



# Project

翟晓雅

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本课件仅用于中科大教学目的，禁止在网络上传播分享！

# Project background



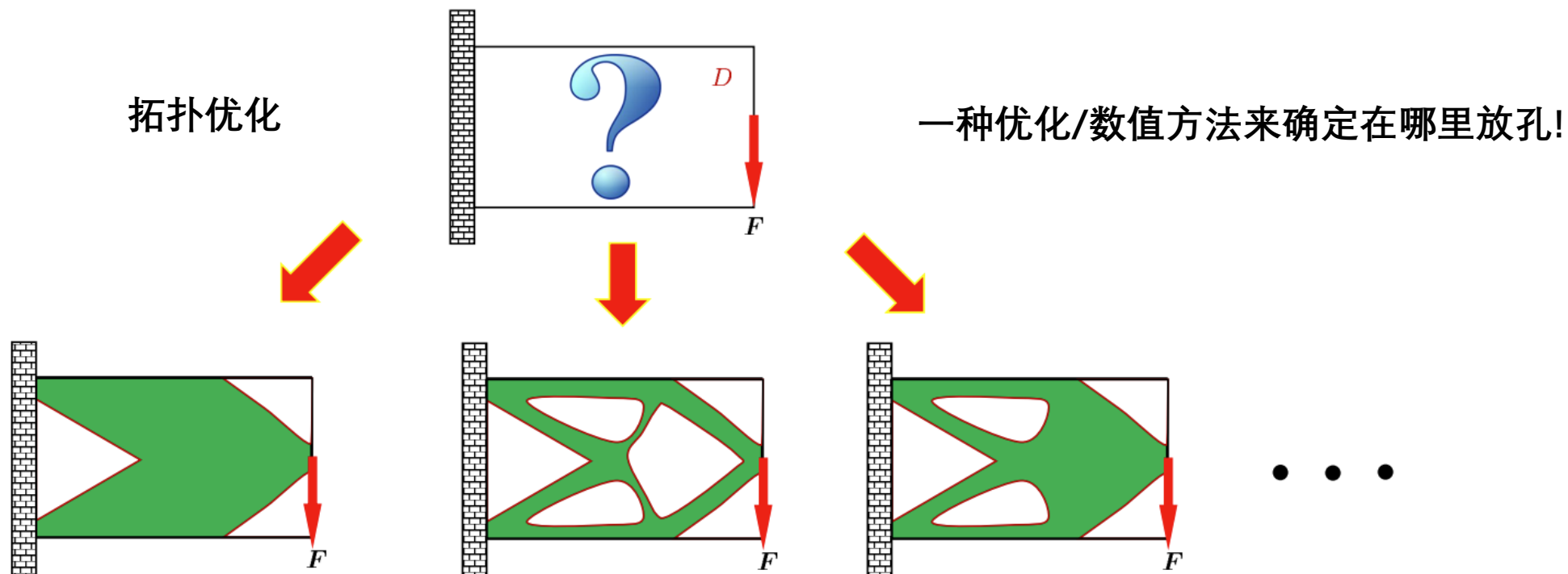
**"The art of structure is where to put the holes"**

**Robert Le Ricolais**

French/American Engineer and Philosopher

# Project background

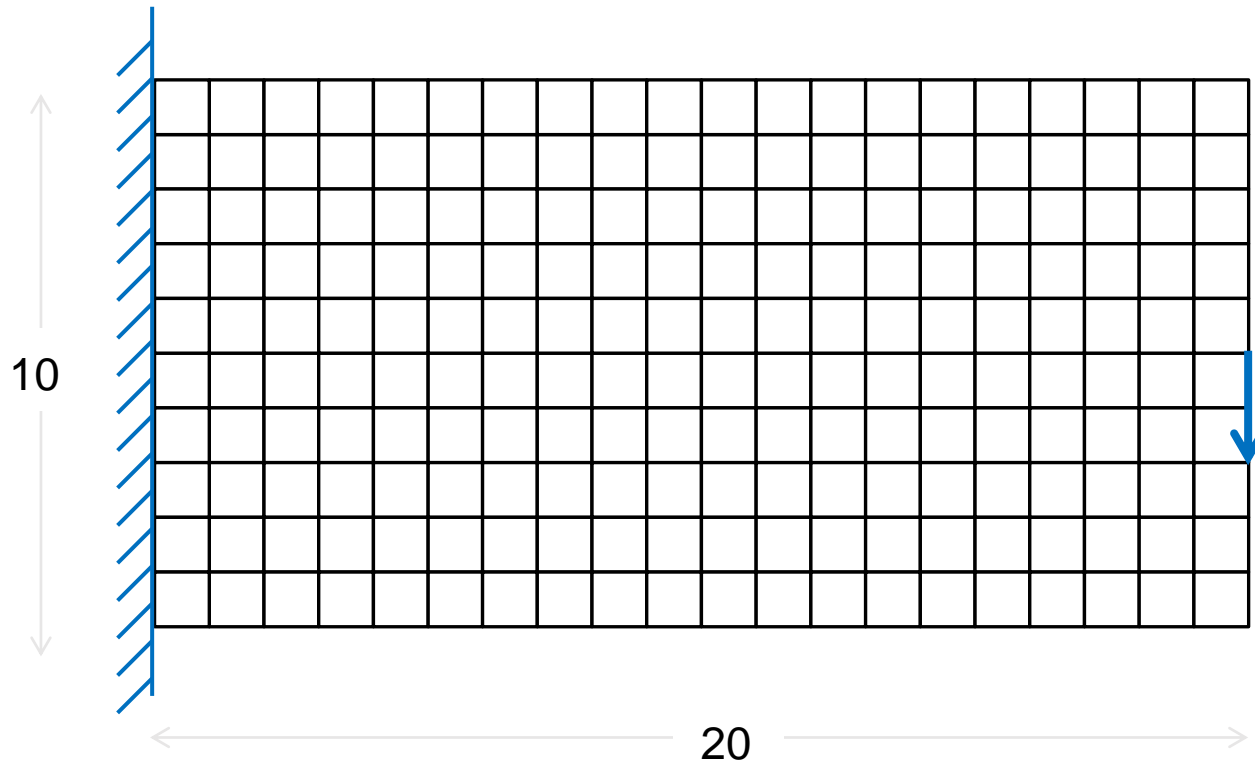
如何设计一种既能减轻重量又能保持刚度的结构？



在设计领域寻求材料的最佳分配!

# Project background

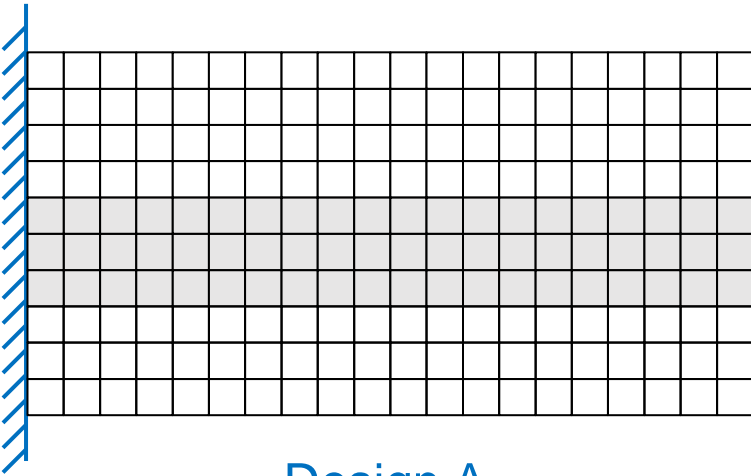
设计最坚固的形状，将60个乐高积木放置在一个 $20 \times 10$ 的网格中



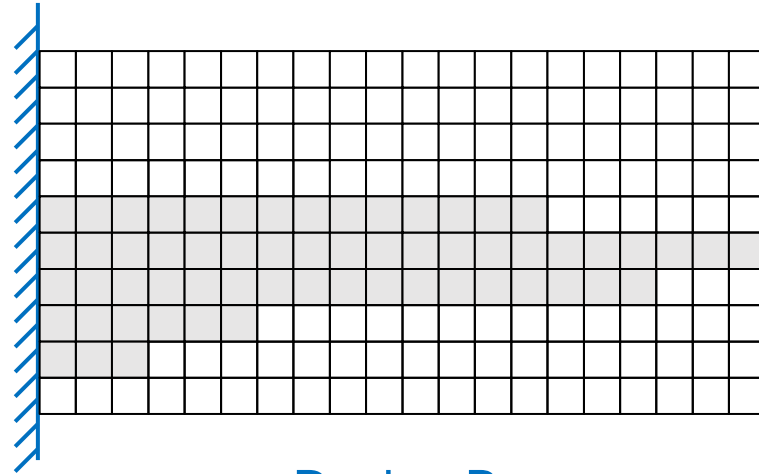


# Project background

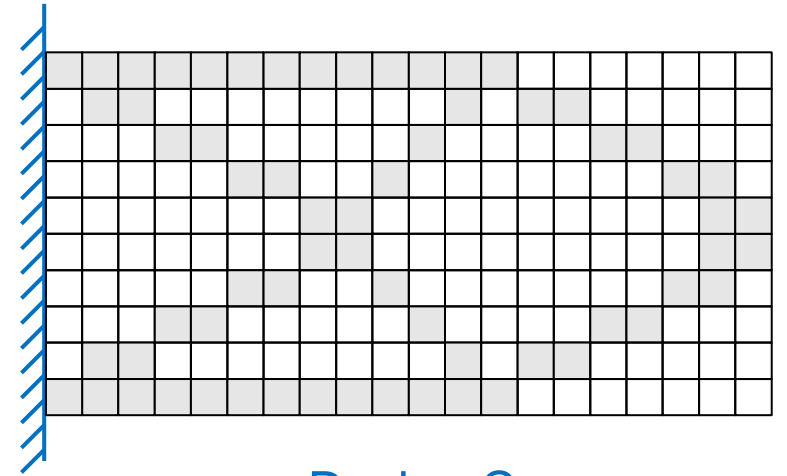
$$C(200,60) = \frac{200!}{60! (200 - 60)!} = 7.04 \times 10^{51}$$



Design A



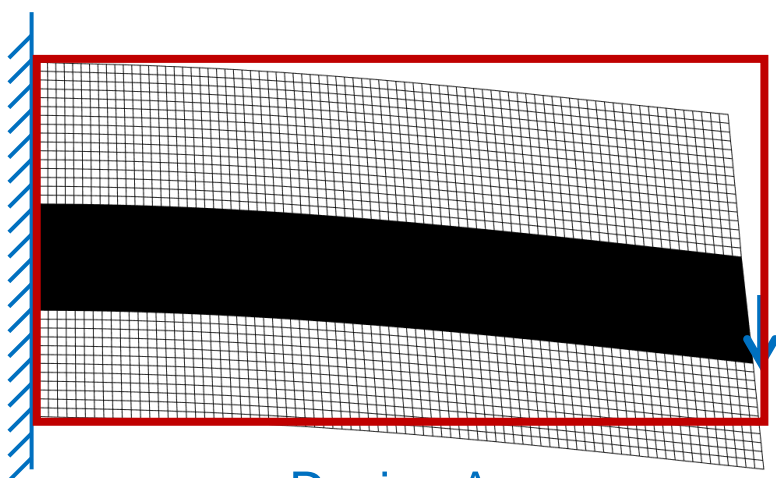
Design B



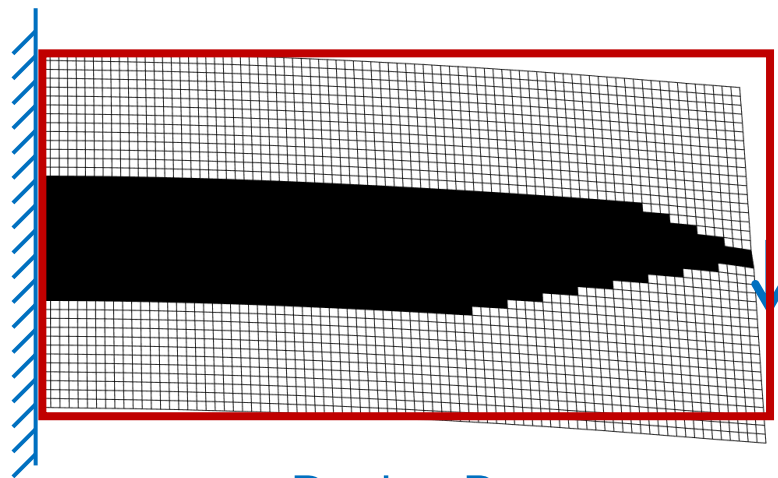
Design C

# Project background

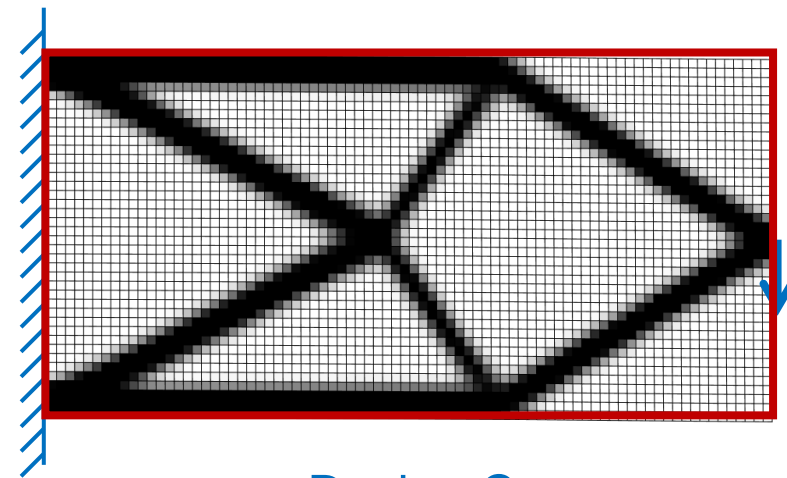
哪一个刚度最大？



Design A



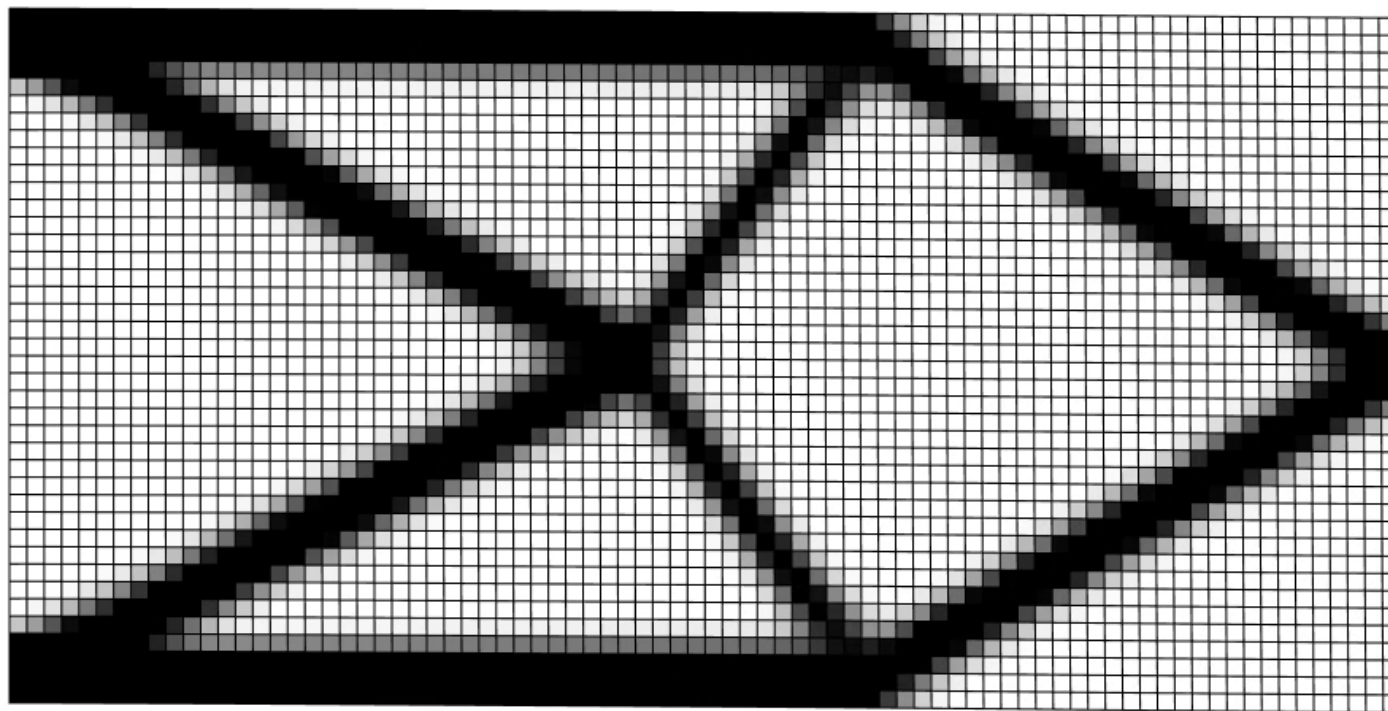
Design B



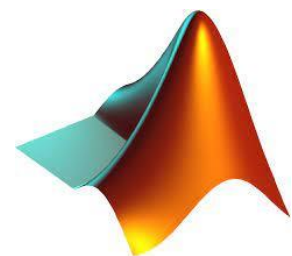
Design C

# Project background

哪一个刚度最大？



# Project background



MATLAB



实验过程

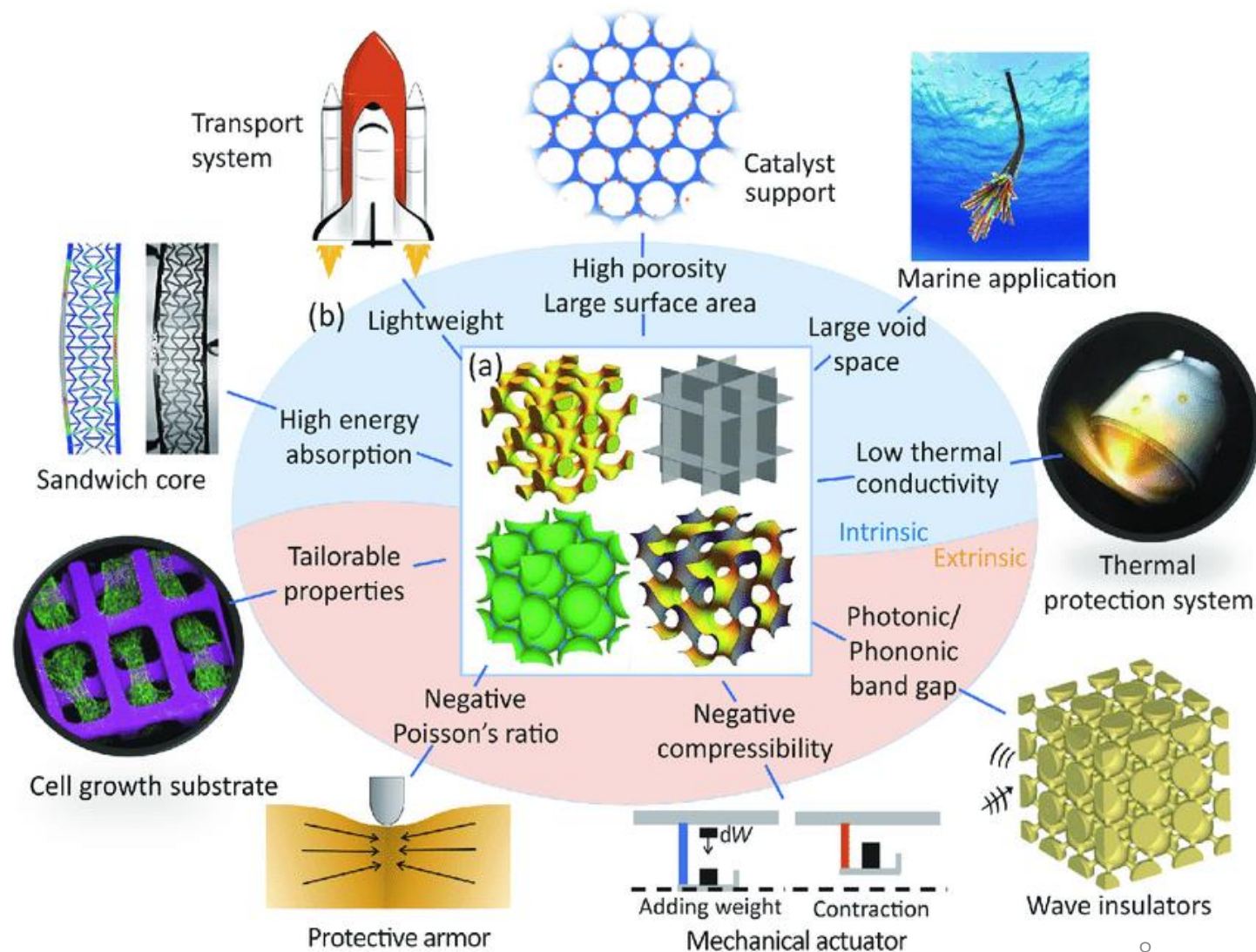
问题背景

基础工具

数值计算

几何表示与优化

制造测试应用





# MATLAB Project

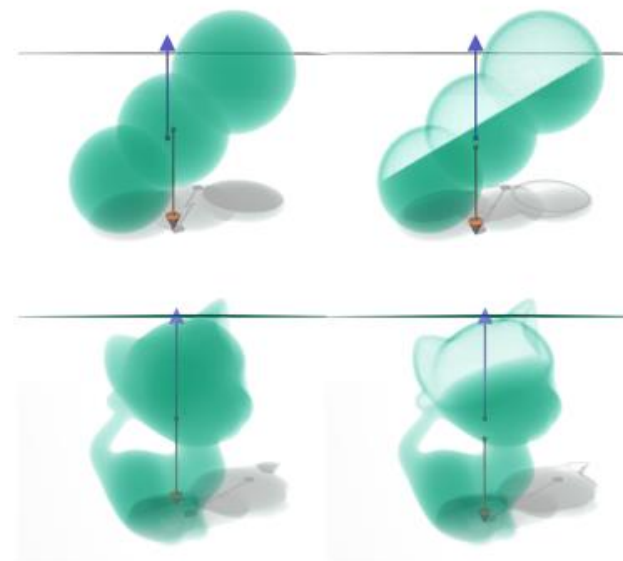
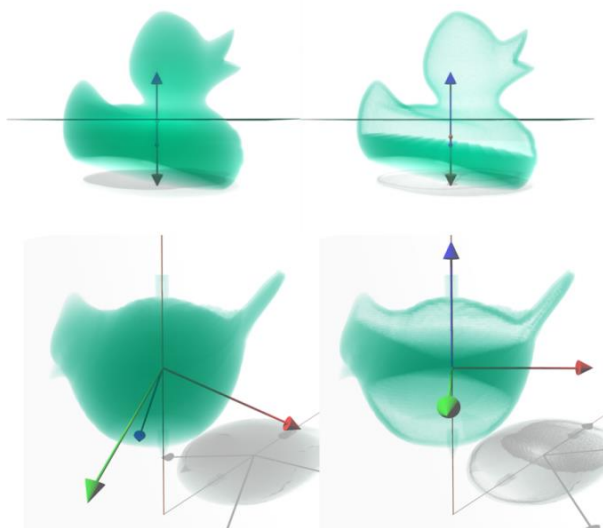
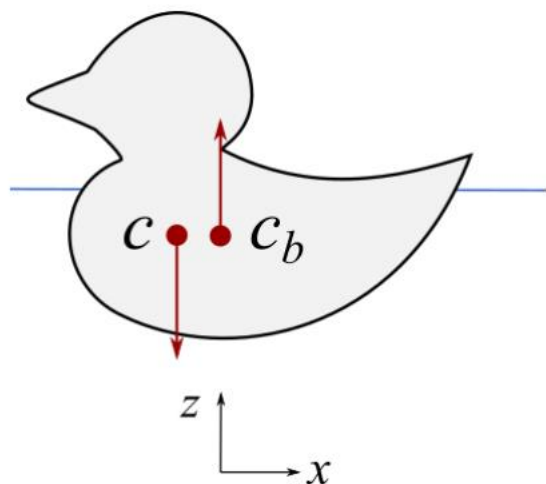
翟晓雅

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# Project 1-平衡问题

## 浮力平衡与旋转平衡问题



模型表示



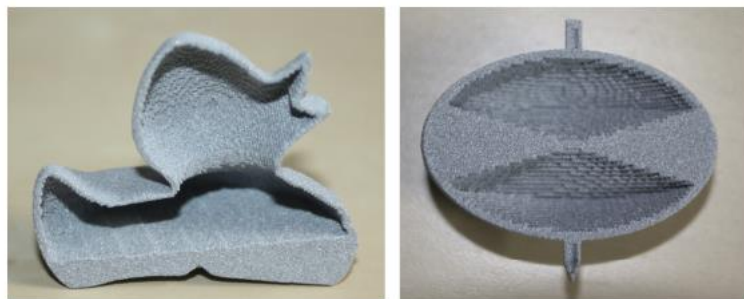
模型优化



模型输出



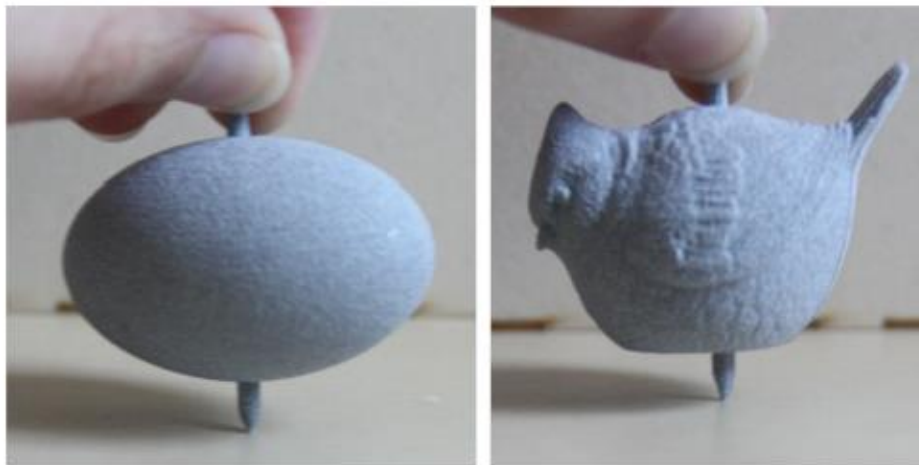
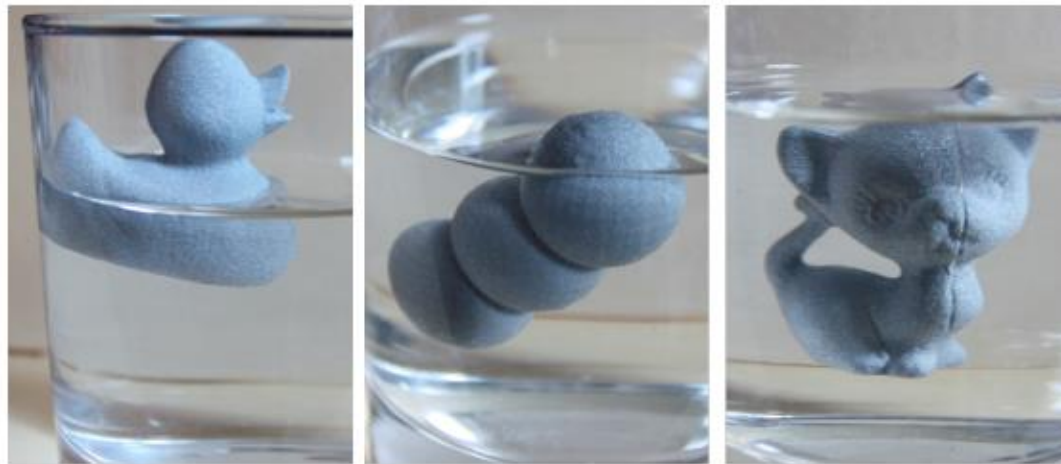
# Project 1-平衡问题



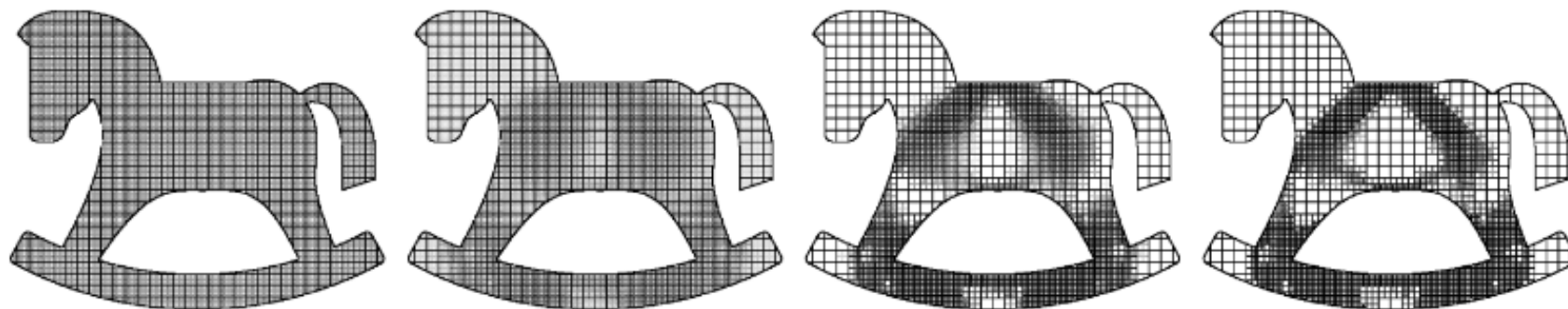
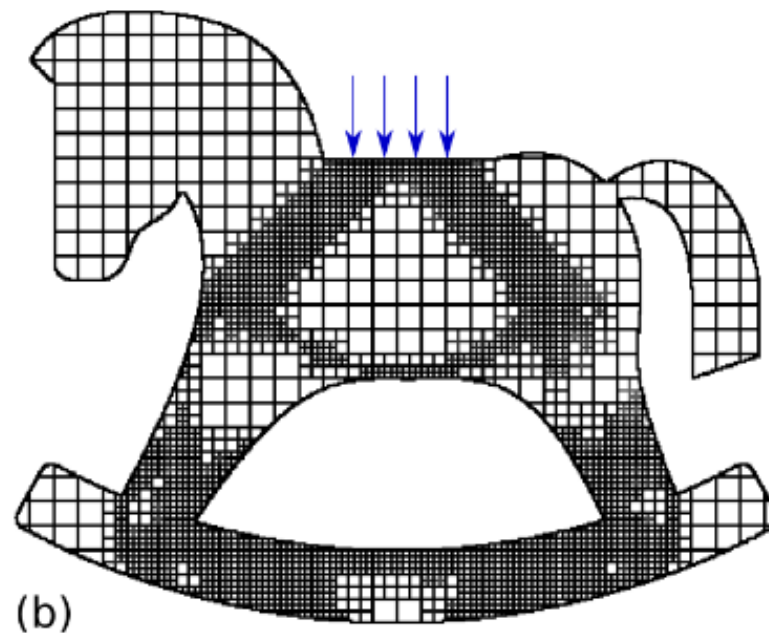
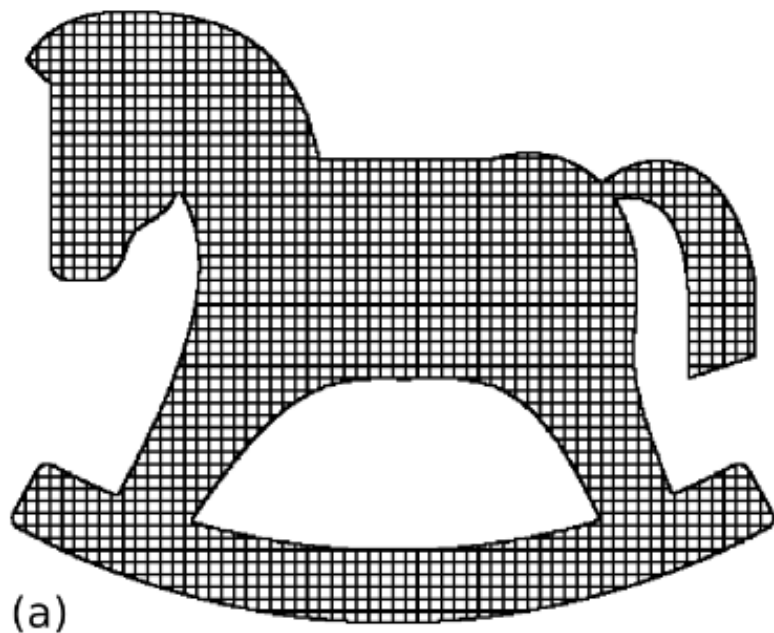
模型制造



模型测试

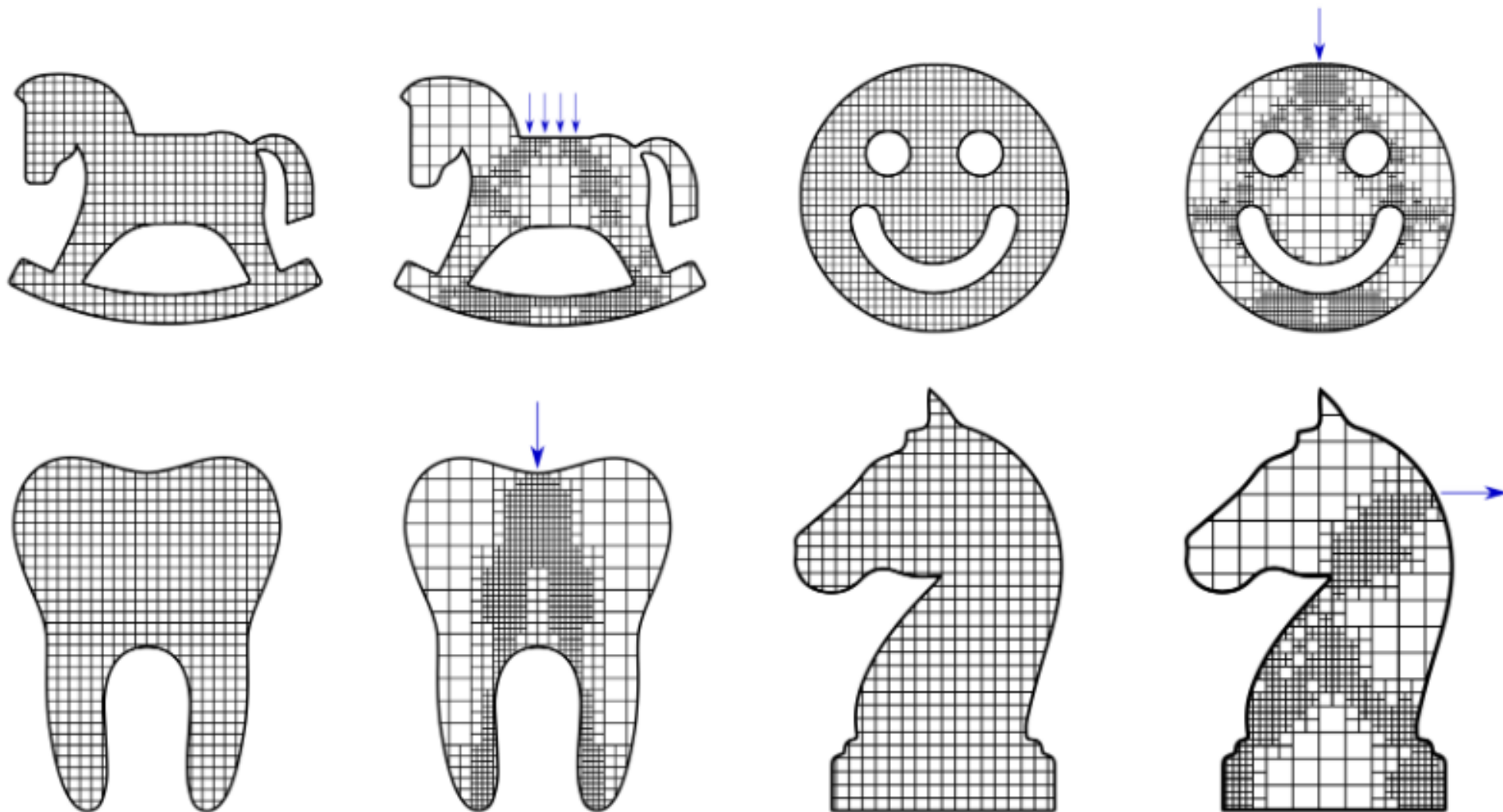


# Project2: 自适应四叉树结构

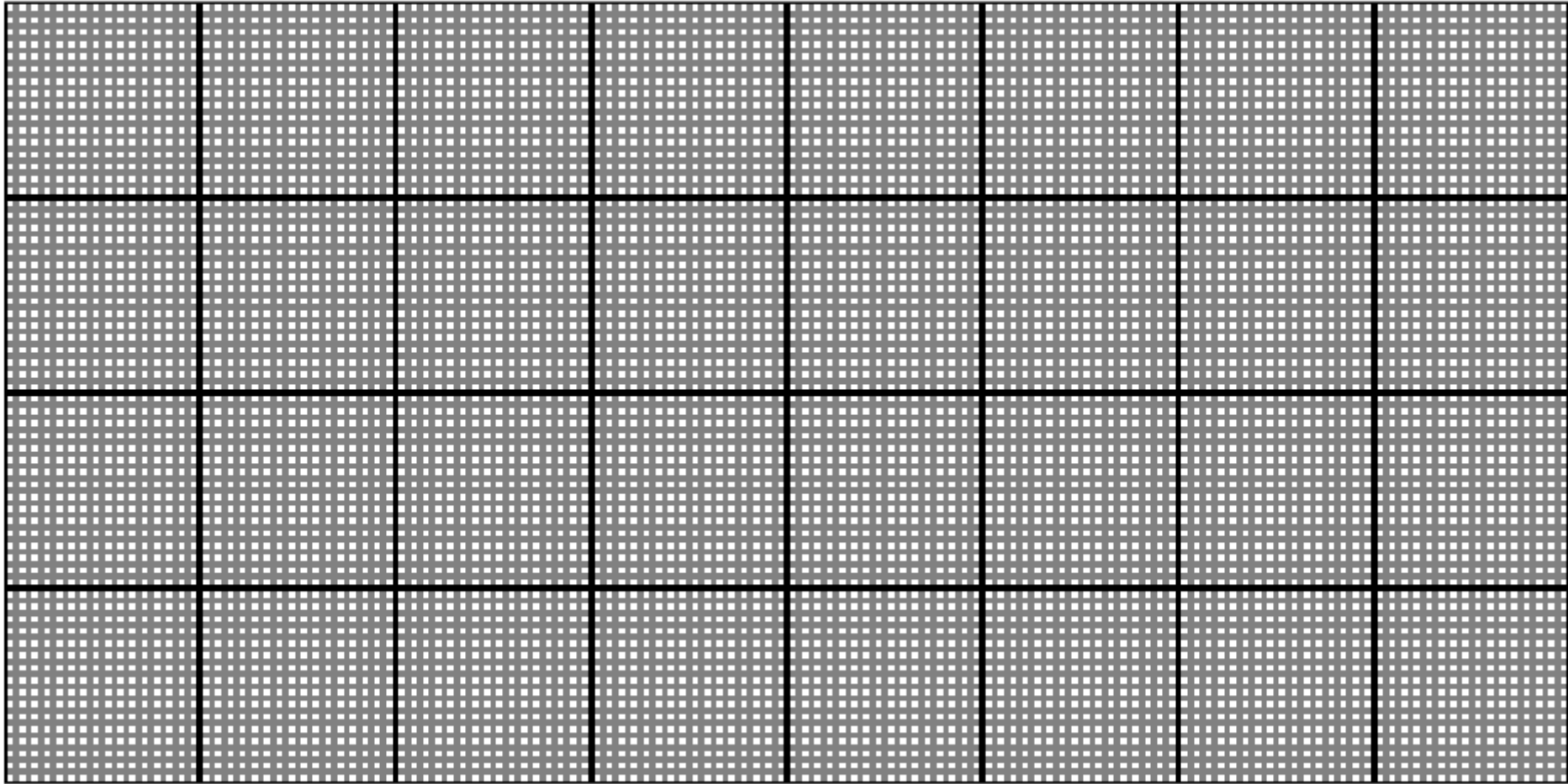




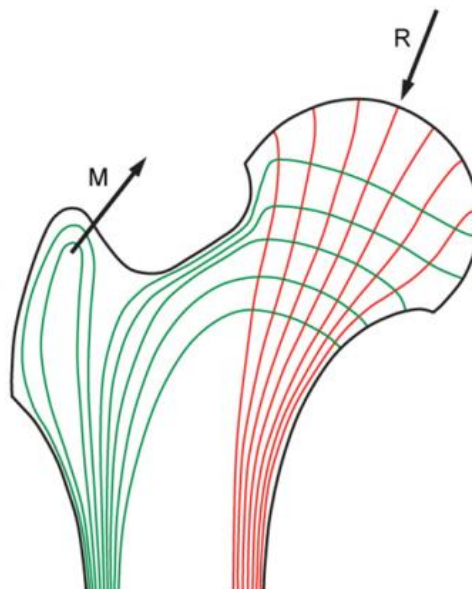
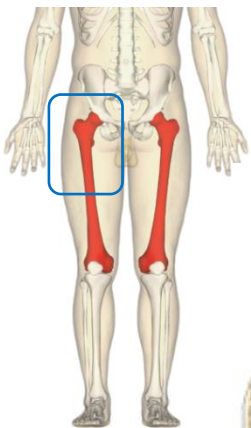
## Project2: 自适应四叉树结构



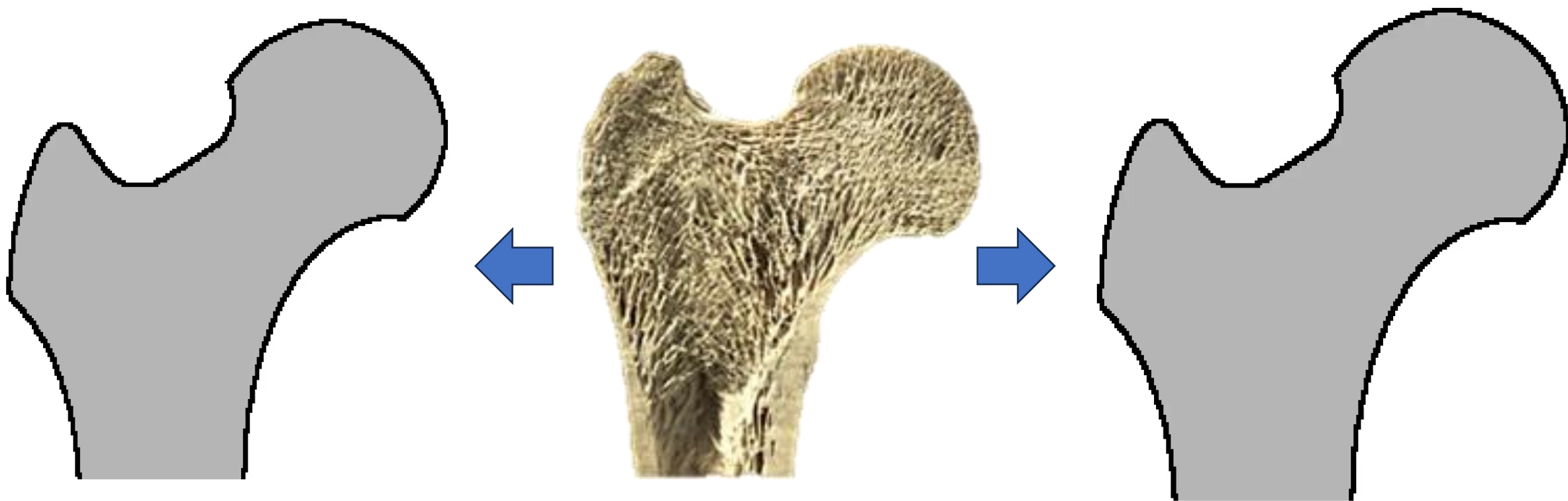
# Project2: 自适应四叉树结构



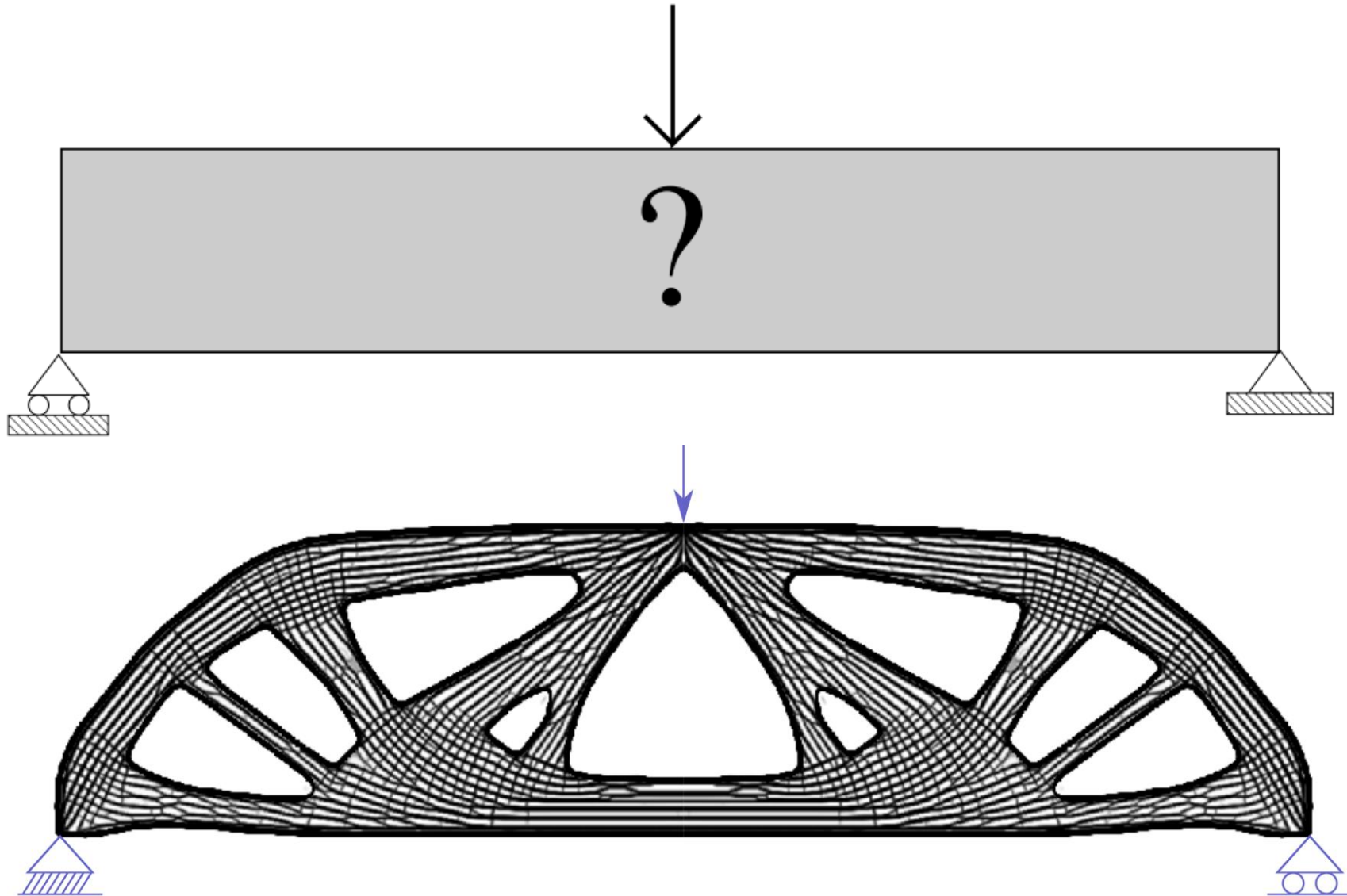
# Project3: 高分辨率骨状结构优化



# Project3: 高分辨率骨状结构优化

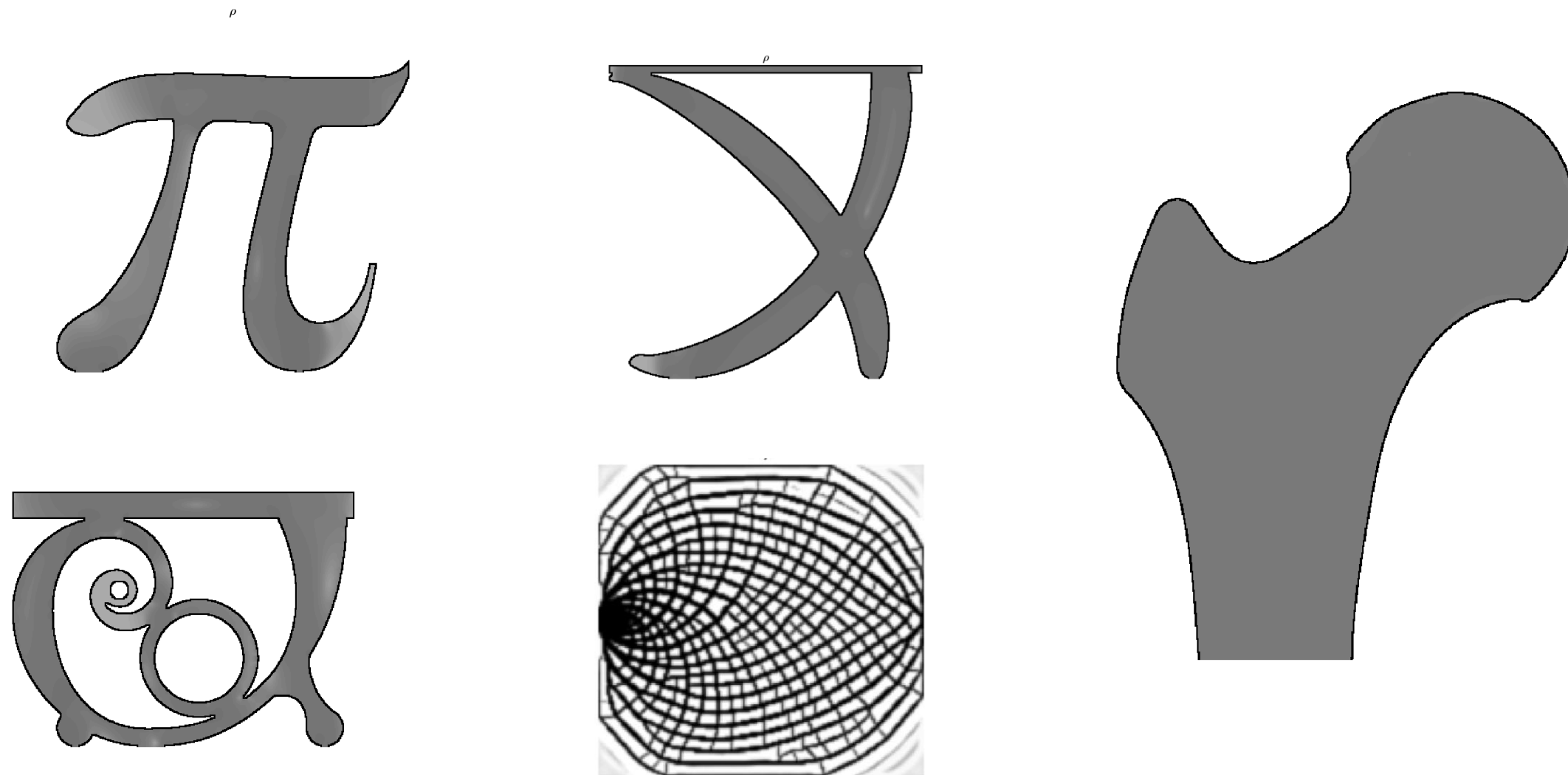


# Project3: 高分辨率骨状结构优化

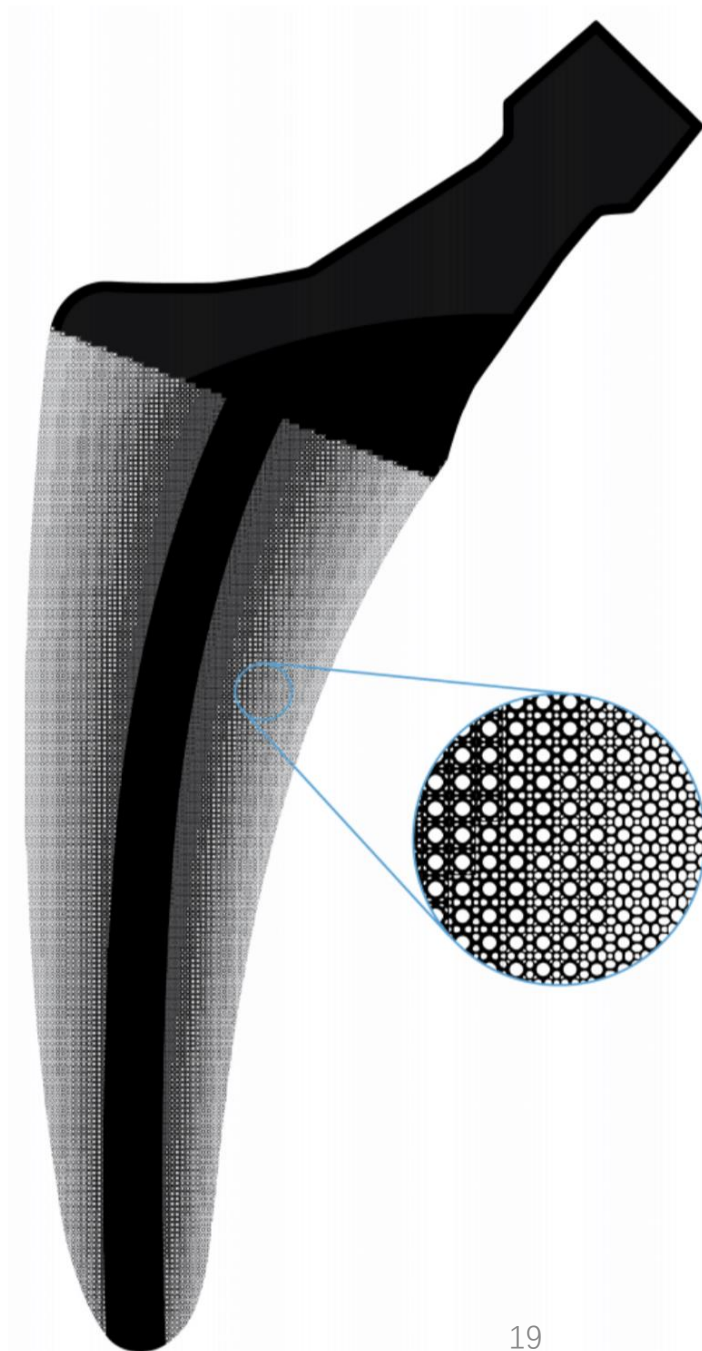
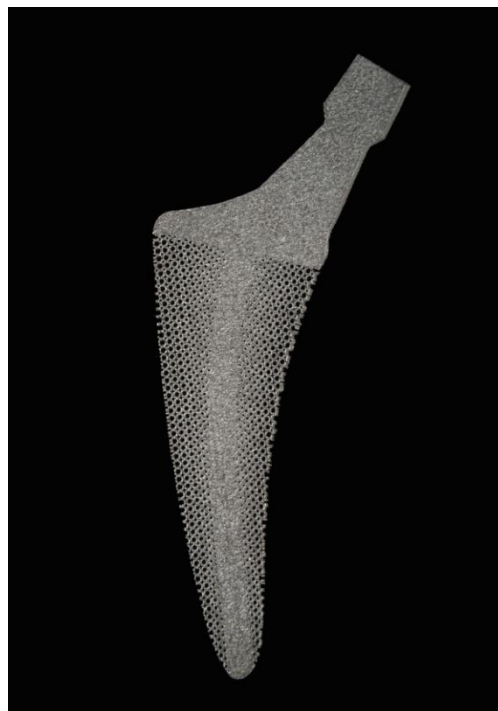
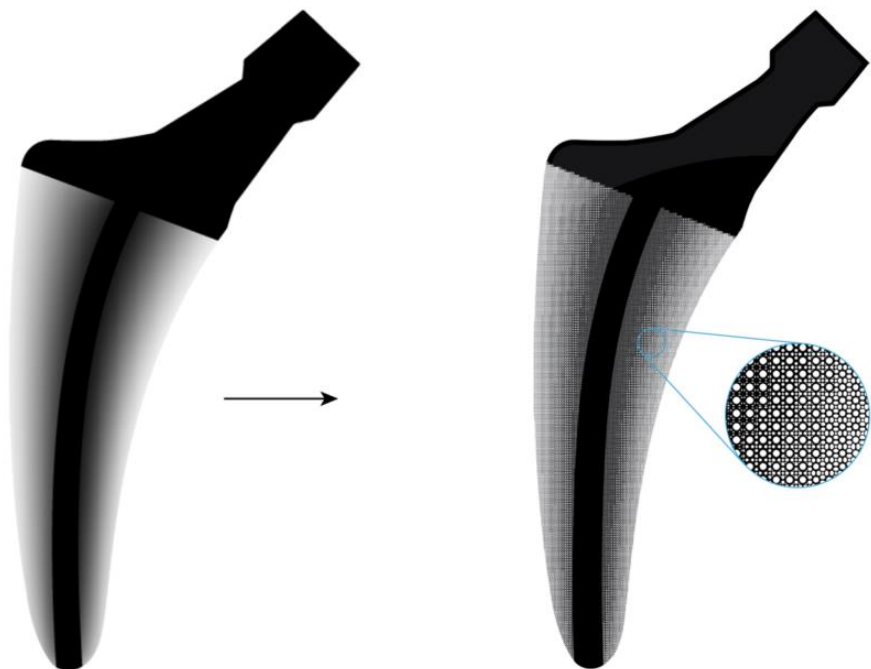




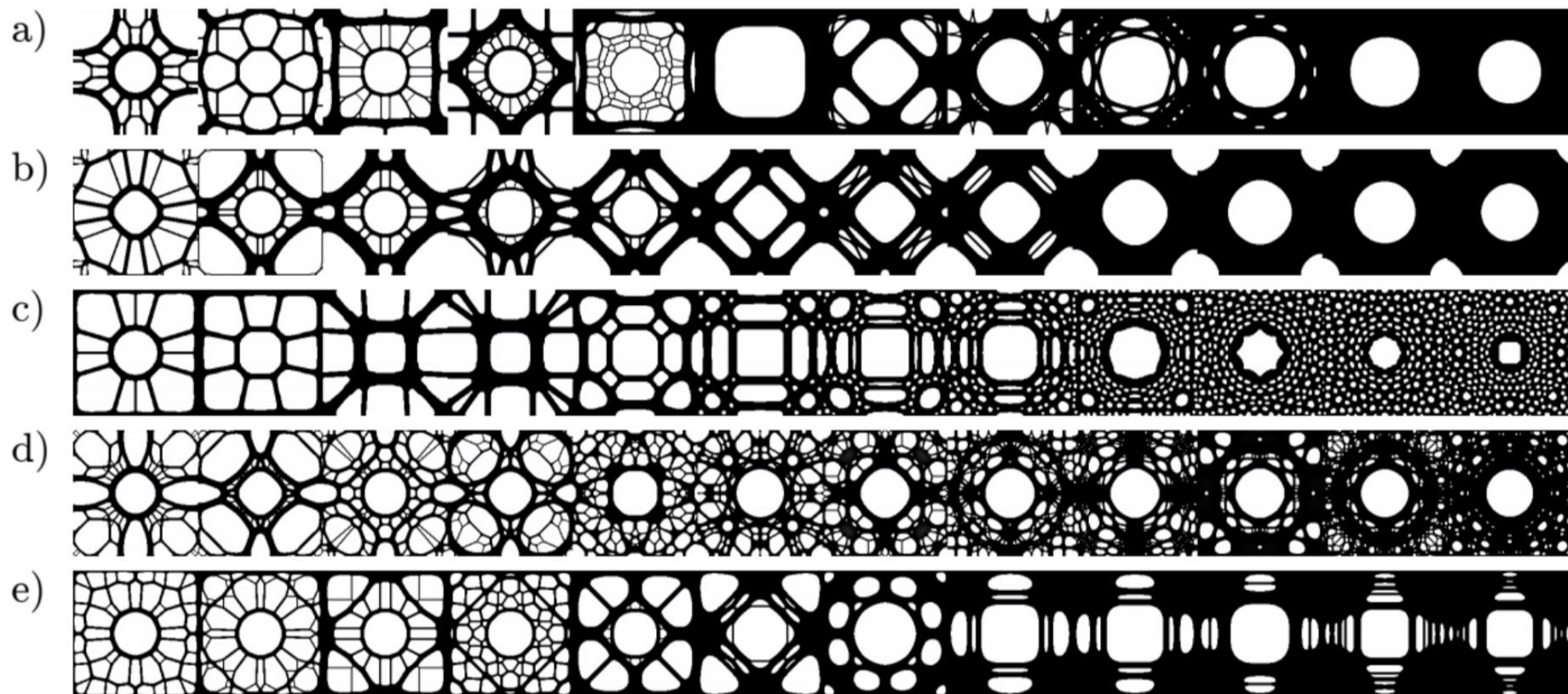
# Project3: 高分辨率骨状结构优化



# Project 4 - 微结构的拓扑优化

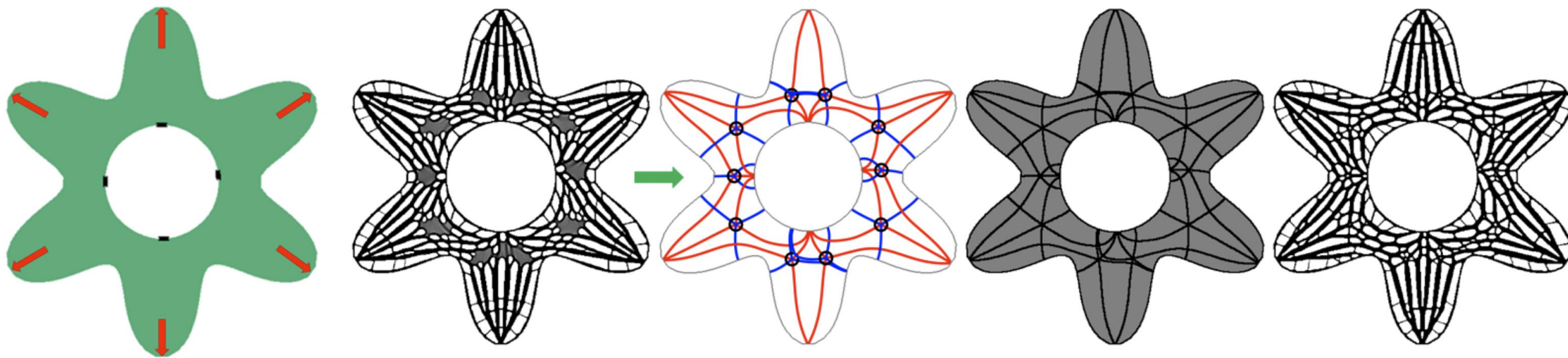


# Project 4 - 微结构的拓扑优化

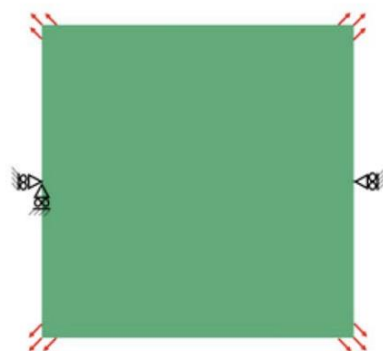




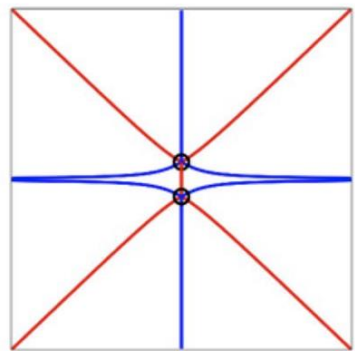
## Project 5: 应力流线的求解与绘制



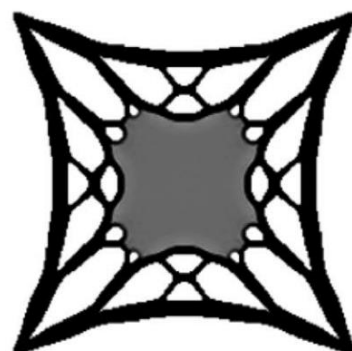
# Project 5: 应力流线的求解与绘制



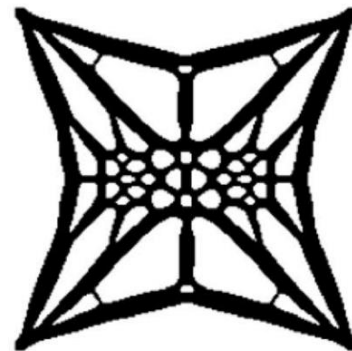
(a)



(b)



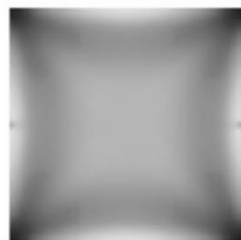
(c)  $c = 26.02, v = 0.400,$   
 $s = 1.4 \times 10^{-1}$



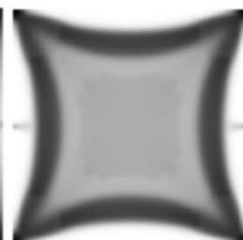
(d)  $c = 25.96, v = 0.378,$   
 $s = 1.5 \times 10^{-3}$



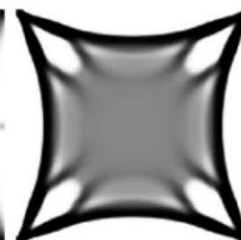
Initialization



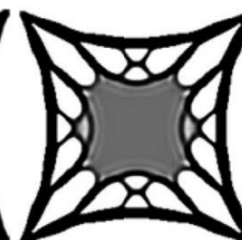
Iteration: 50



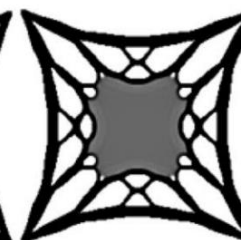
100



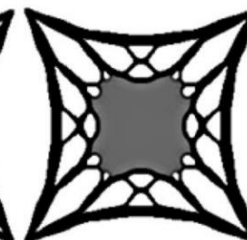
200



300

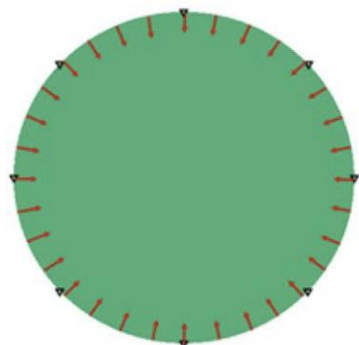


600

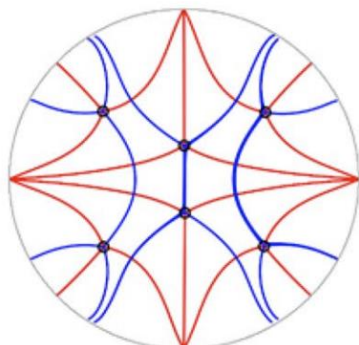


800

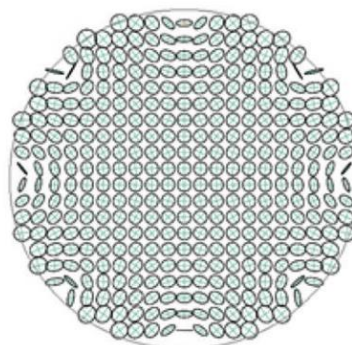
# Project 5: 应力流线的求解与绘制



(a)



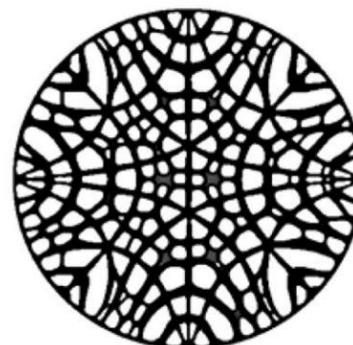
(b)



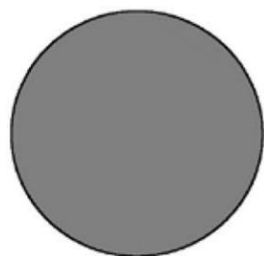
(c)



(d)  $c = 0.28, v = 0.580,$   
 $s = 6.2 \times 10^{-1}$



(e)  $c = 0.26, v = 0.545,$   
 $s = 1.0 \times 10^{-2}$



Initialization



Iteration: 50



100



200



300



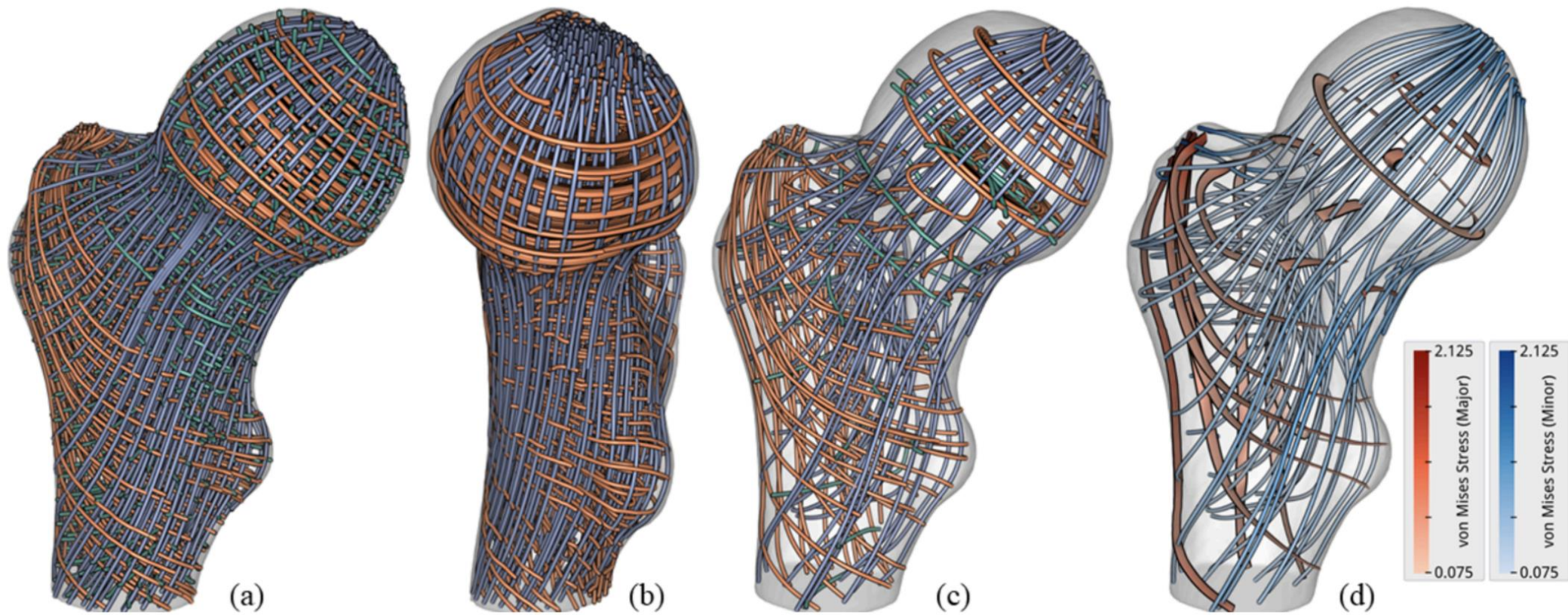
600



800

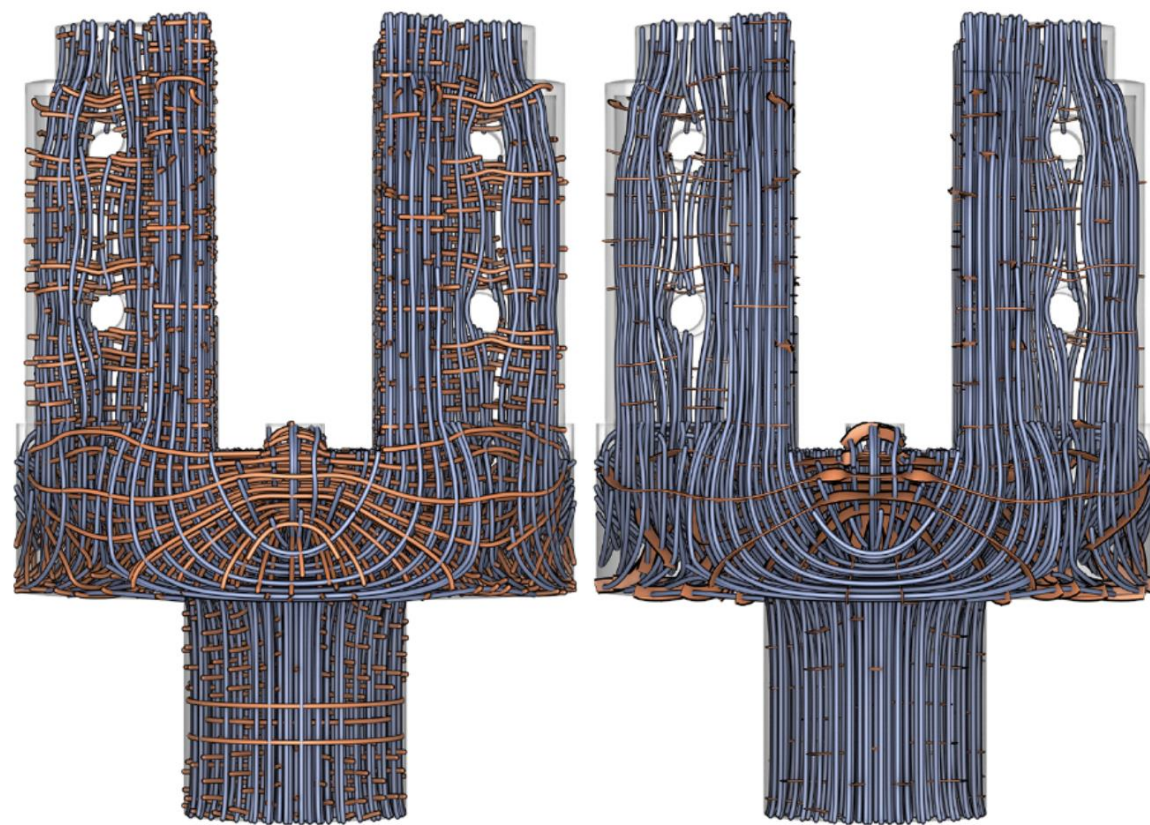
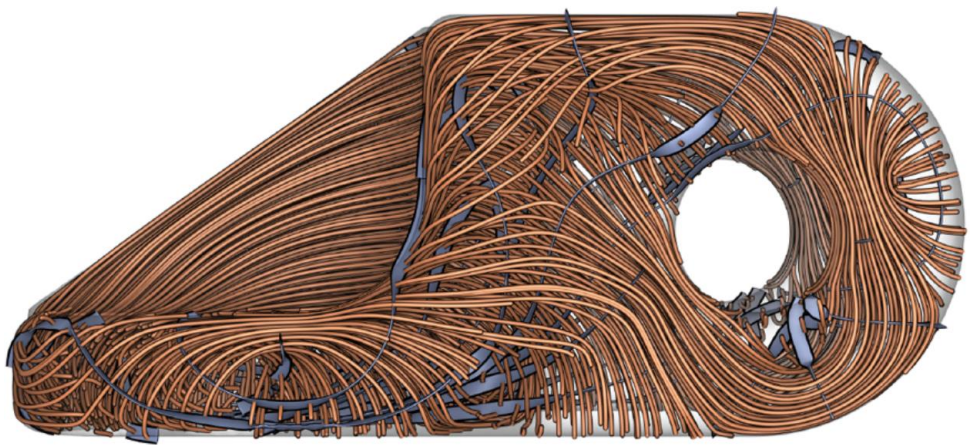
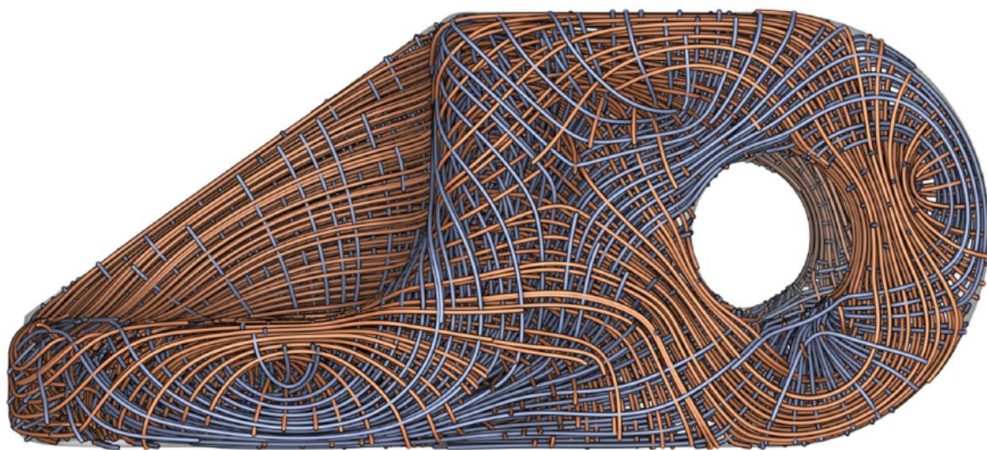
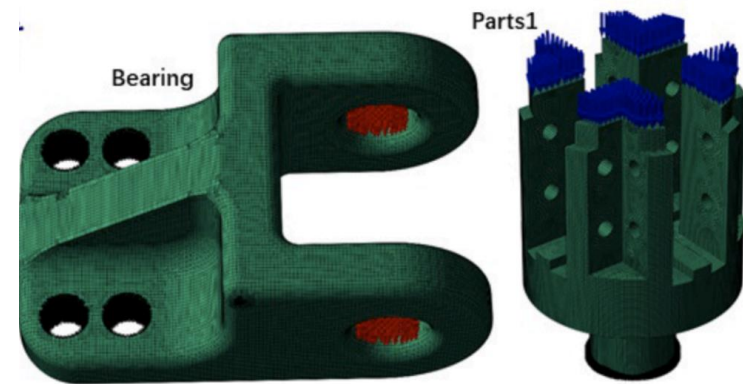


# Project 6: 应力流线的求解与绘制



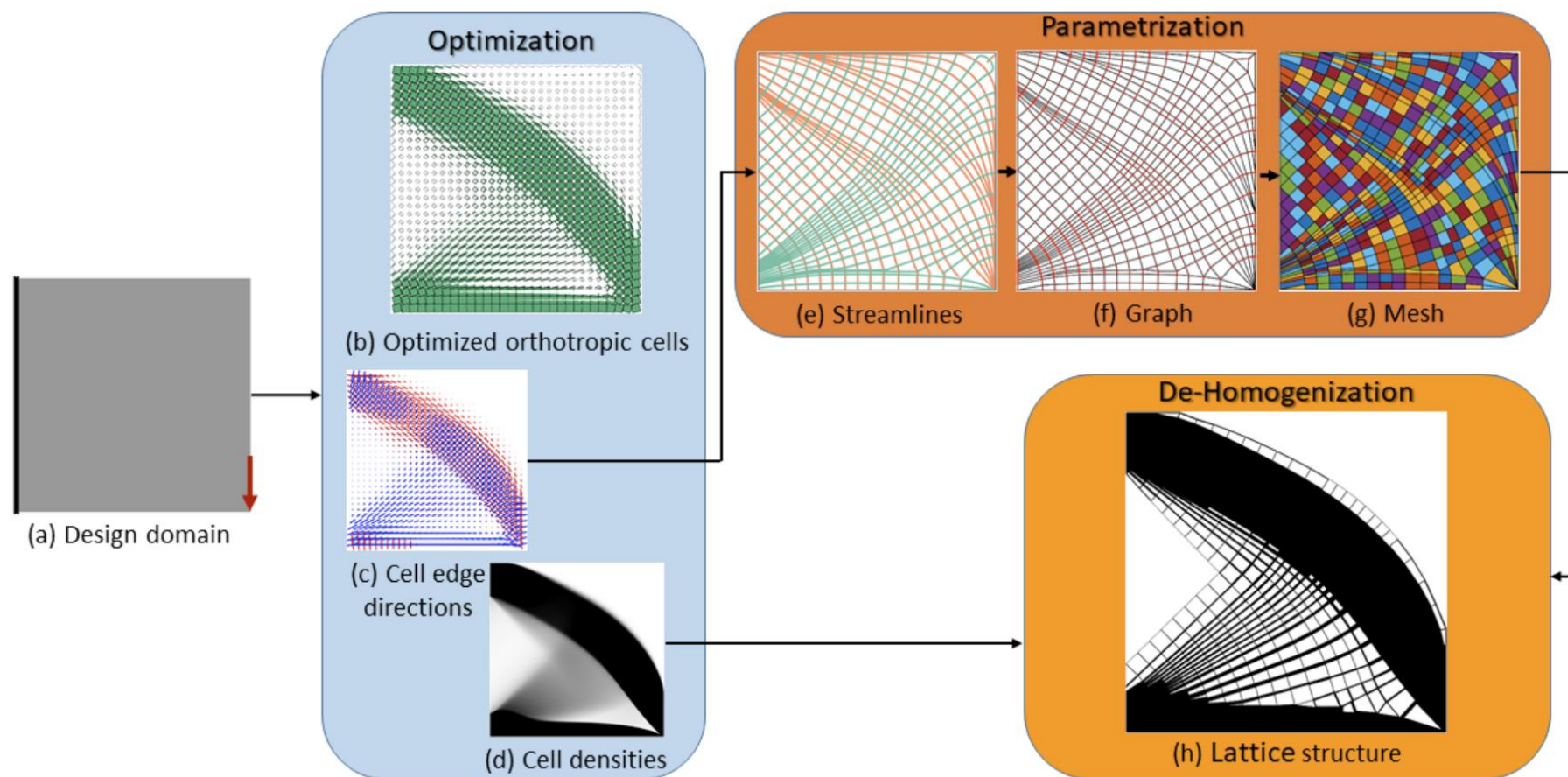


# Project 6: 应力流线的求解与绘制

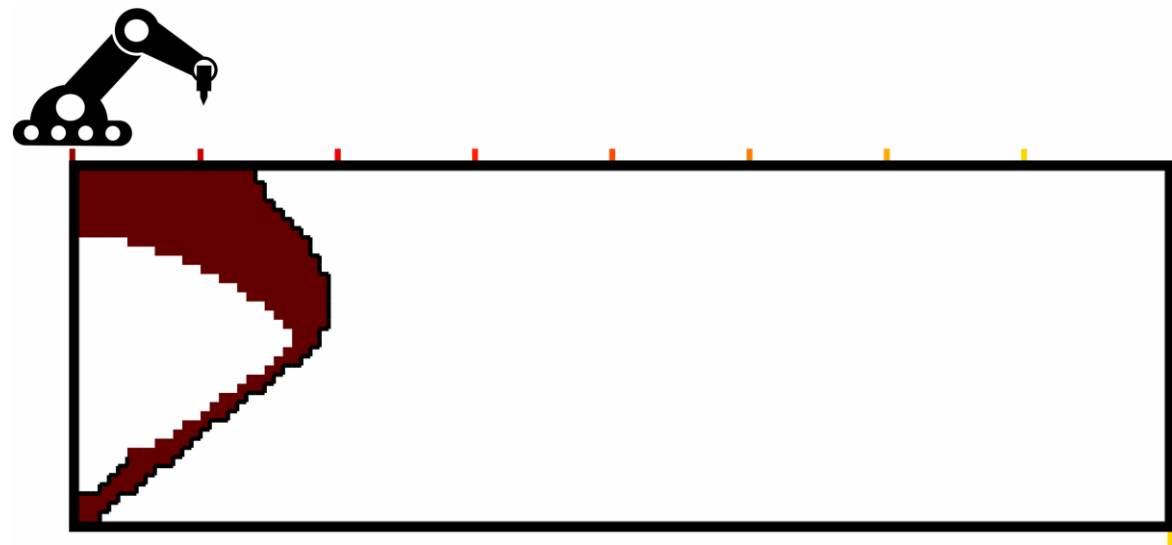




# Project 7: 应力线驱动的多孔设计

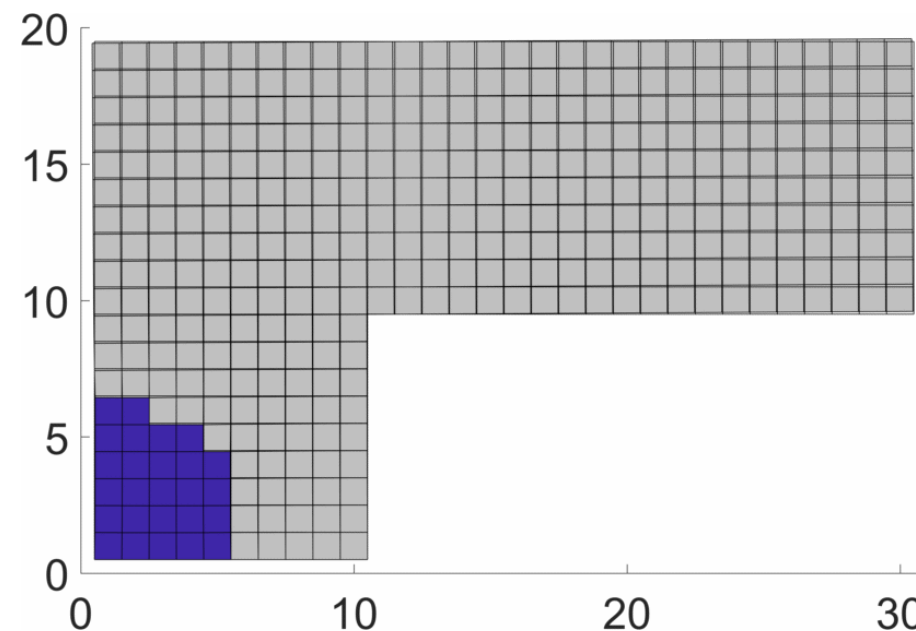
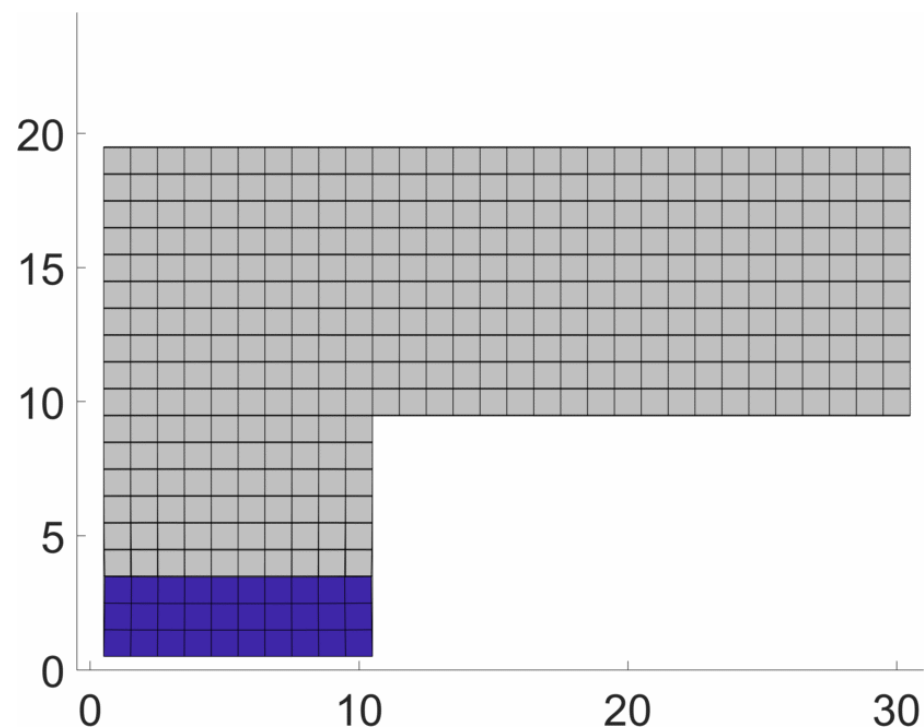


# Project 8: 基于时序的制造优化



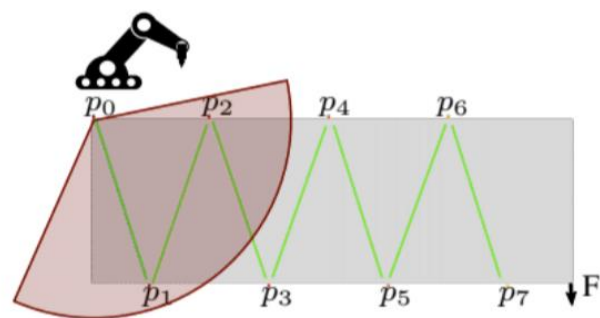
# Project 8: 基于时序的制造优化

减少线材和电弧增材制造中的变形和残余应力





# Project 8: 基于时序的制造优化



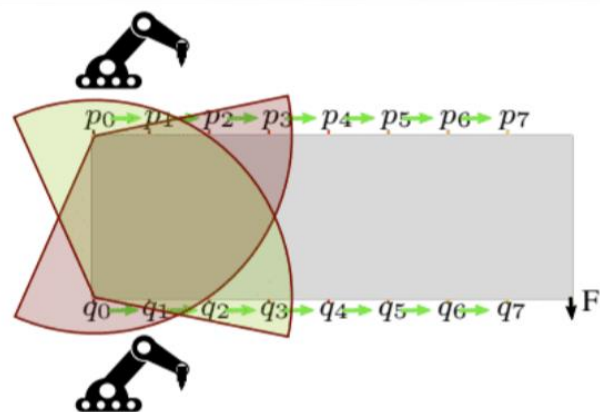
Lower bounds



Upper bounds



Compliance: 160.80



Lower bounds

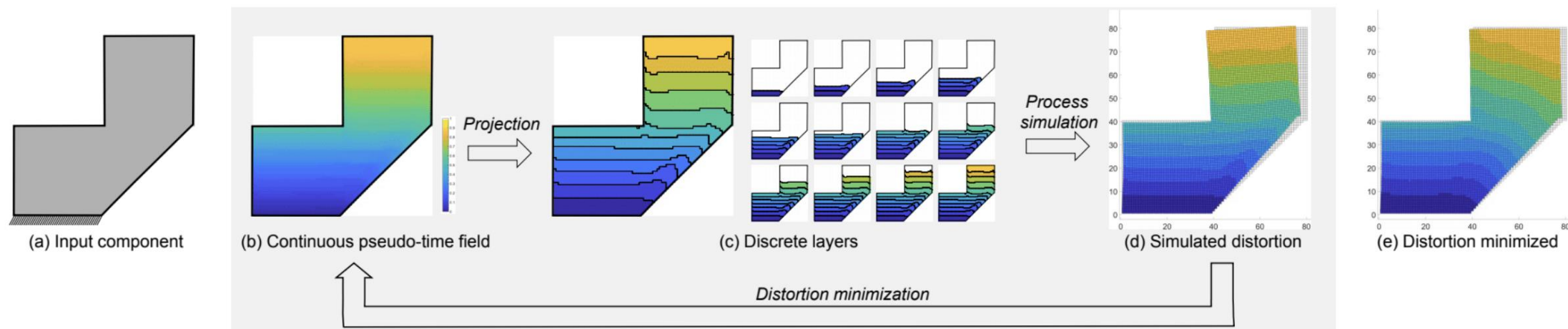


Upper bounds

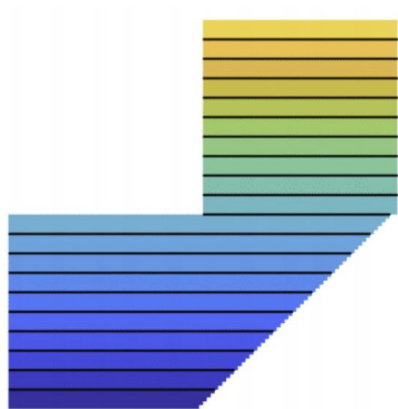


Compliance: 163.92

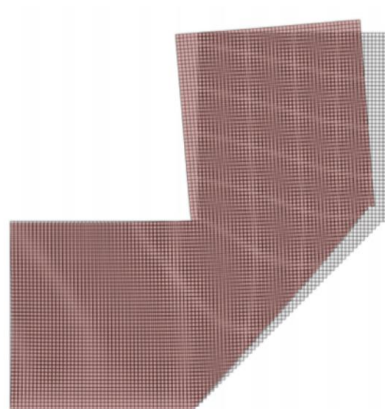
# Project 9: 基于时序的制造优化



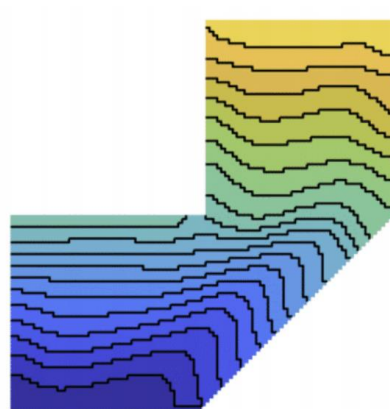
# Project 9: 基于时序的制造优化



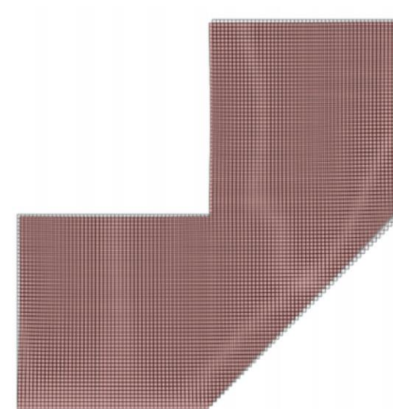
(a) Planar layers



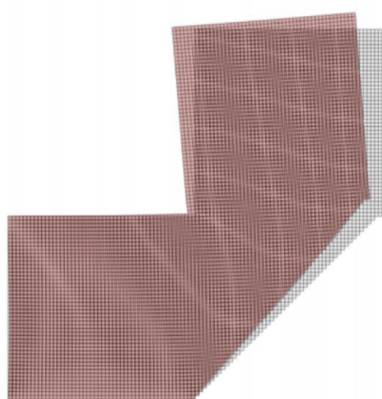
(b) Planar layers simulated with an isotropic strain



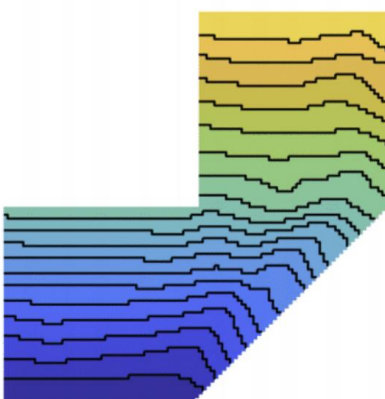
(c) Curved layers, optimized with an isotropic strain



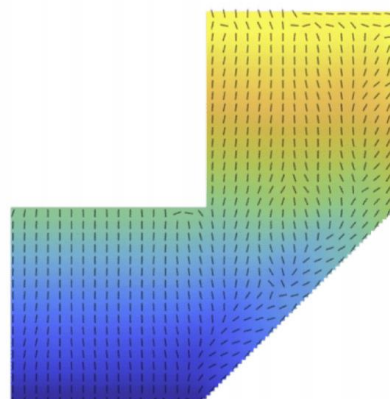
(d) Optimized curved layers, simulated with an isotropic strain



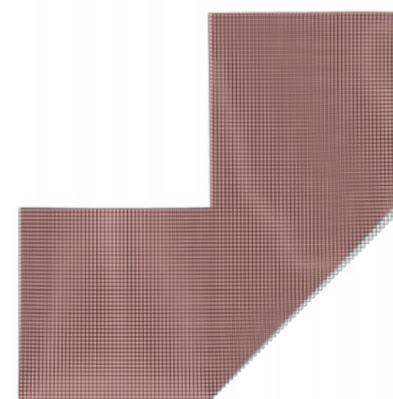
(e) Planar layers simulated with an anisotropic strain



(f) Curved layers, optimized with an anisotropic strain



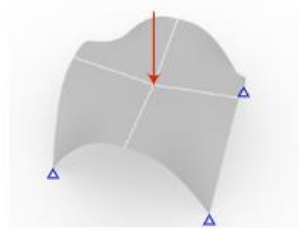
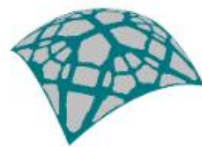
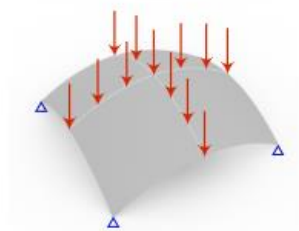
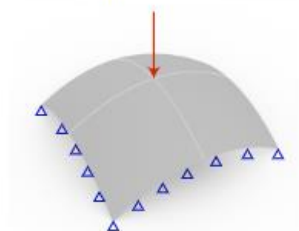
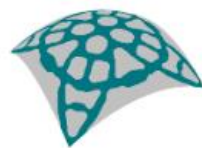
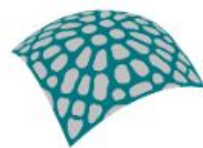
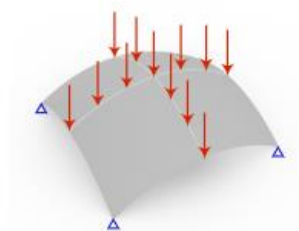
(g) Gradient of the optimized time field, i.e., an axis of anisotropy



(h) Optimized curved layers, simulated with an anisotropic strain



# Project 10: 壳的拓扑优化



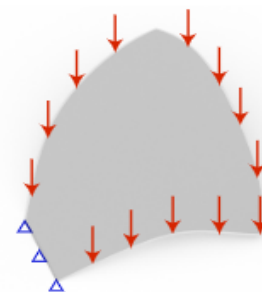
(a)

(b)

(c)

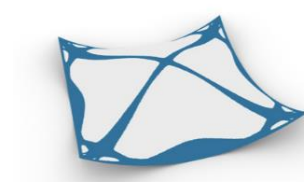
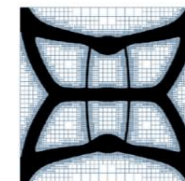
(d)

(e)



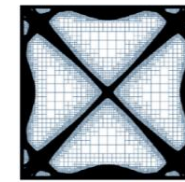
PHT-spline

C: 117.159



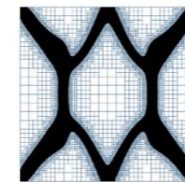
PHT-spline

C: 610.711



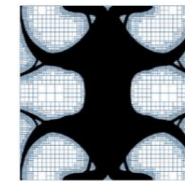
PHT-spline

C: 264.358



PHT-spline

C: 1144.634





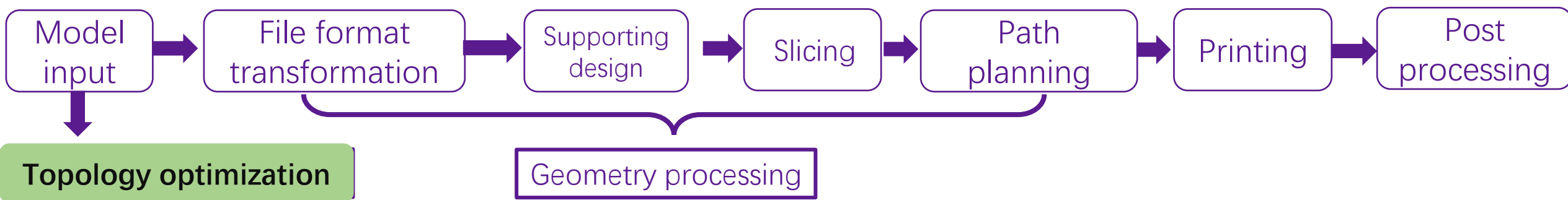
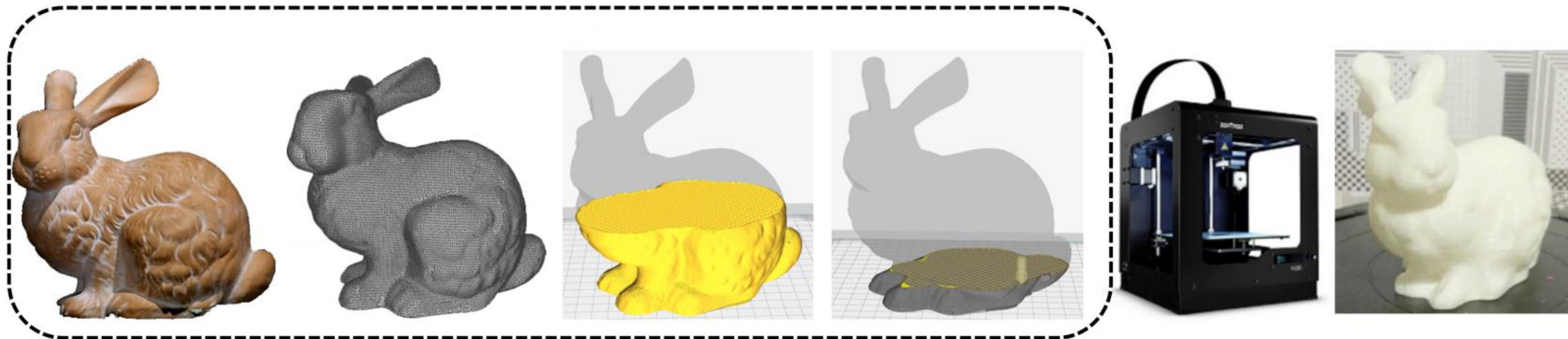
# C++ Project

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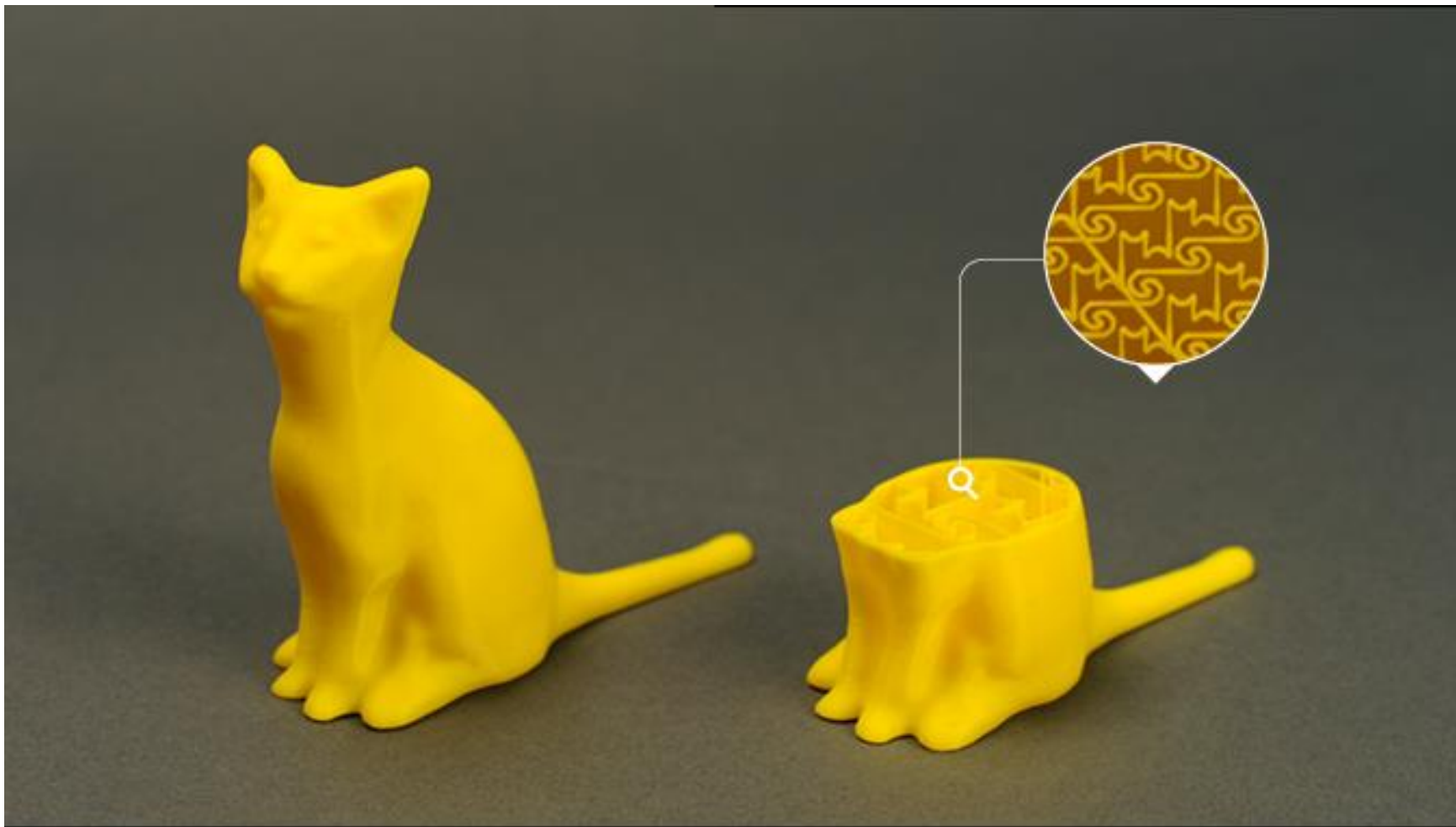
Email: [xiaoyazhai@ustc.edu.cn](mailto:xiaoyazhai@ustc.edu.cn)

Homepage: <https://xiaoyazhai.github.io/>

# 增材制造流程

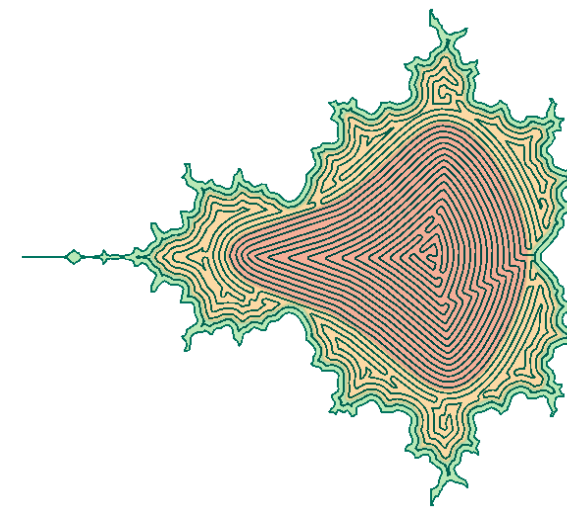
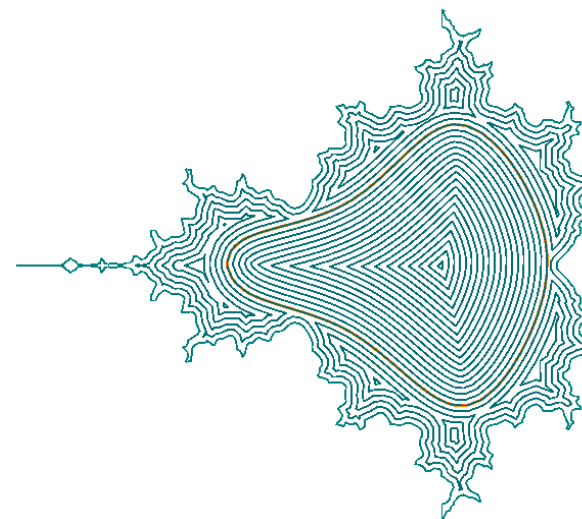
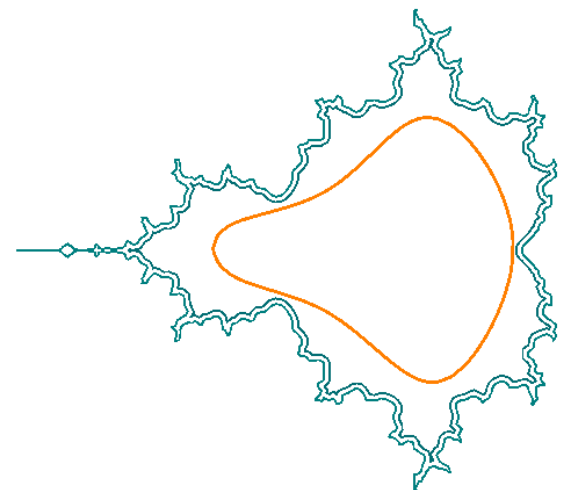
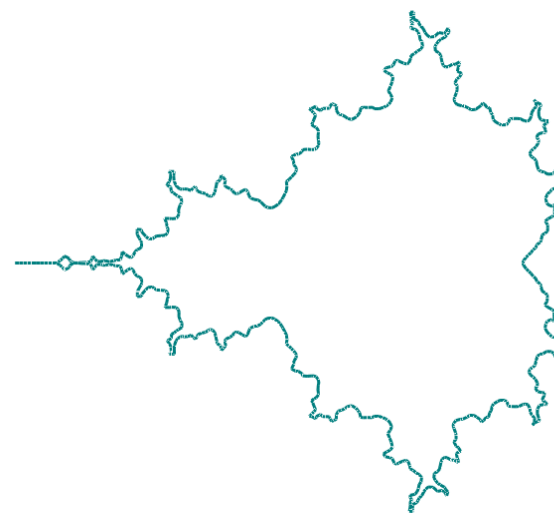
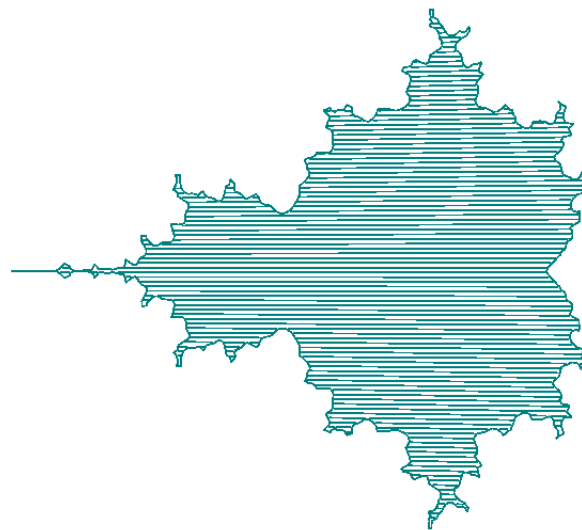
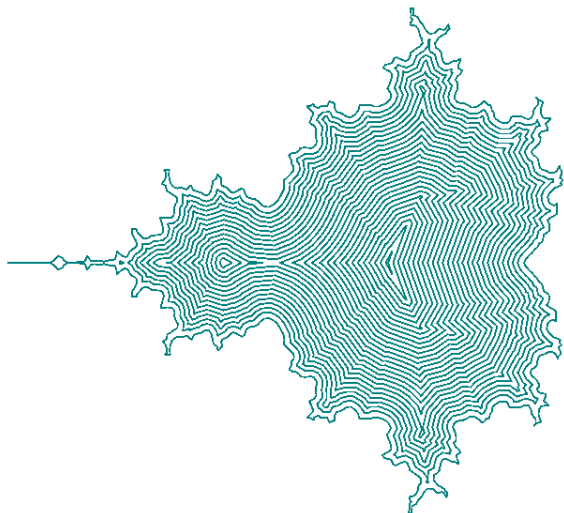
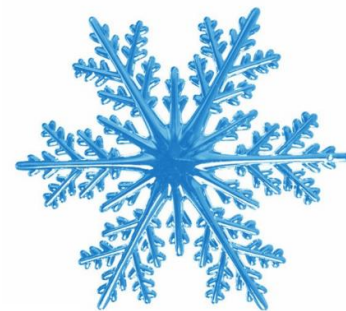


# Project 1: 内部填充



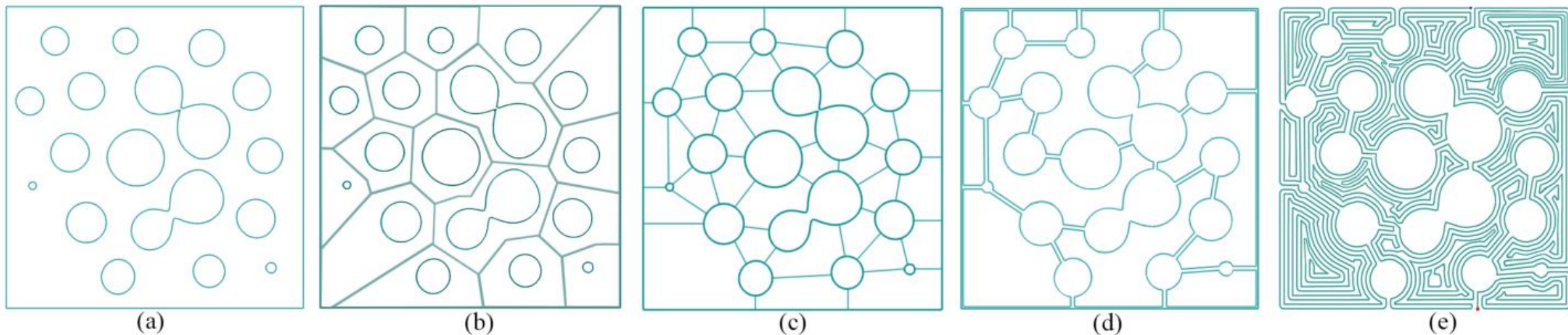
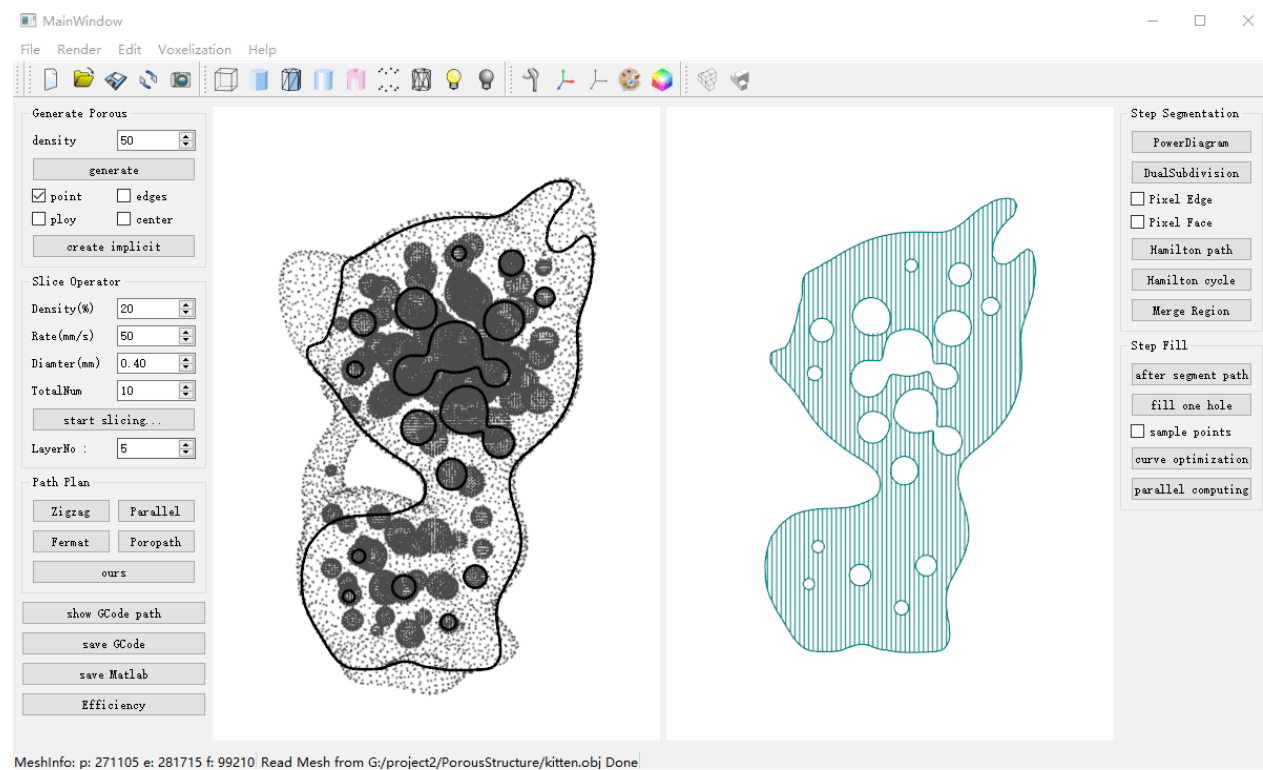
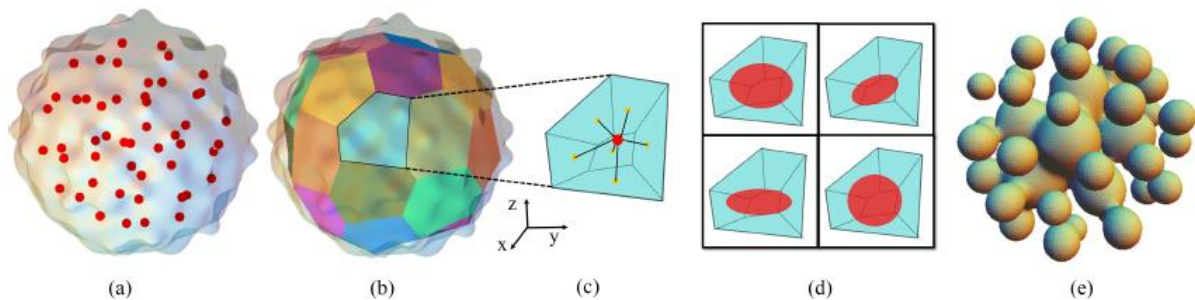


# Project 1: 内部填充

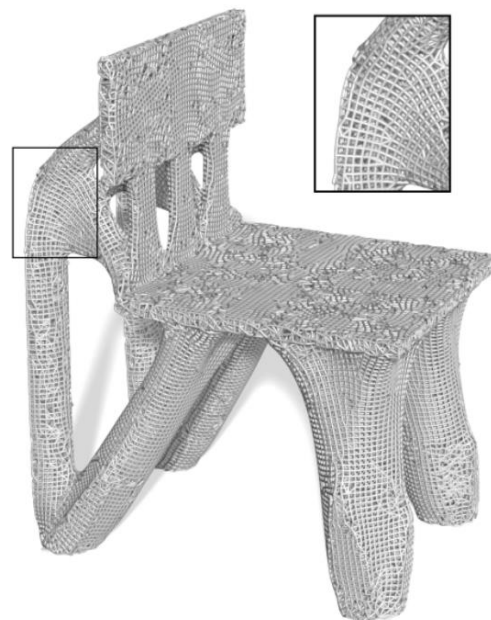
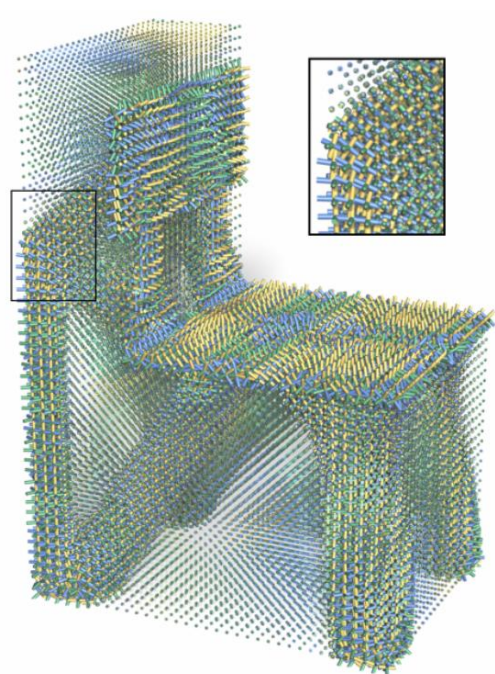
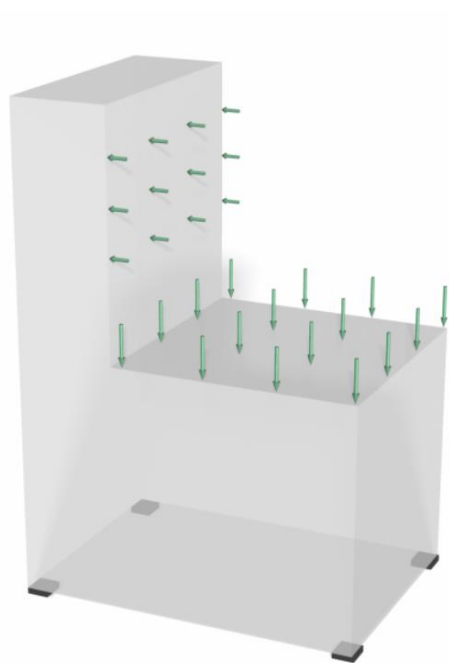




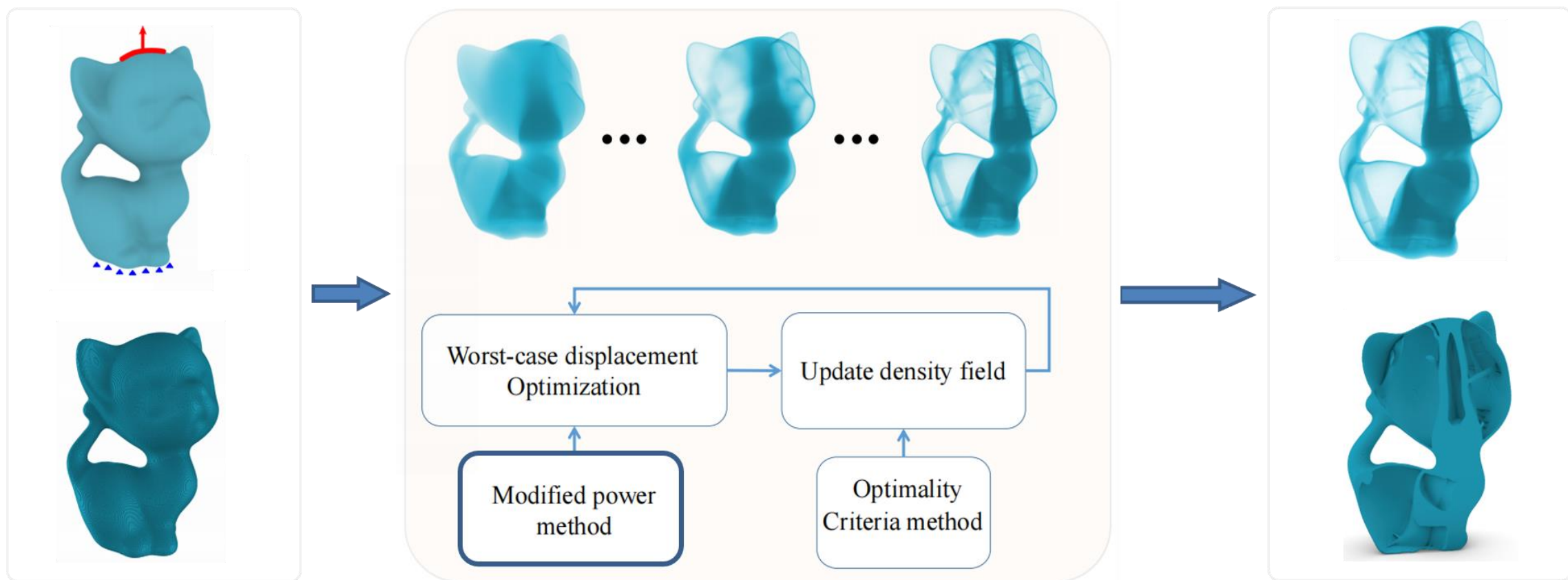
# Project 2: 内部填充



# Project 3: 高分辨率多孔填充

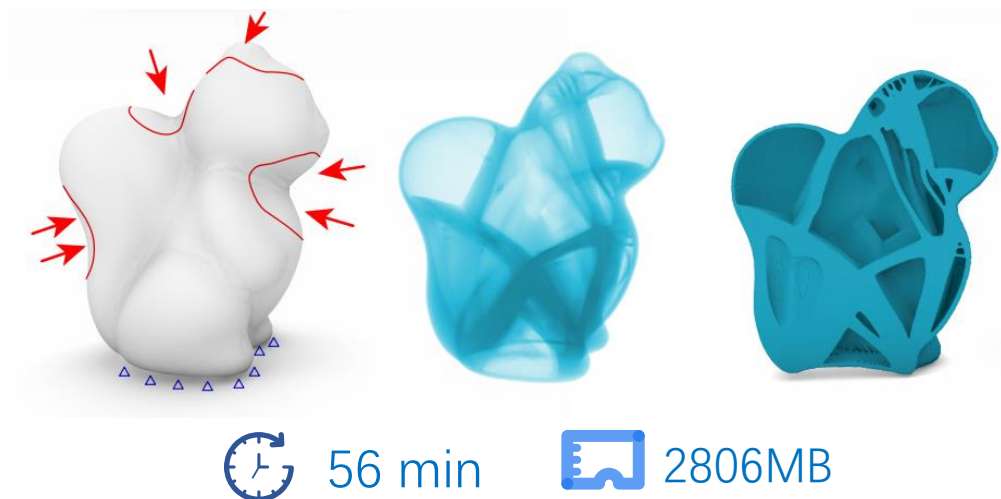
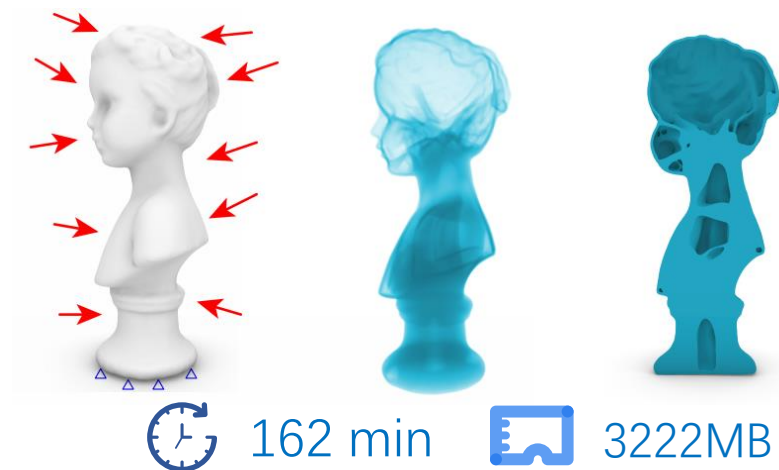
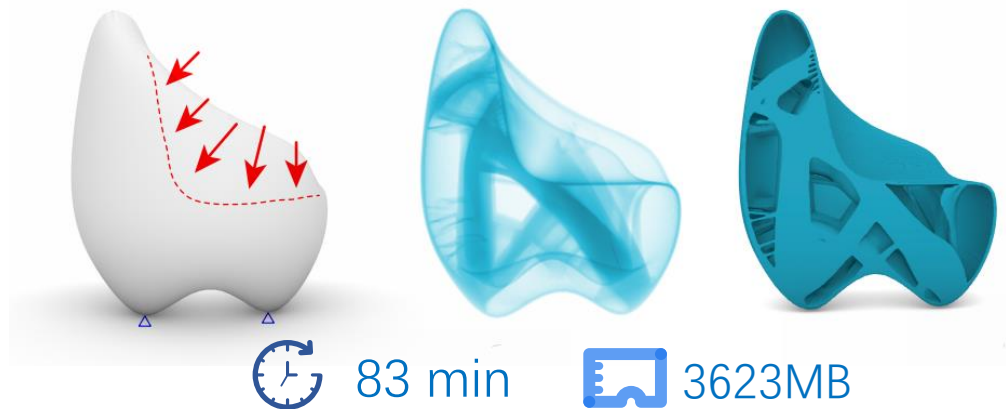


# Project 4: 高分辨率鲁棒性拓扑优化





# Project 4: 高分辨率鲁棒性拓扑优化





# Project 5: 缓冲结构设计



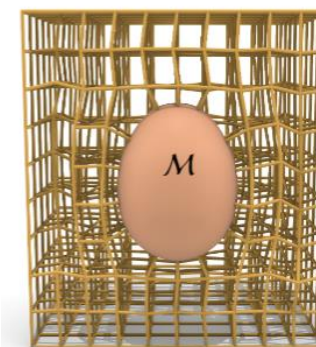
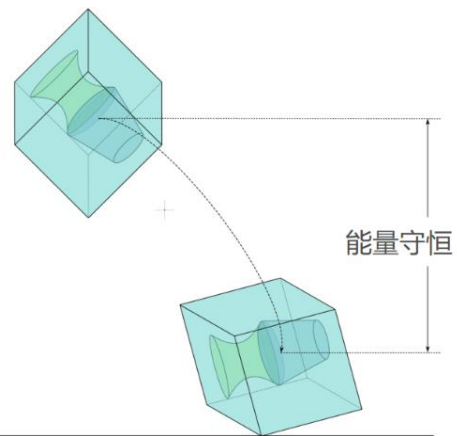
(a) Airbags



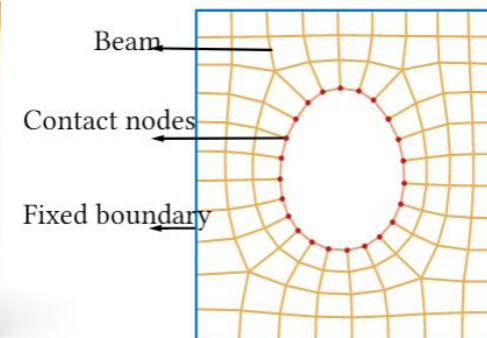
(b) Paper warps



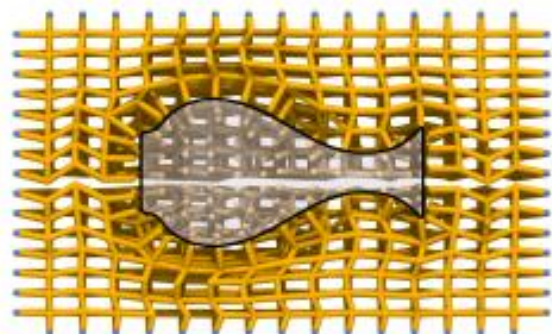
(c) Bubble wraps



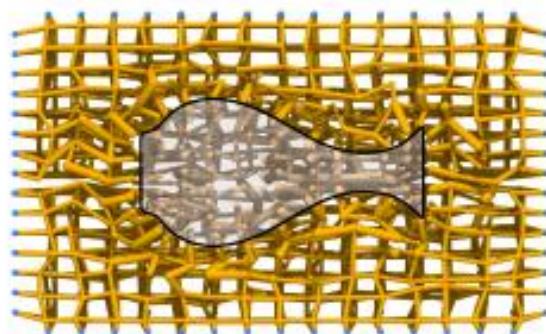
a)



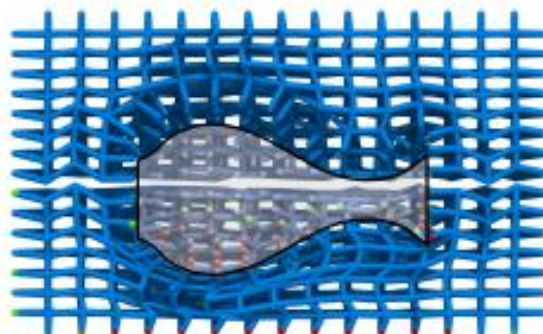
b)



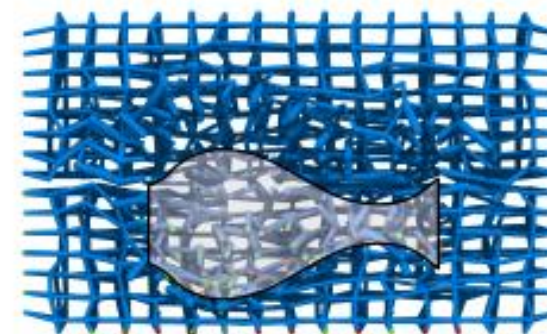
a) Initial frame



b) Optimized frame

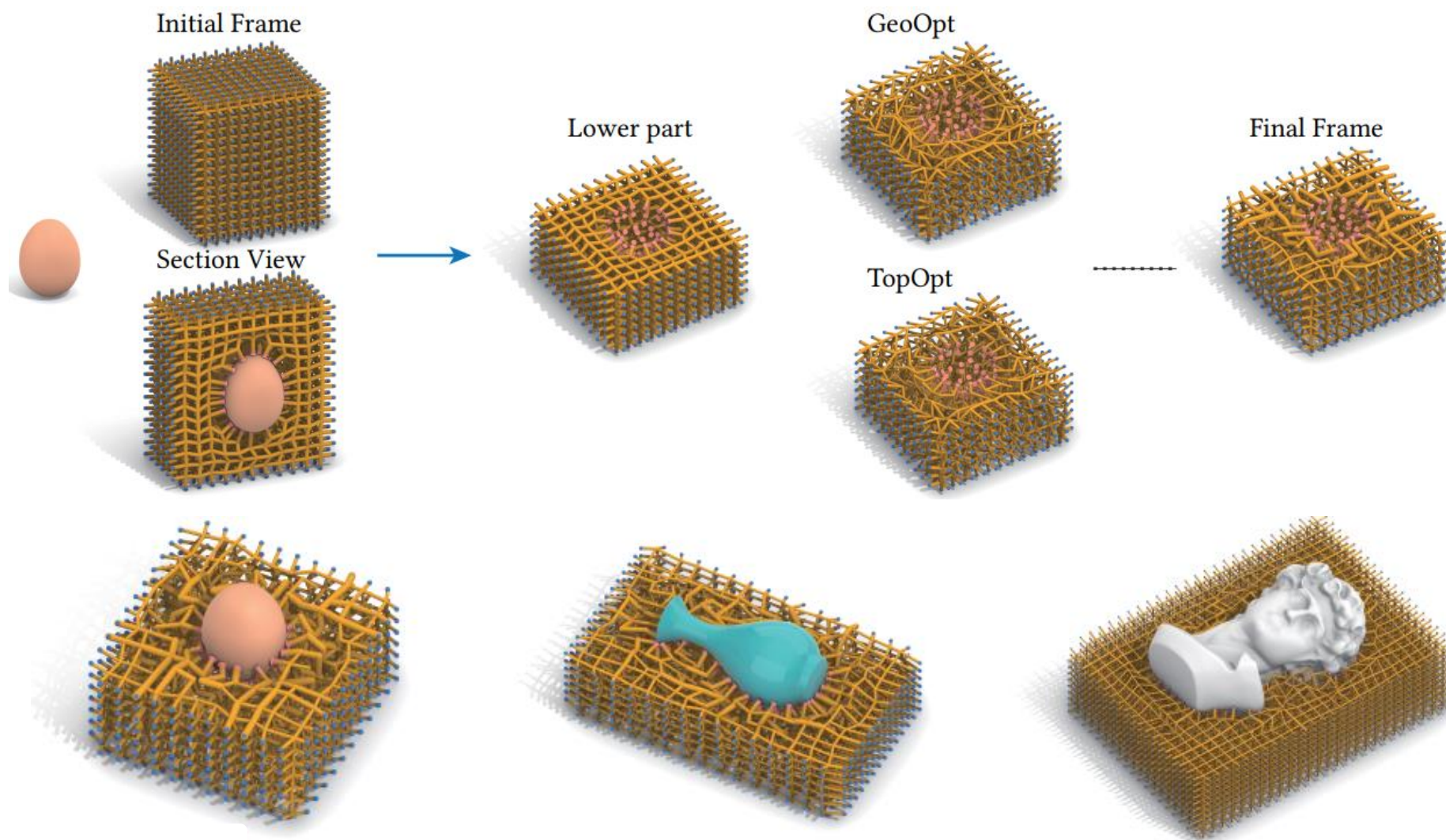


c) Simulation results of a)



d) Simulation results of b)

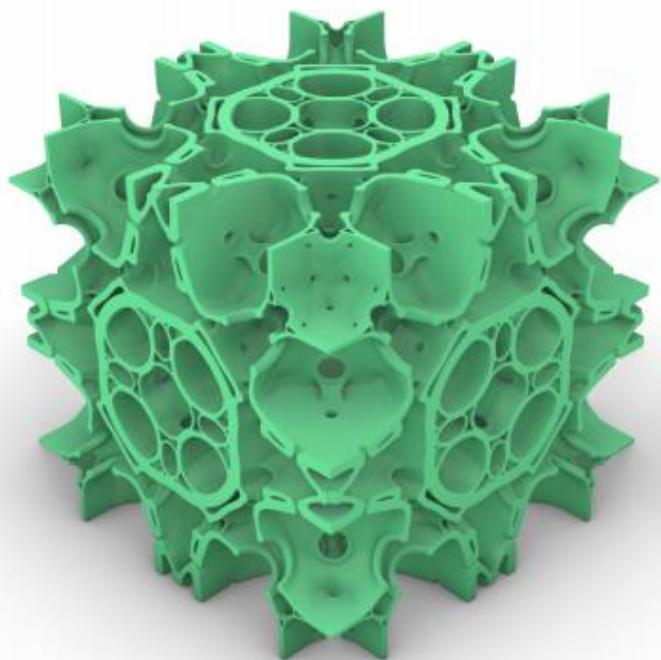
# Project 5: 缓冲结构设计





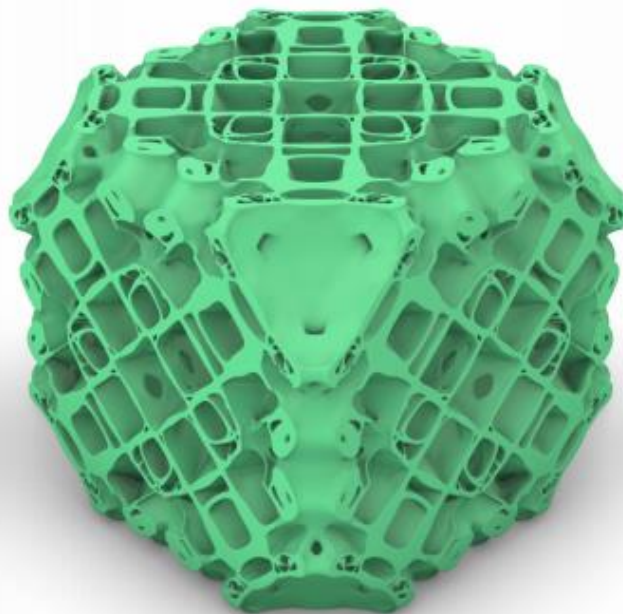
# Project 6: 微结构优化

$B = 0.1094$



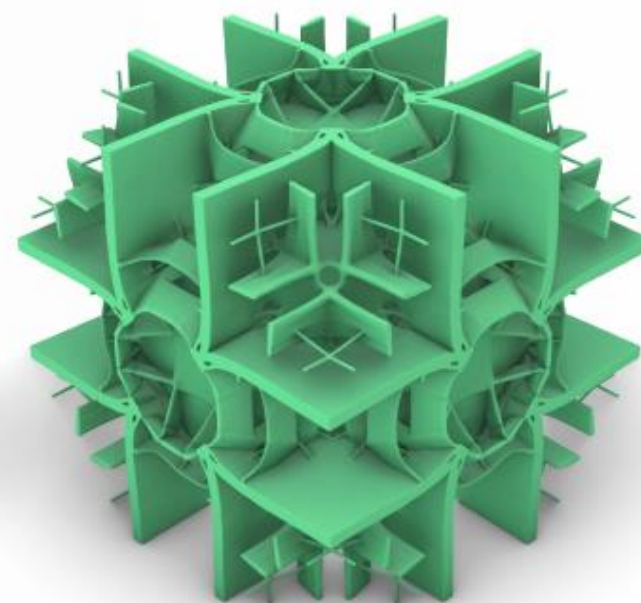
Bulk modulus

$S=0.0684$



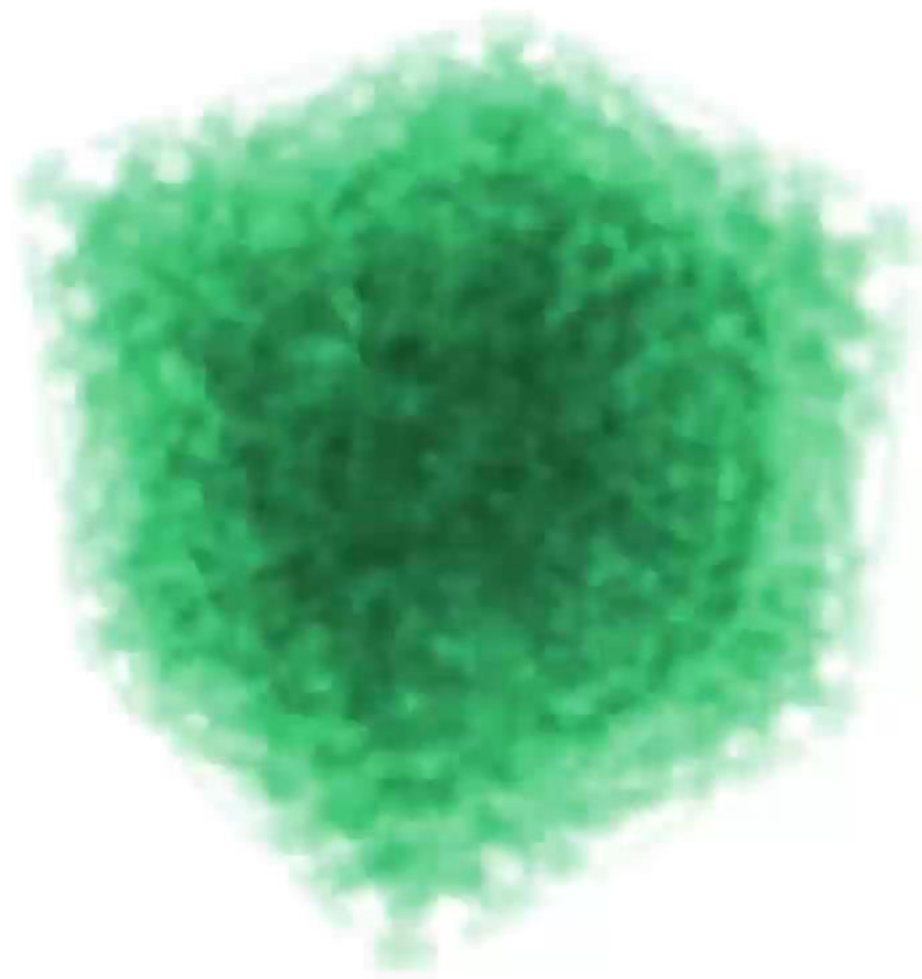
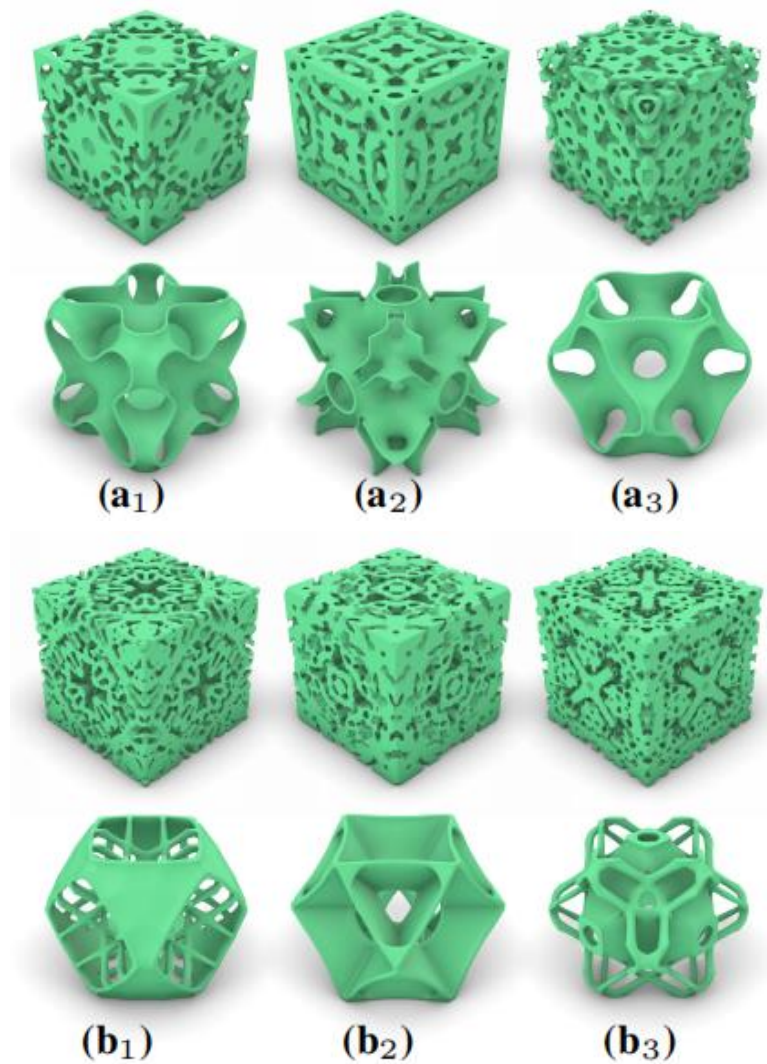
Shear modulus

$R = -0.6644$



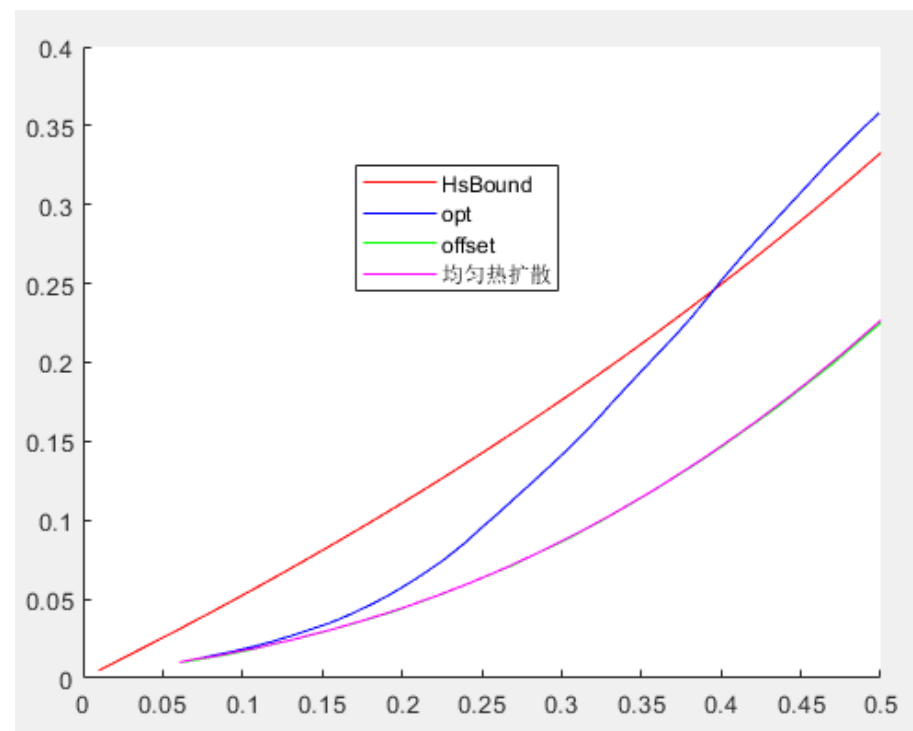
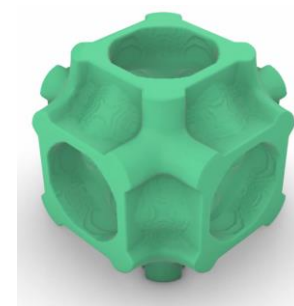
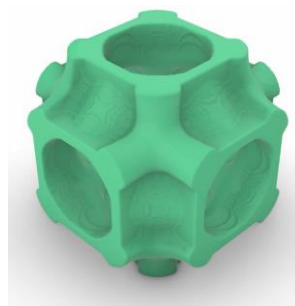
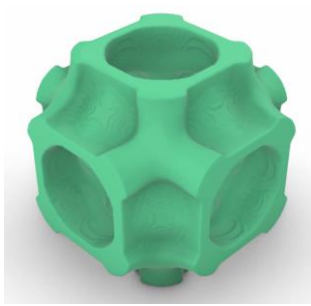
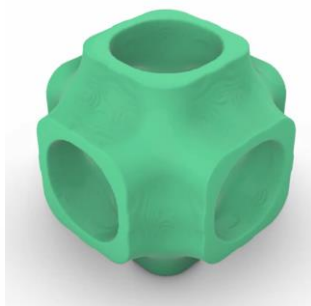
Poisson's ratio

# Project 6: 微结构优化

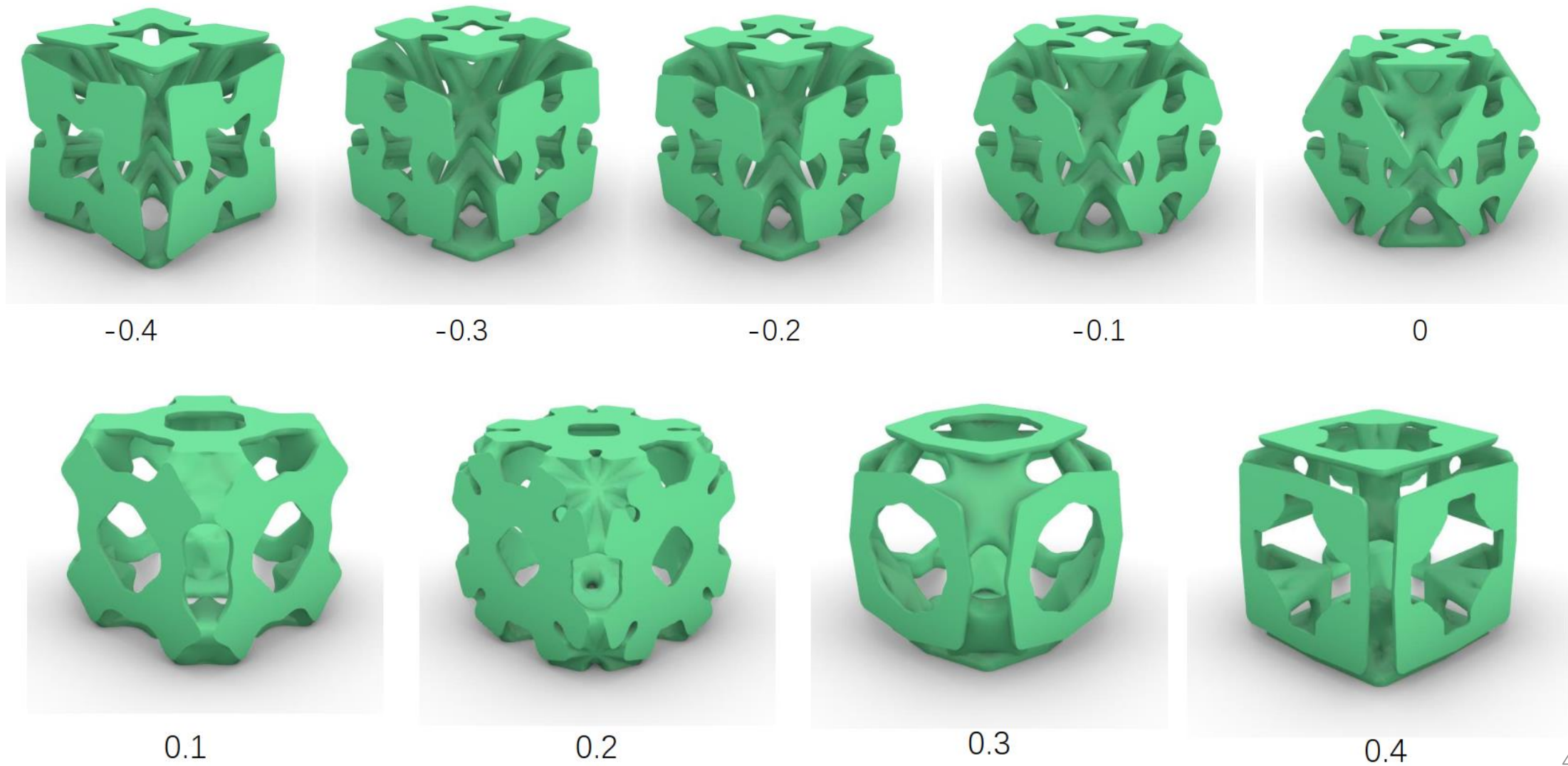




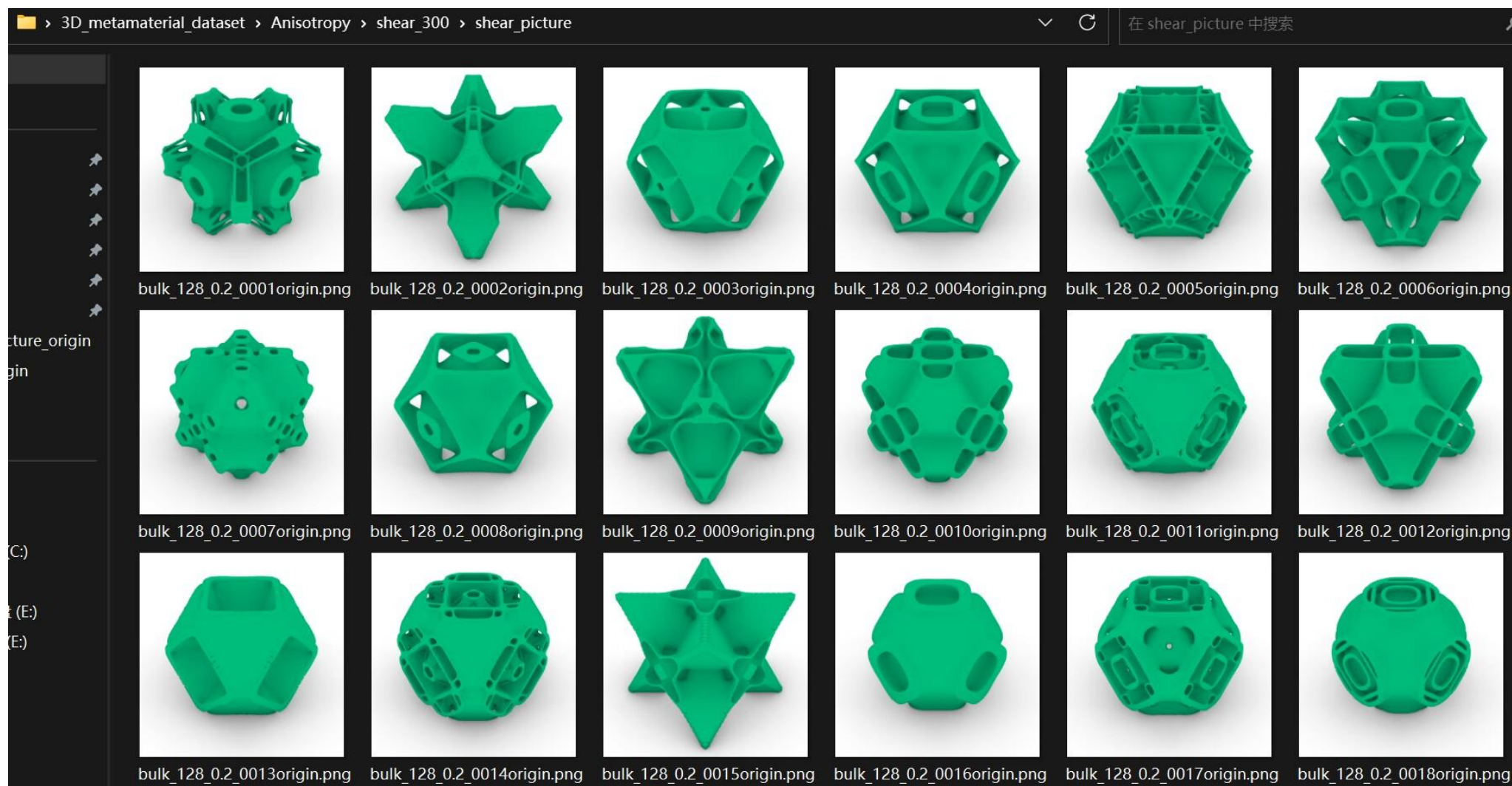
# Project 7: 微结构优化序列优化



# Project 8: 微结构优化序列优化

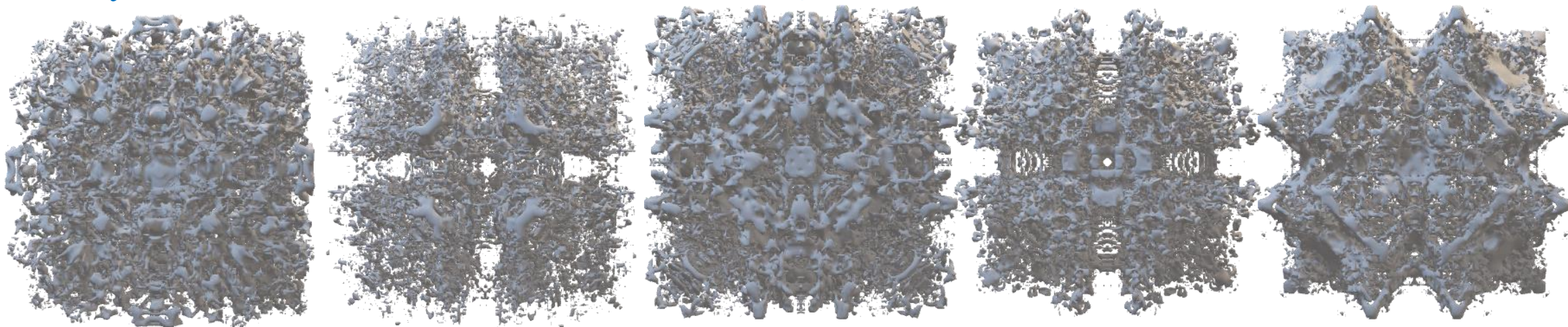


# Project 9: 微结构数据库的生成

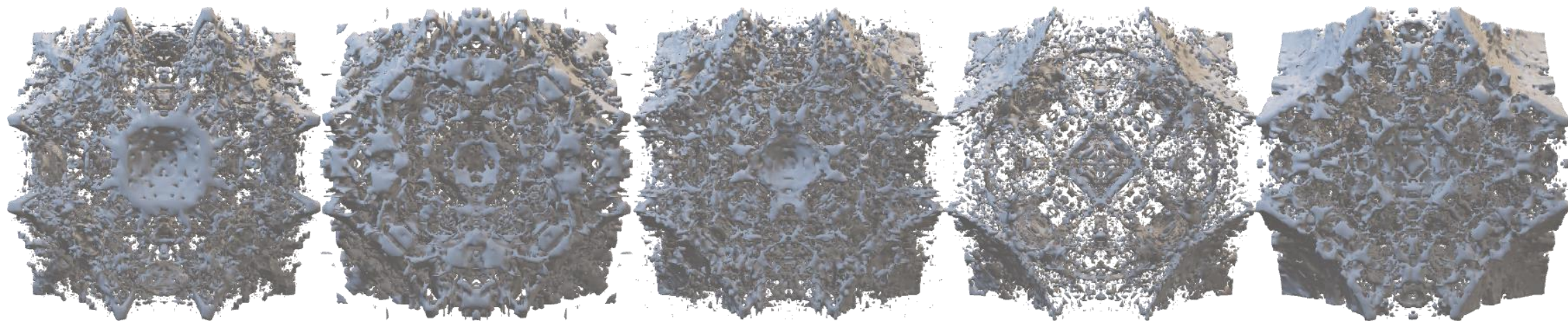




# Project 9: 微结构数据库的生成



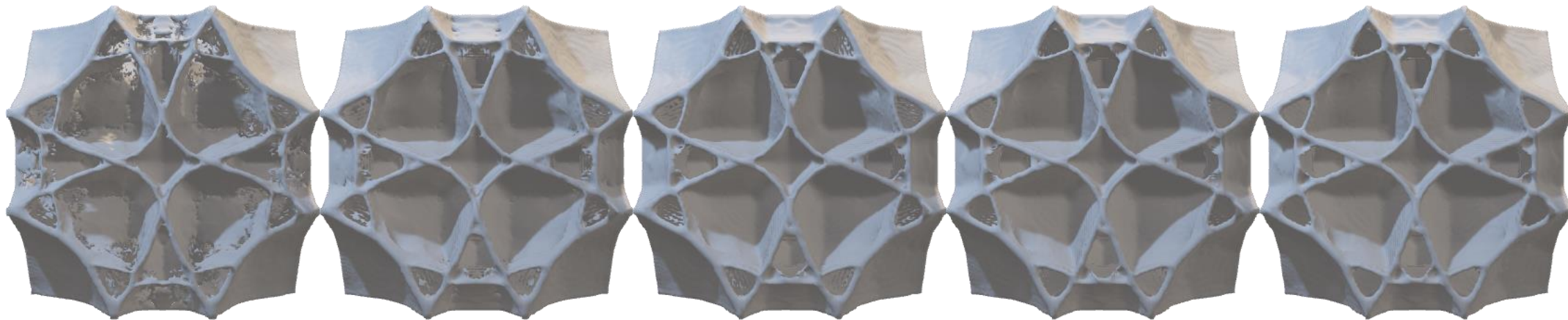
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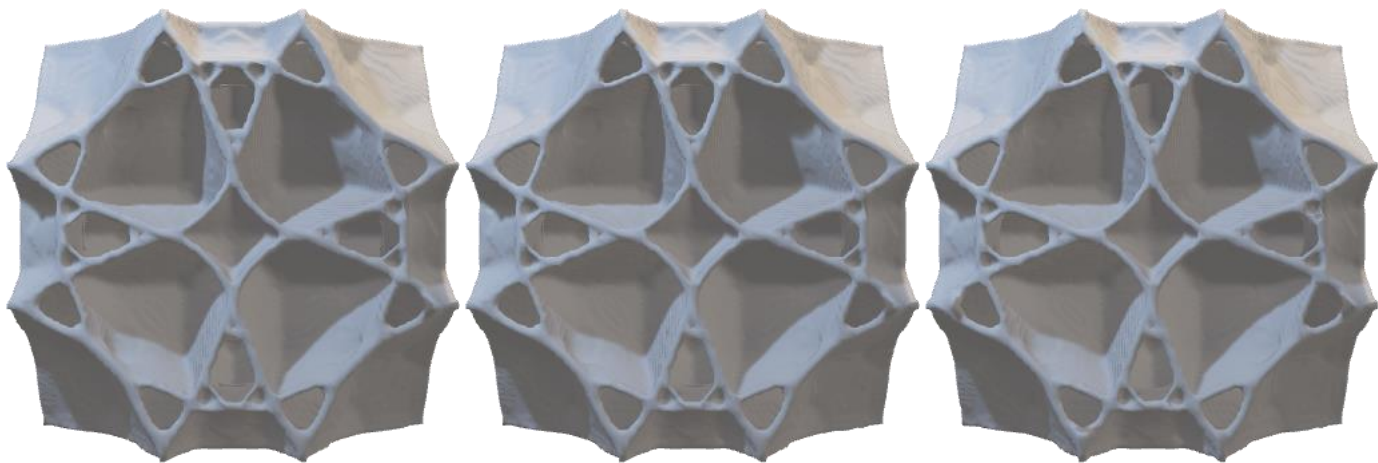
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# Project 9: 微结构数据库的生成

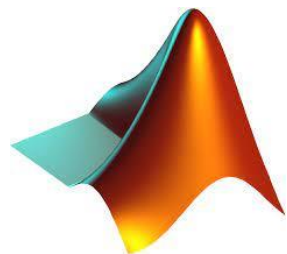


Youngs\_128\_0.2\_0041 Youngs\_128\_0.2\_0042 Youngs\_128\_0.2\_0043 Youngs\_128\_0.2\_0044 Youngs\_128\_0.2\_0045



Youngs\_128\_0.2\_0046 Youngs\_128\_0.2\_0047 Youngs\_128\_0.2\_0048

# 总结



MATLAB



实验过程

问题背景



基础工具



数值计算

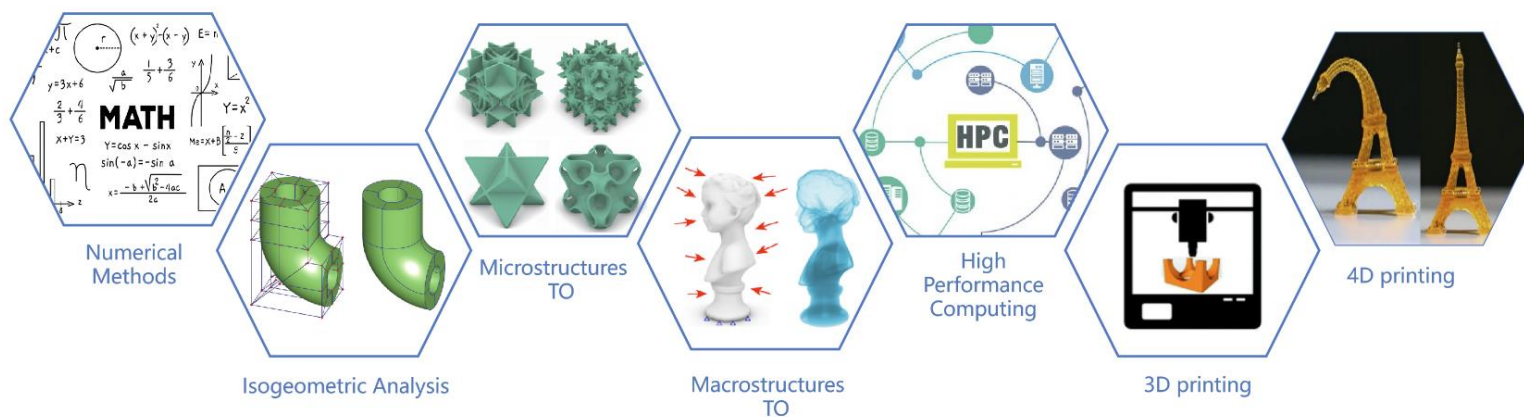


几何表示与优化



制造测试应用

## Computational Mathematics on Mechanical Engineering



# 总结

路径规划  
应力线  
平衡问题  
拓扑优化  
多孔结构 缓冲结构  
壳结构优化  
时空序列优化  
序列生成 支撑约束



# Open Project

翟晓雅

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# Project 1: 天幕的形状优化



# Project 1: 天幕的形状优化

圆顶帐示意图



两根帐杆  
顶部交叉



知乎 @林员外



鱼脊帐示意图

圆顶帐简化版

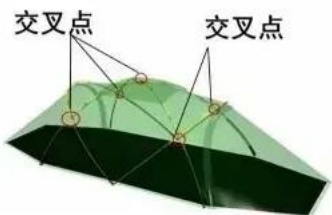


知乎 @林员外

金字塔帐示意图



测地线帐篷示意图



交叉点

交叉点



知乎 @林员外

隧道帐示意图



平行帐杆



知乎 @林员外

单人圈式帐篷示意图



只有一根  
弧形帐杆



知乎 @林员外

A字塔帐示意图



知乎 @林员外

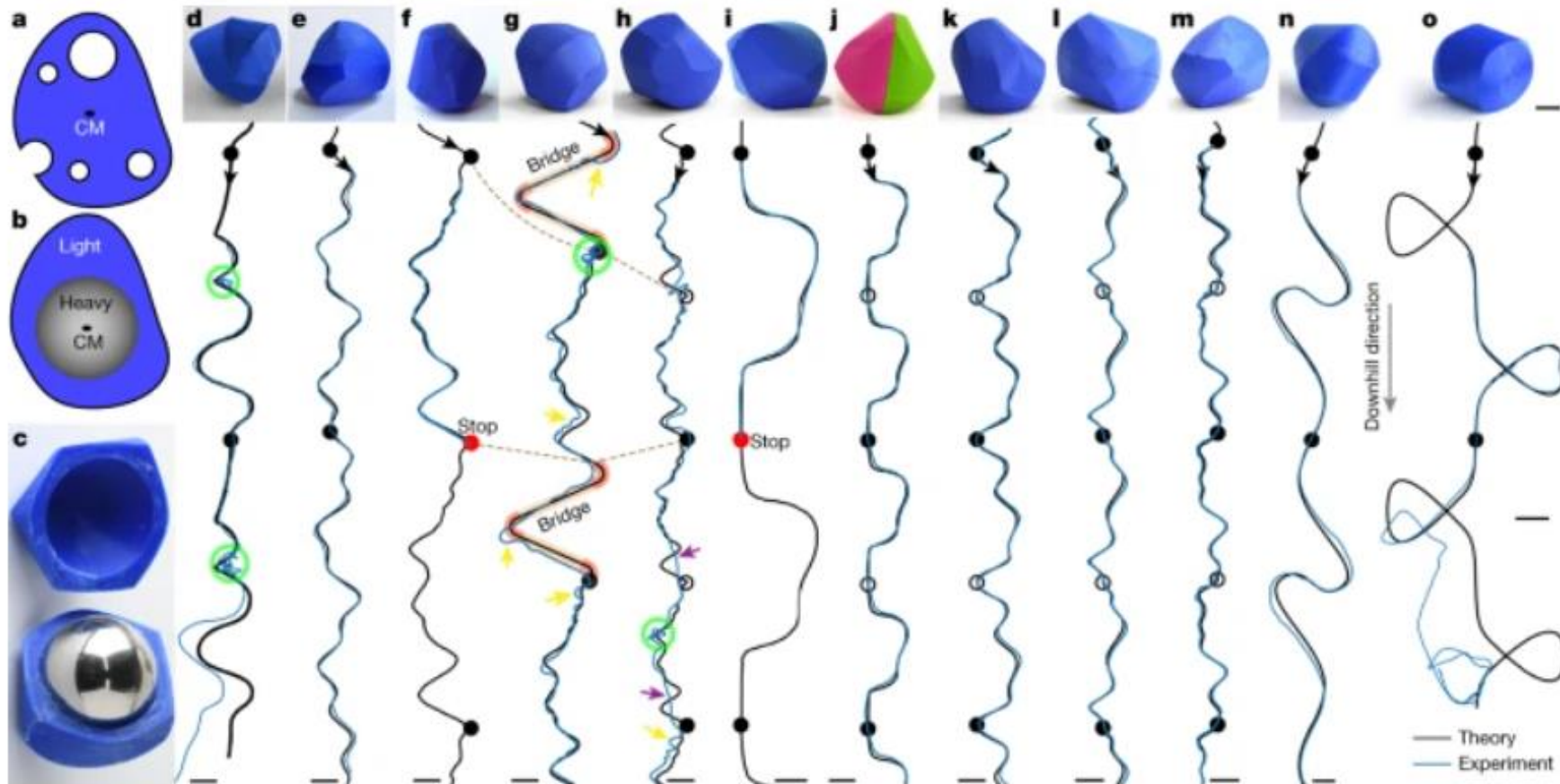
# Project 1: 天幕的形状优化

- 好的帐篷/天幕应该满足什么条件？
- 怎么分析帐篷/天幕的稳定性？稳定性的条件是什么？
- 如何优化天幕的形状使得它更“好”？



# Project 2: 如何让结构按照指定的路径前进?

Fig. 4: Experimental validation.



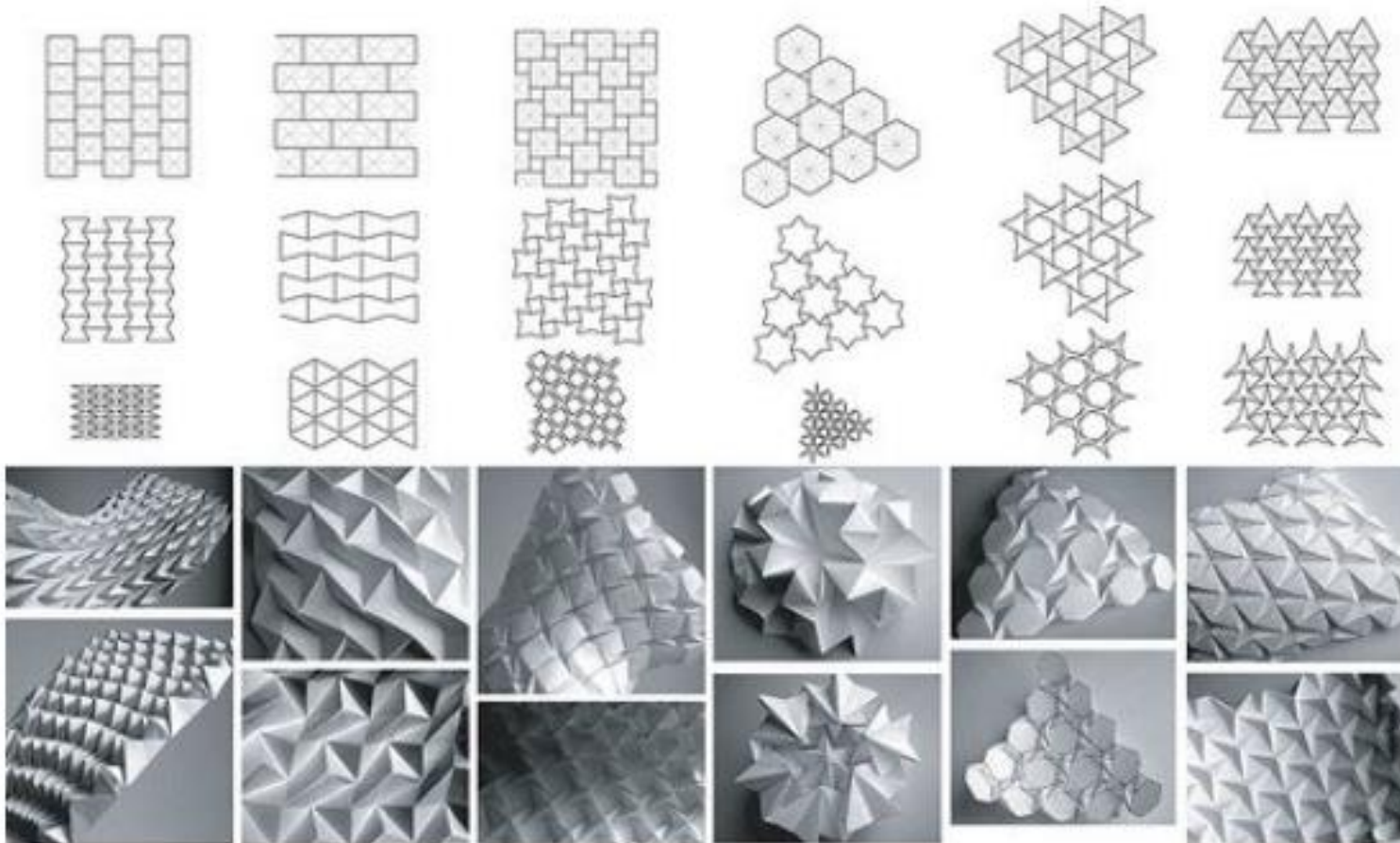
Solid-body trajectoids shaped to roll along desired pathways, Nature, 2023



## Project 2: 如何让结构按照指定的路径前进?

- 能否通过结构的质量分布的变化实现路径的前进?
- 这个问题该如何思考? 如何建模?

# Project 3: 折纸结构的设计



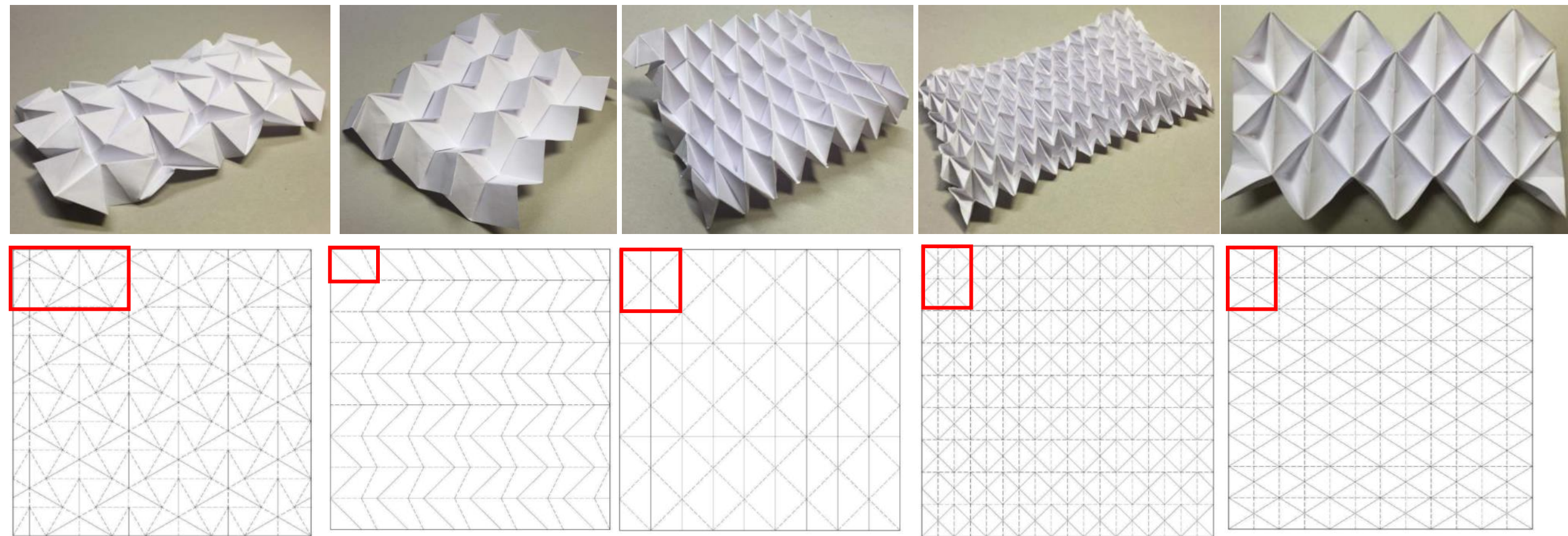
**How NASA Engineers Use Origami To Design Future Spacecraft?**

[https://www.youtube.com/watch?v=L y3hMBD4h5E&ab\\_channel=Seeker](https://www.youtube.com/watch?v=L y3hMBD4h5E&ab_channel=Seeker)

**Why the Future of Tech is in Origami (Space Development, Batteries, Humans)**

[https://www.youtube.com/watch?v=IGU1x OW0Sus&ab\\_channel=VentureCity](https://www.youtube.com/watch?v=IGU1x OW0Sus&ab_channel=VentureCity)

# Project 3: 折纸结构的设计

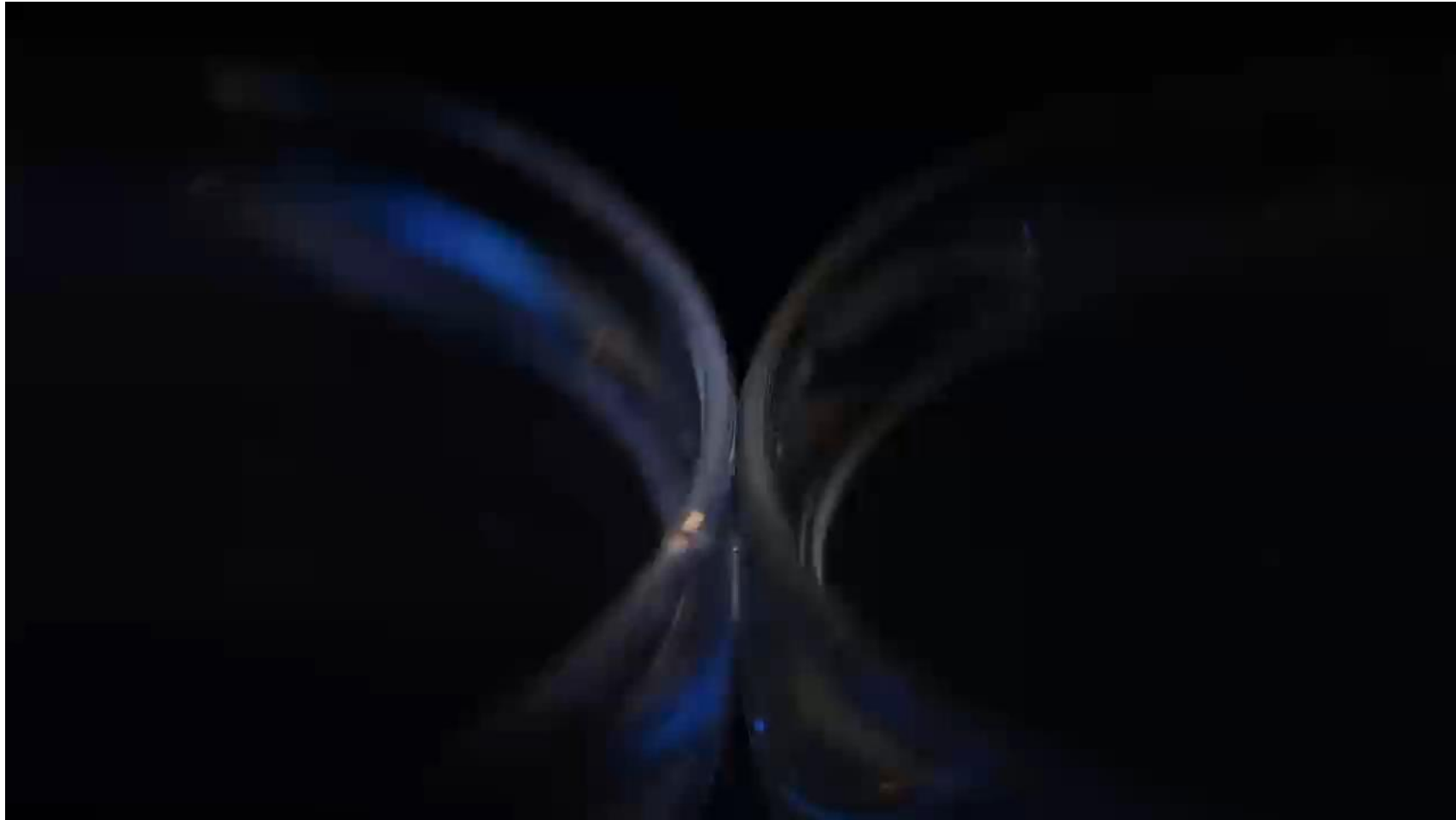


# Project 3: 折纸结构的设计

- 这个问题该如何思考？如何建模？
- 里面包含什么样的数学问题？



# Project 4: 4D打印



# Project 4: 4D打印

Question

How to manufacture surface structure by 3D printing?



Printable surface structure design

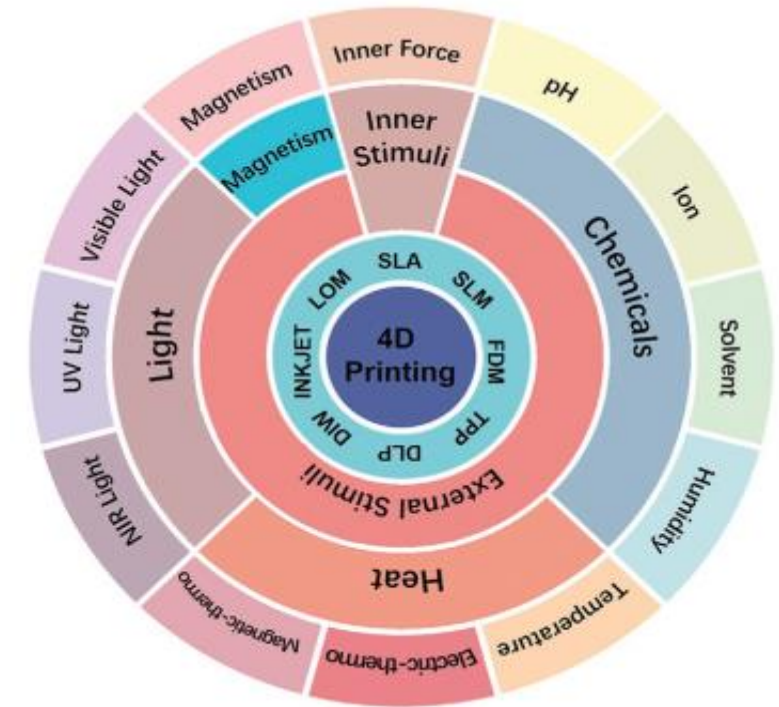
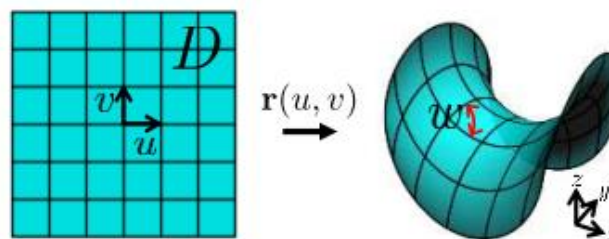
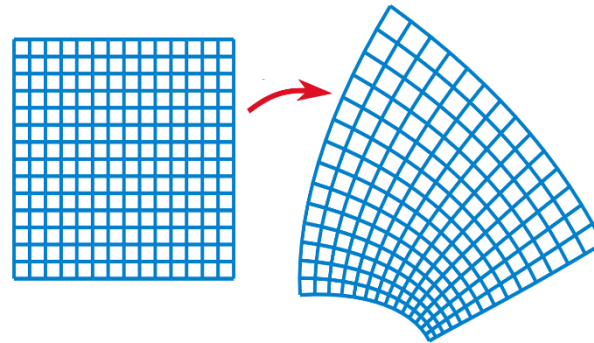


Combine with 4D printing

**Programmable deformation behaviors**



Print plane and then deformed to determined surface!



# Project 4: 4D打印

How to print surface model?



How to print **complex** surface model?



Simple surface



Open surface  
with details



Close surface  
with details



Hollowed  
surface



simpleness

complexity

# Project 4: 4D打印

- 如何思考？如何建模？
- 运用什么样的理论模型？





# Q&A?

## 下节课内容 实验五：素数

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