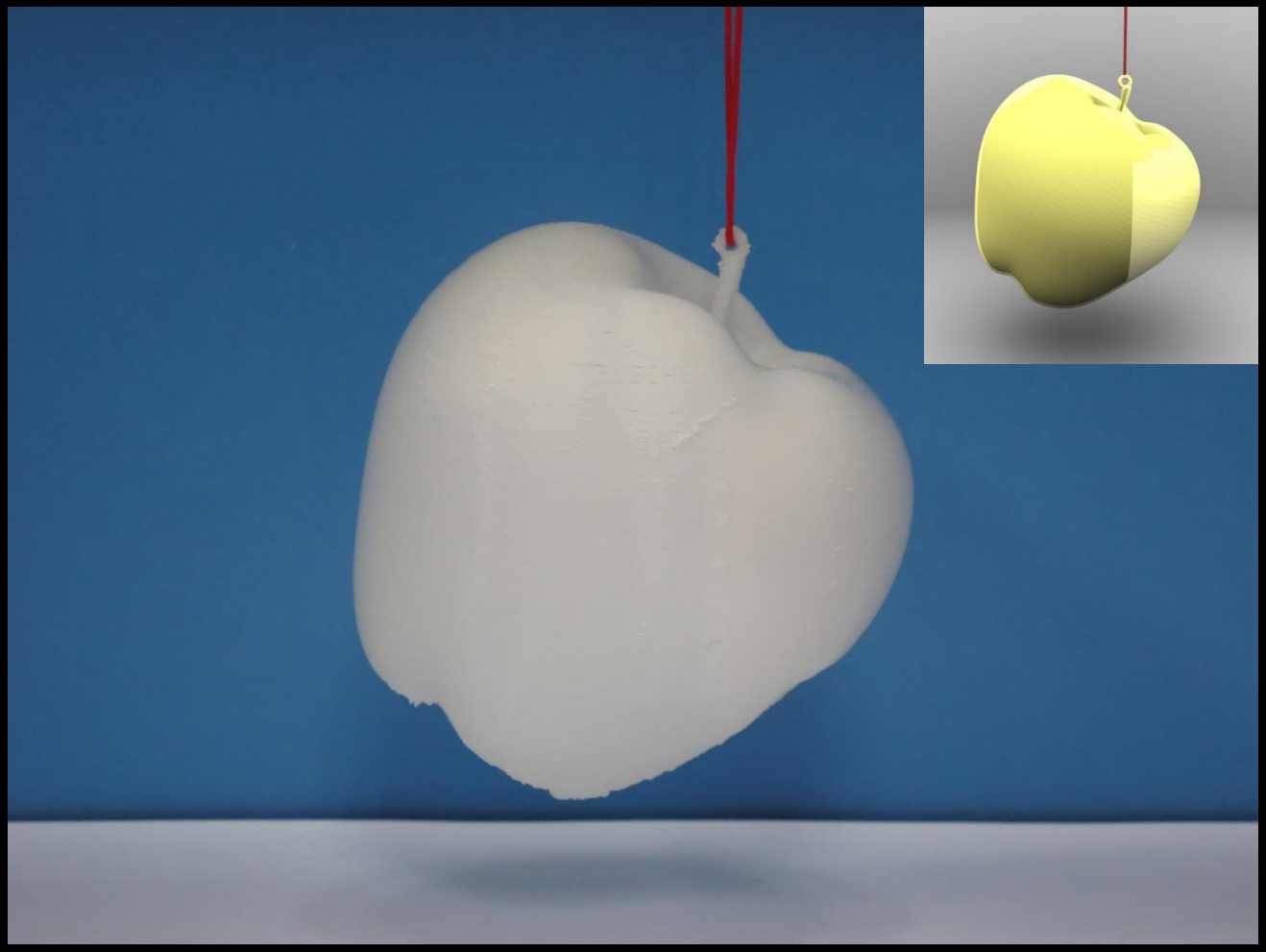
Balancing bird standing on a pivot



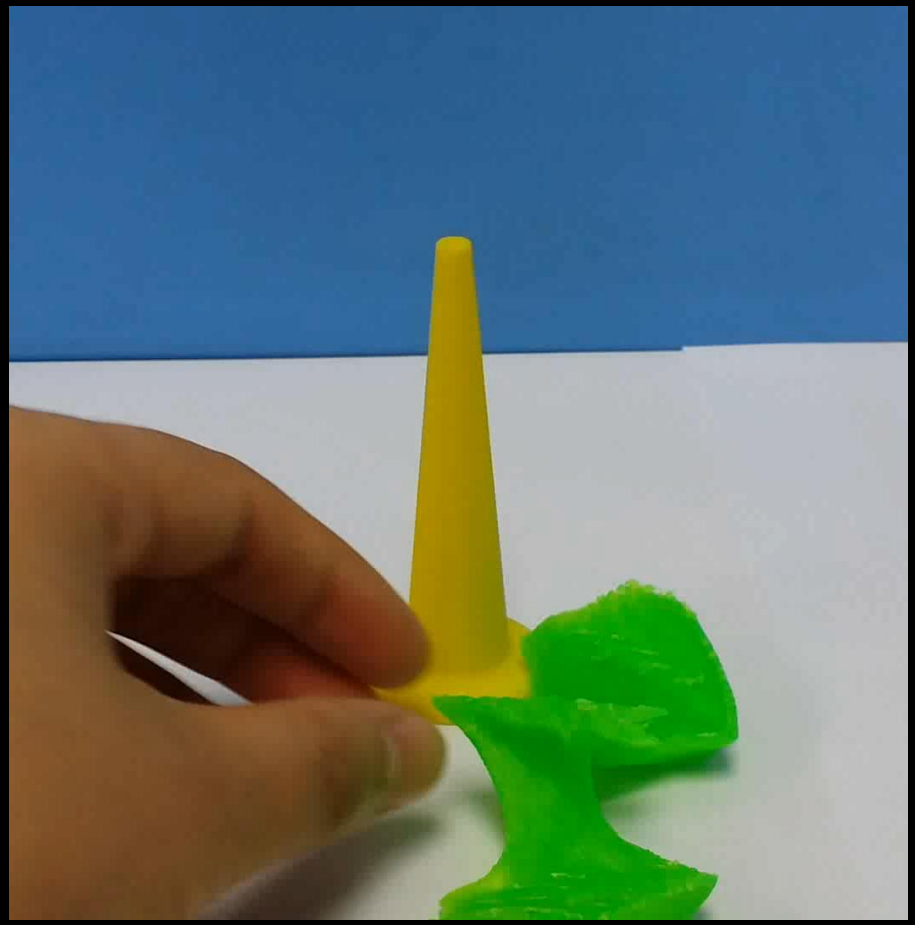
Balancing elephant standing on the plane



Suspended balancing apple

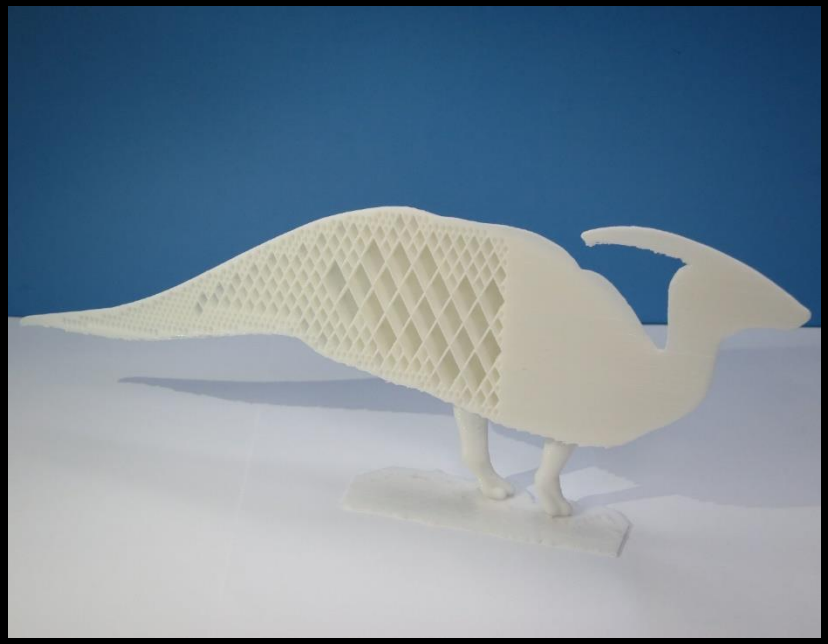


Balancing bat with extra weights



Comparison with [Wu et al. 2016]

Rhombic structure
[Wu et al. 2016]



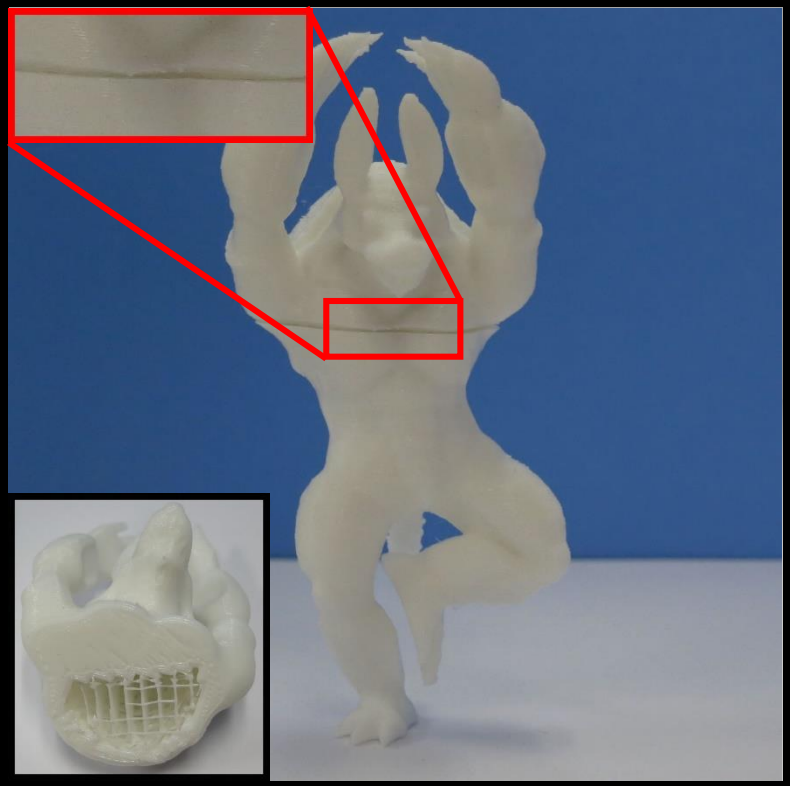
Volume: 1.011×10^5 mm^3

Ours

Volume: 0.335×10^5 mm^3

Comparison with [Prévost et al. 2013]

Make It Stand
[Prévost et al. 2013]



Ours

Conclusion

- We propose a novel hollow-to-fill strategy to compute interior support-free structures for 3D printing.

- Limitation and future work
  - Limited by the voxel representation
  - Stress analysis
  - Bijective volumetric deformation

Thank you!