

# Thermal-Comfort Design of Personalized Casts

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<sup>1</sup>



<sup>2</sup>



ACM User Interface Software and Technology Symposium

# Traditional Casts

Bulky, poor breathability, molding requires training



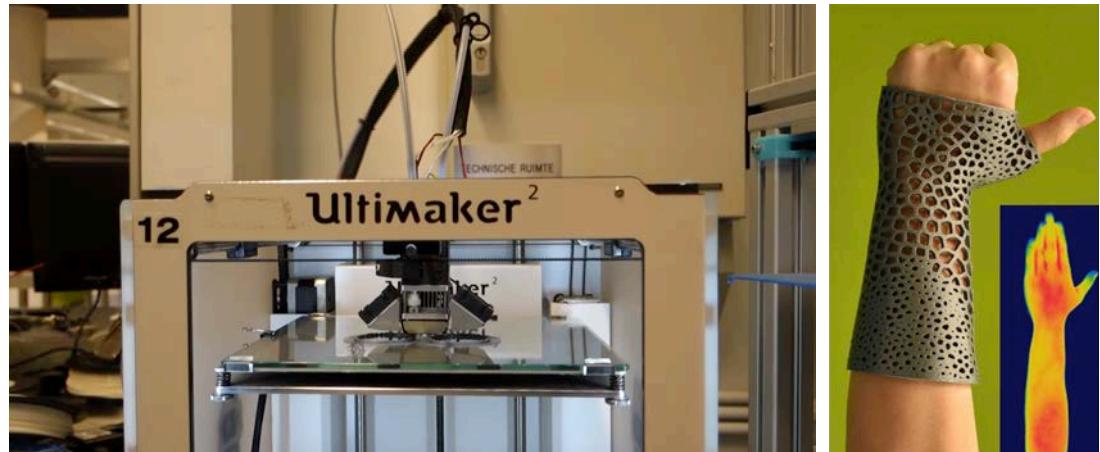
# Traditional Casts



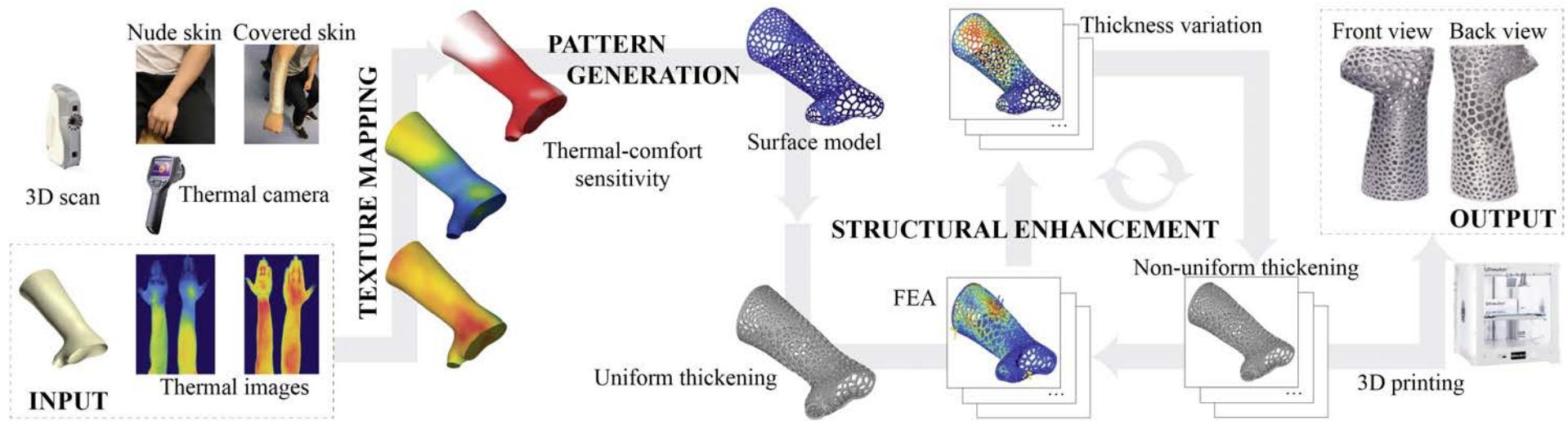
[Image source: [www.drycast.com](http://www.drycast.com)]

# Our Casts

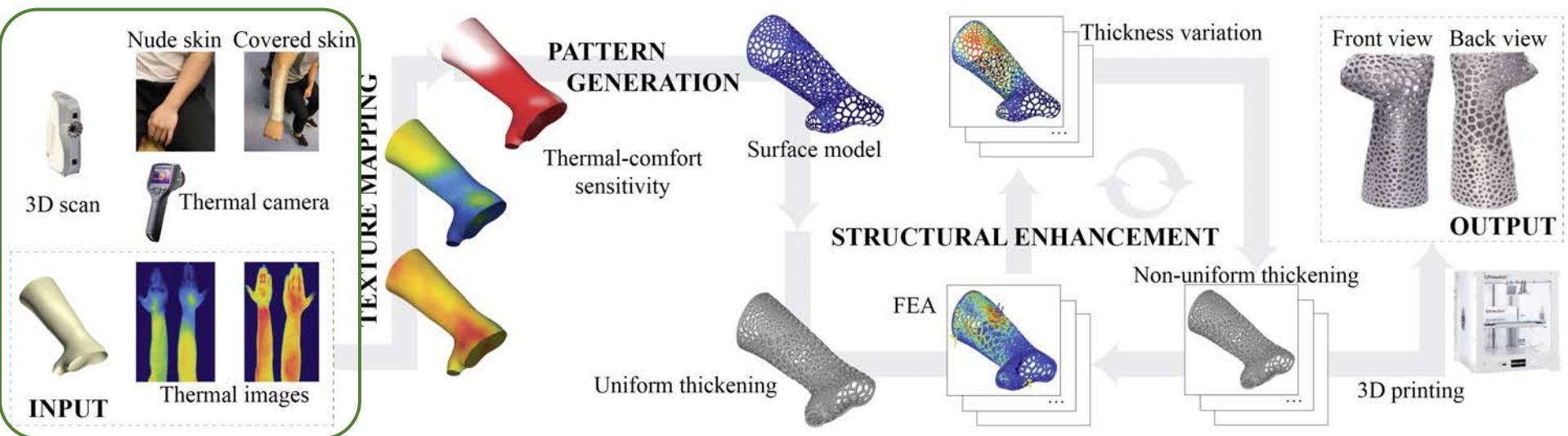
- Daily usage
- Thermal-comfort
- 3D printed



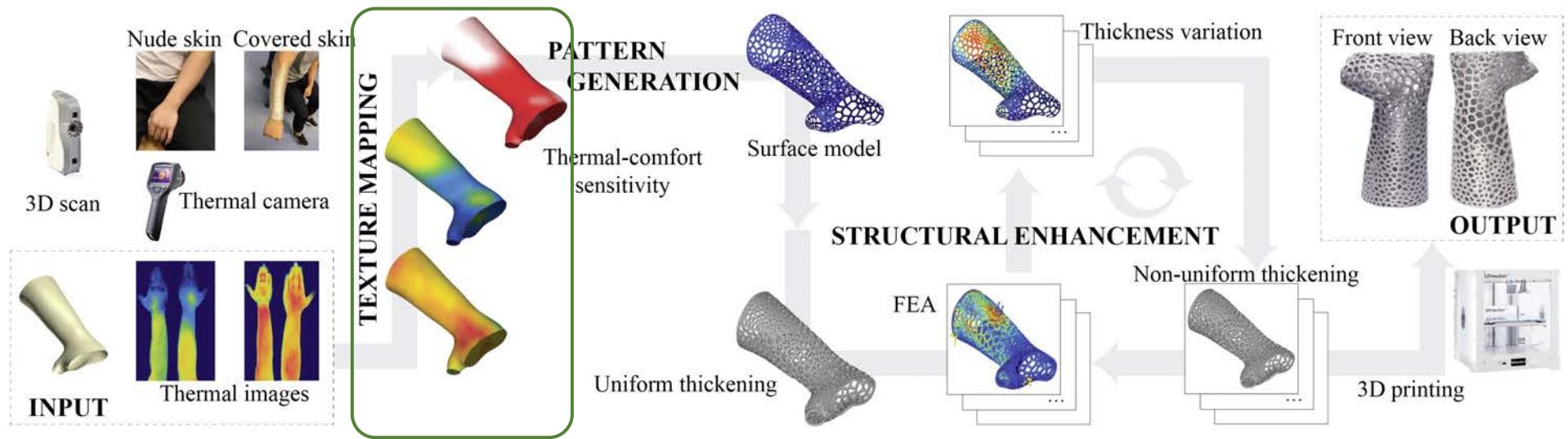
# Pipeline



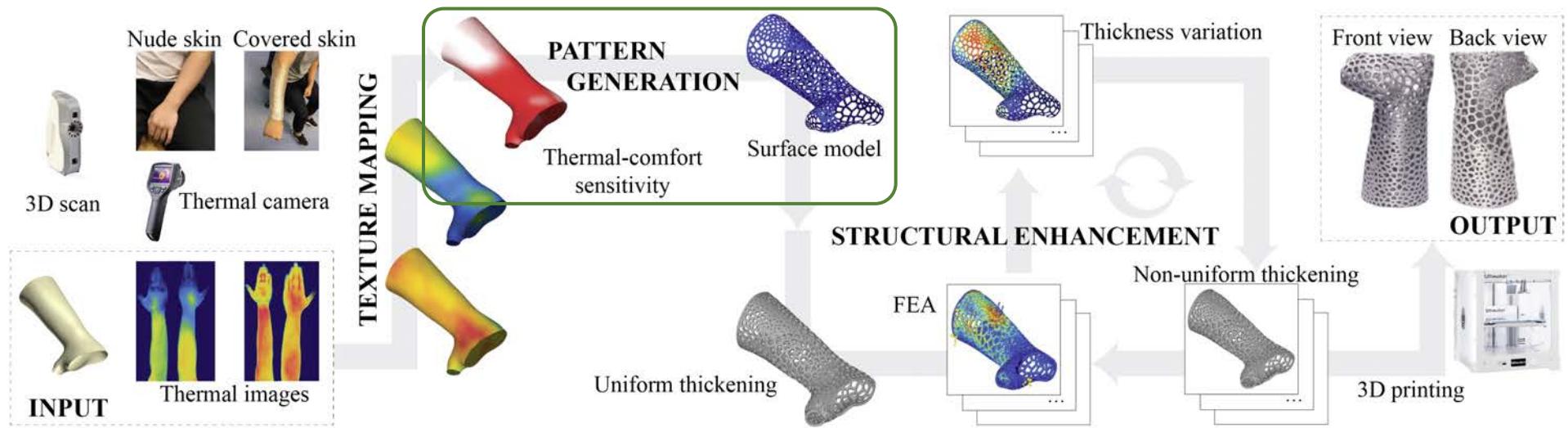
# Pipeline



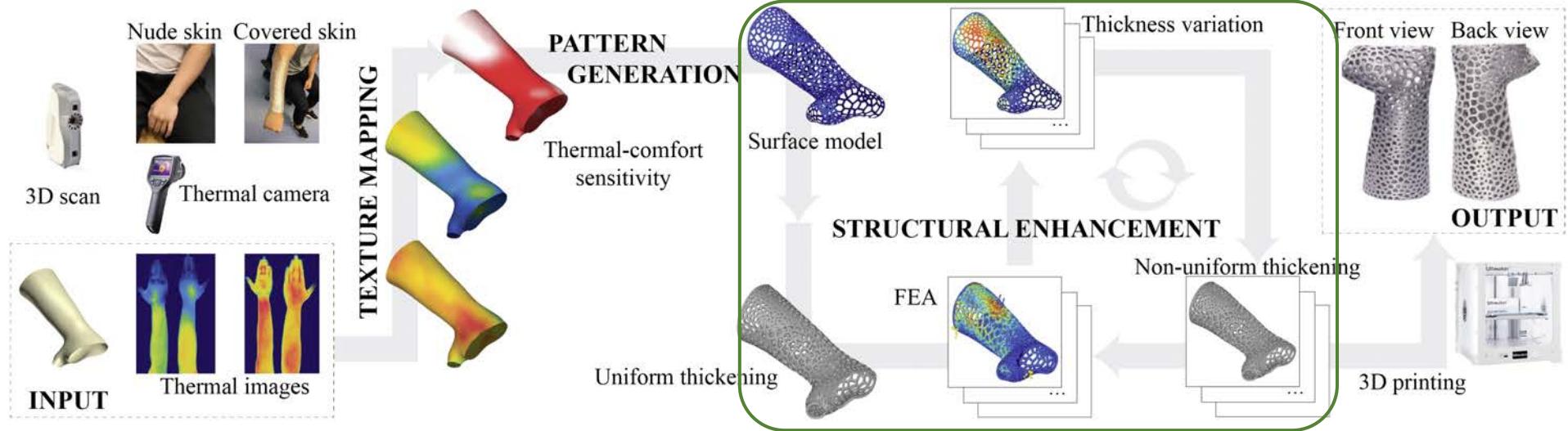
# Pipeline



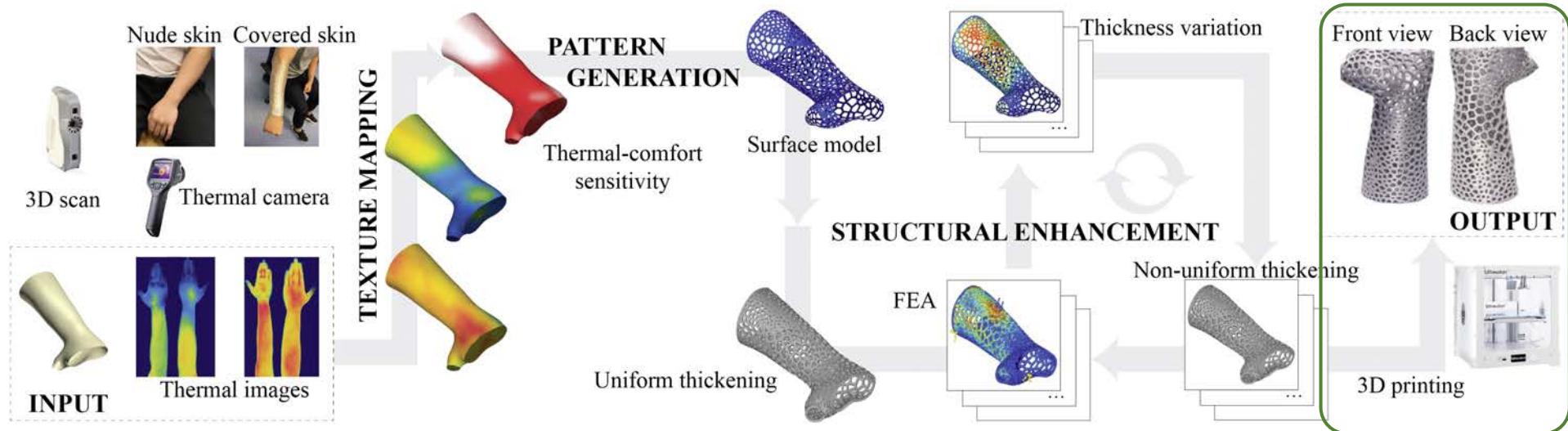
# Pipeline



# Pipeline



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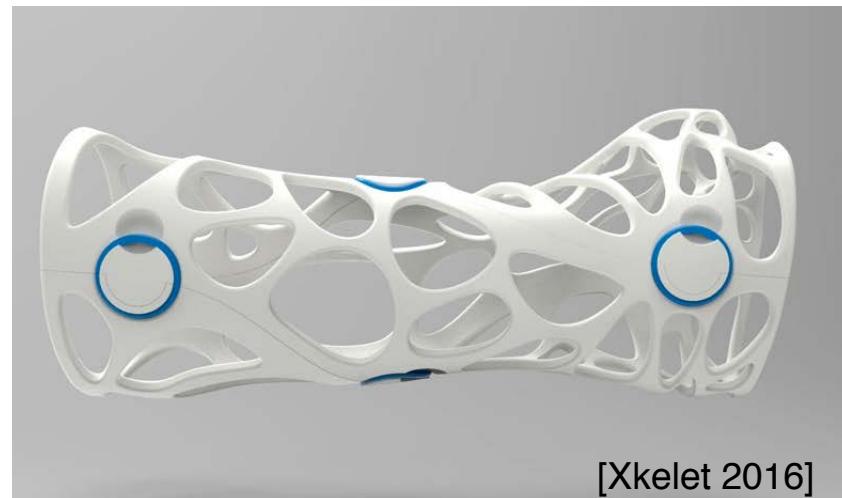
# Related Work

## — 3D Printed Casts

[Evill 2016]



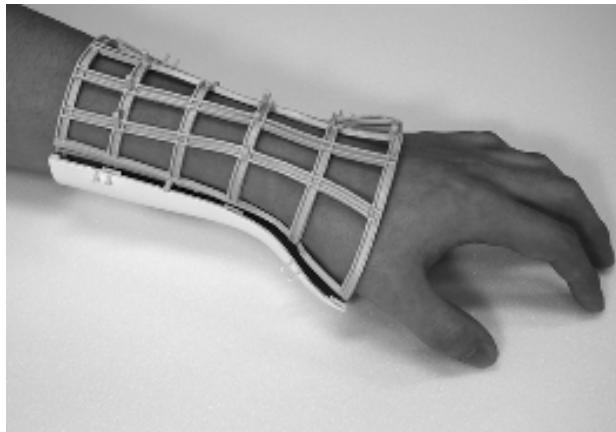
[Karasahin 2016]



[Xkelet 2016]

# Related Work

## — 3D Printed Casts

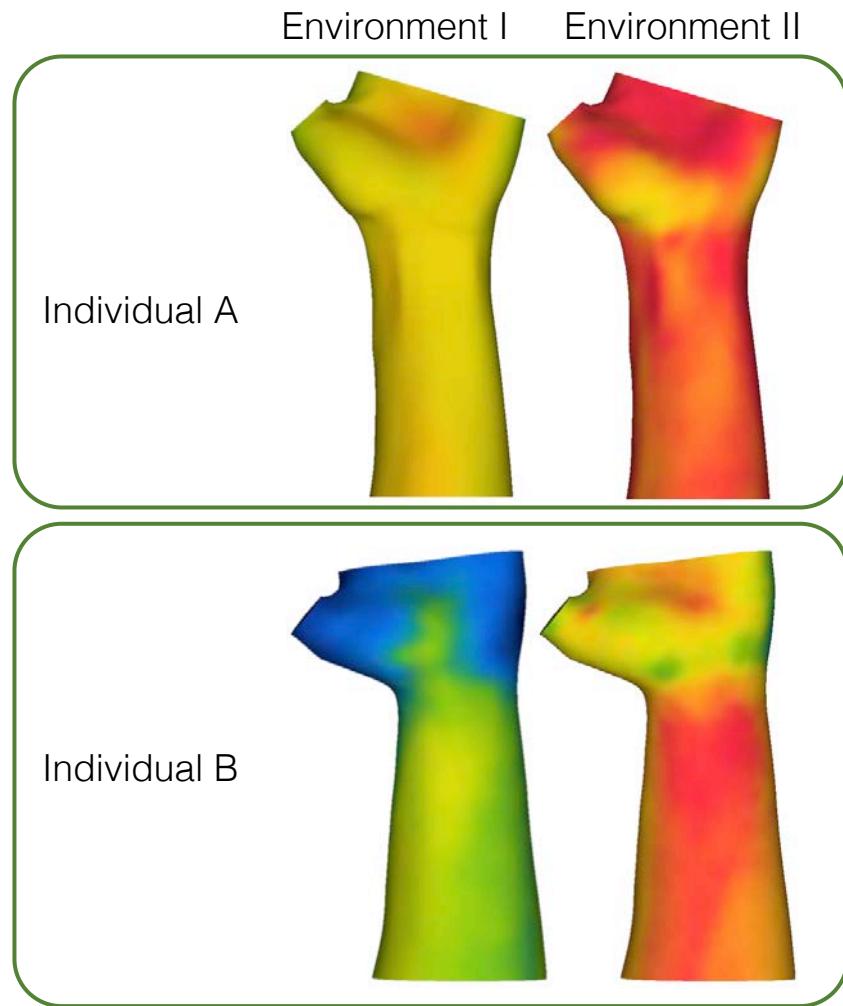


[Kim and Jeong 2016]



[Lin et al. 2016]

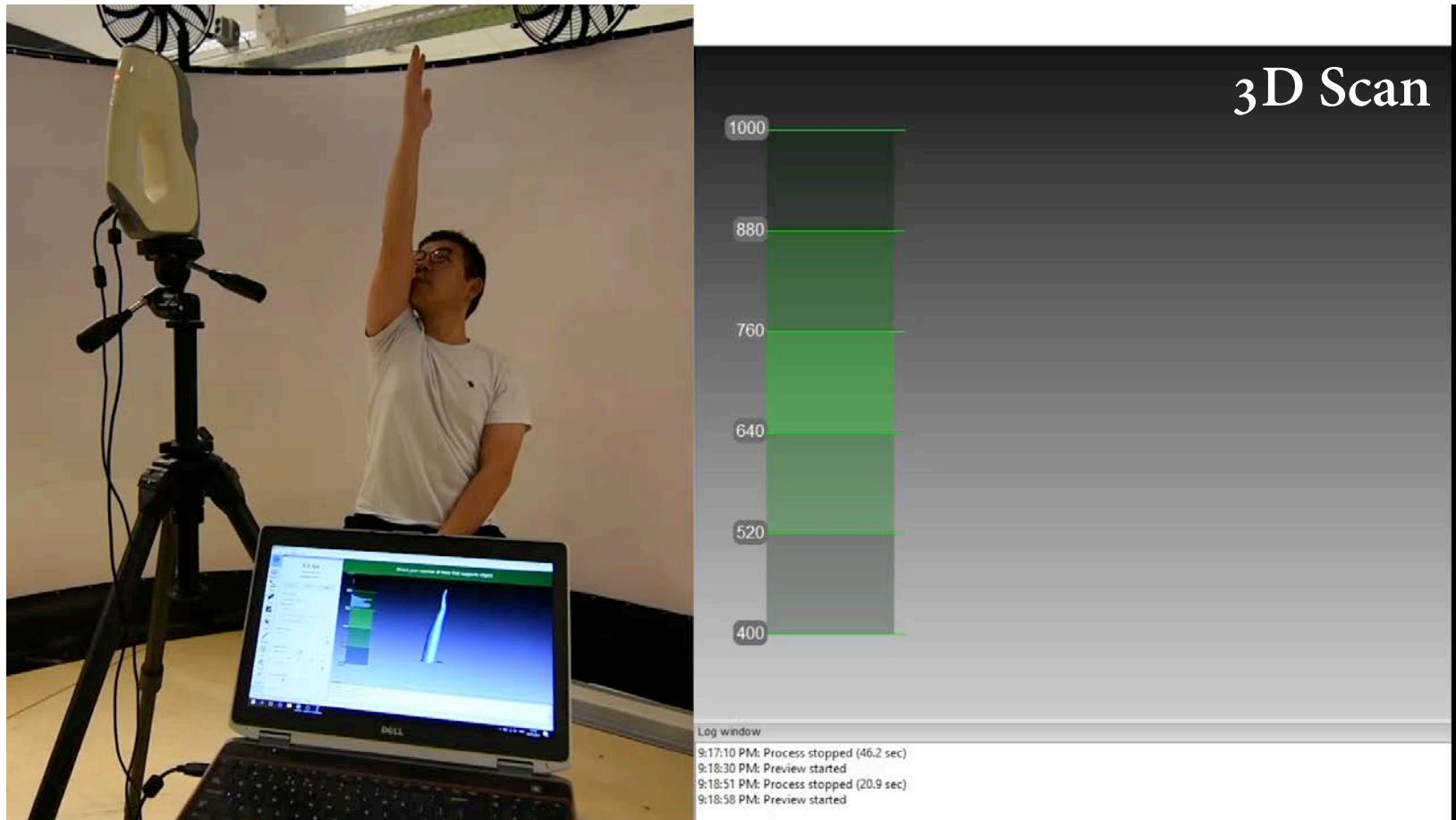
# Design Principles



## cast design goals:

1. custom shape
2. mechanical stiffness
3. thermal-comfort

# Thermal-Comfort: Data Acquisition



# Thermal-Comfort: Data Acquisition



# Thermal-Comfort: Data Acquisition



# Thermal-Comfort Sensitivity

index	thermal-comfort
4	very comfortable
2	comfortable
+0	just comfortable
-0	just uncomfortable
-2	uncomfortable
-4	very uncomfortable

thermal-comfort sensitivity

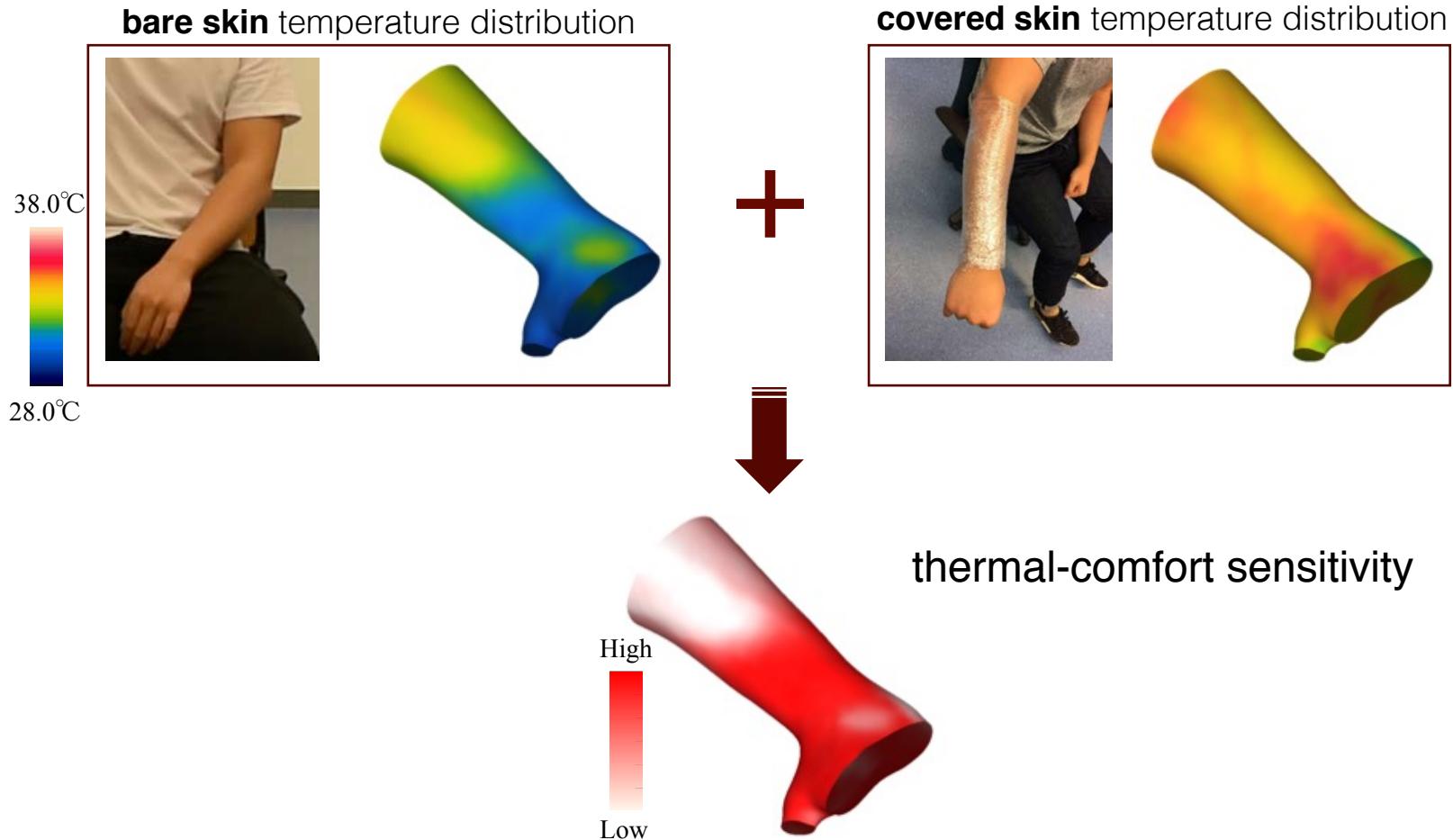
$$C(\mathbf{x}) = \frac{1}{1+e^{-\alpha\Delta T(x)}}$$

$\Delta T(x)$ : local skin temperature change

$\alpha$  : coefficient

[Zhang et al. 2010]

# Thermal-Comfort Sensitivity



# Voronoi Tessellation

$$\min \quad \hat{E}(\Psi) = \boxed{E_P(\Psi)} + \lambda E_T(\Psi)$$

Pattern control term

$E_P(\Psi)$  = centroidal Voronoi tessellation

Uniform distribution



# Voronoi Tessellation

$$\min \quad \hat{E}(\Psi) = E_P(\Psi) + \lambda E_T(\Psi)$$

Thermal term

$E_P(\Psi)$  = centroidal Voronoi tessellation

Thermally sensitive distribution

- Sensitive to temperature
- Not sensitive



# Voronoi Tessellation

$$\min \quad \hat{E}(\Psi) = E_P(\Psi) + \lambda E_T(\Psi)$$

Thermal term

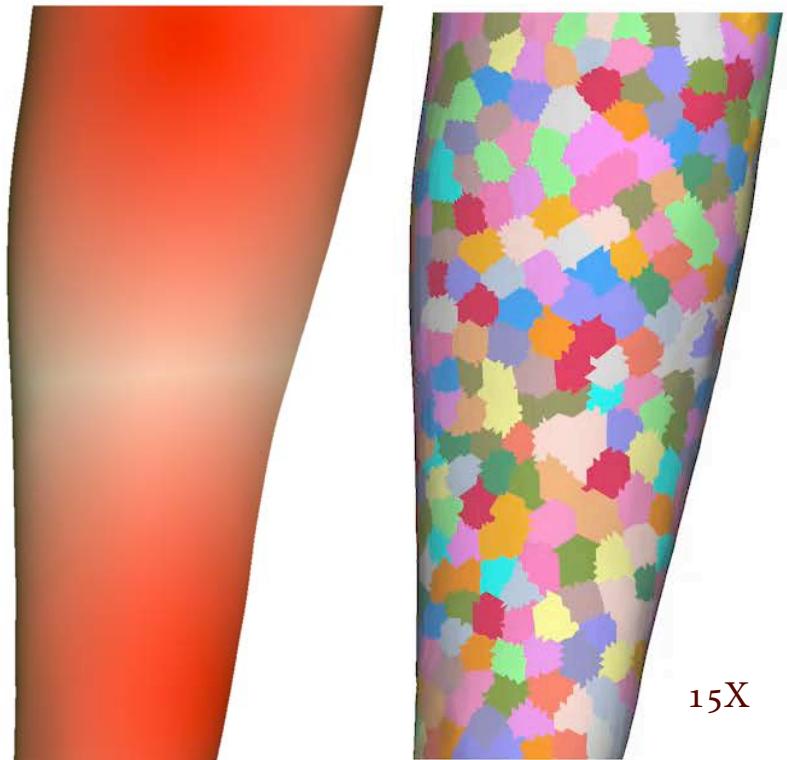
$E_P(\Psi)$  = centroidal Voronoi tessellation

$$E_T(\Psi) = \int_{P_\Psi} C(\mathbf{x}) d\mathbf{x}$$

solid part of cast:  
Voronoi cell edges

- Sensitive to temperature
- Not sensitive

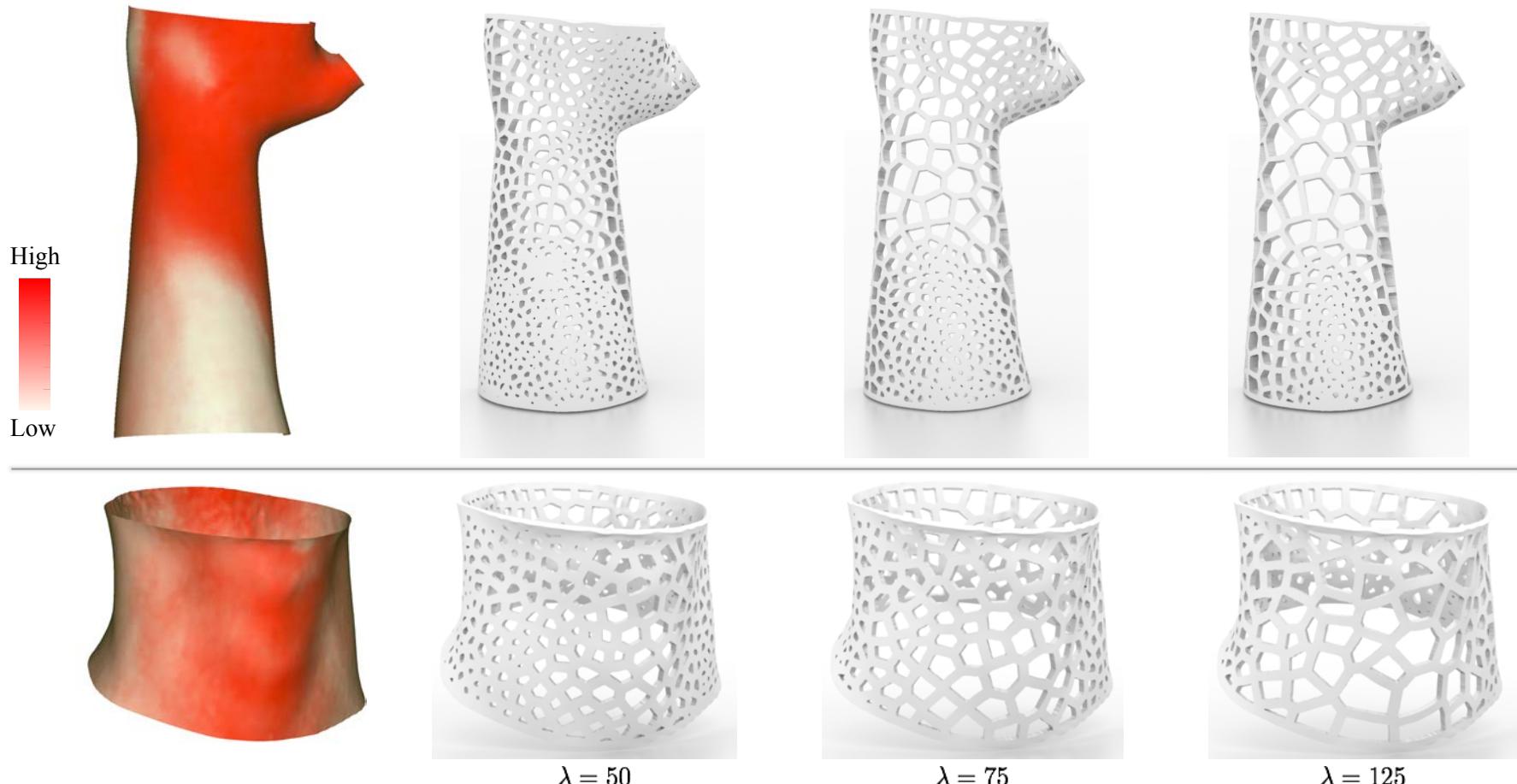
Thermally sensitive distribution



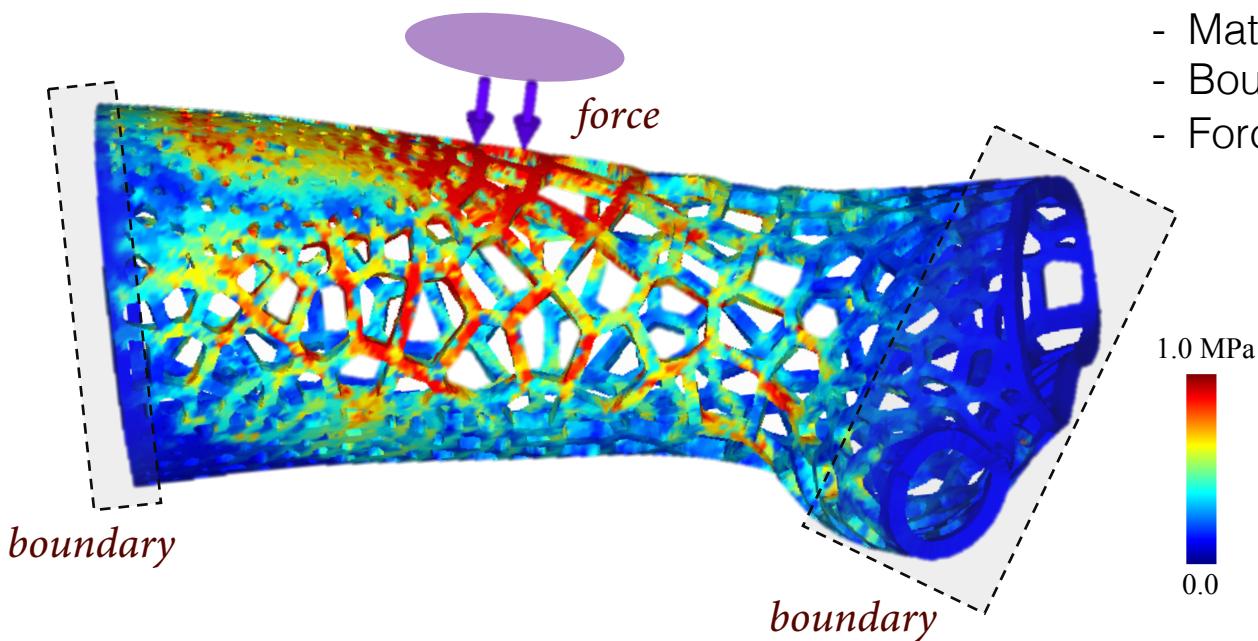
# Pattern Generation

$$\min \quad \hat{E}(\Psi) = E_P(\Psi) + \boxed{\lambda} E_T(\Psi)$$

Contrast coefficient



# Structural Enhancement

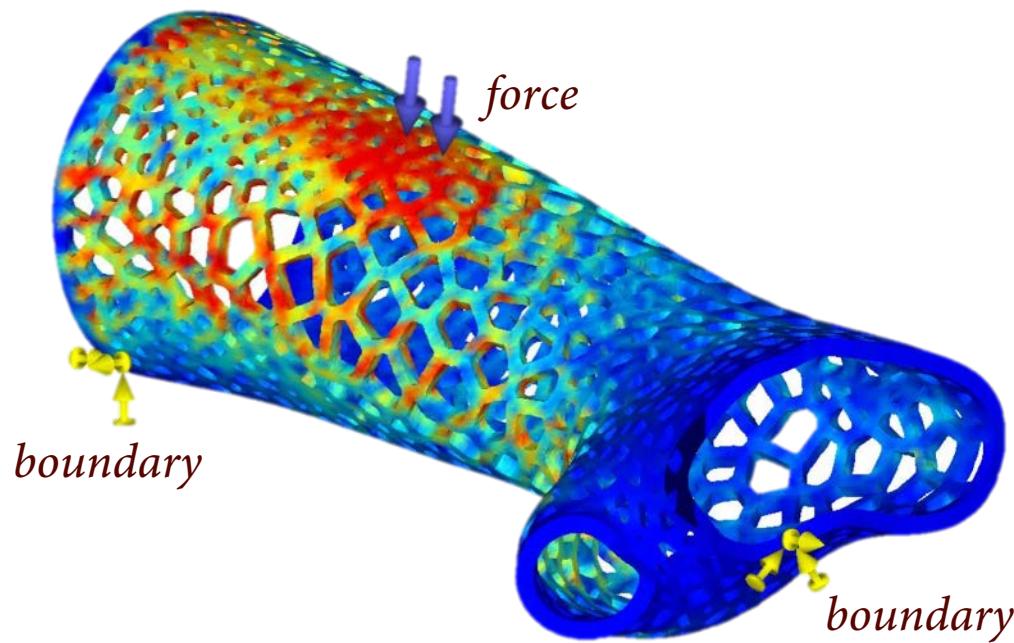


3-point bending test

- Material: PLA
- Boundary: 2 extreme sides
- Force: applied mid-span

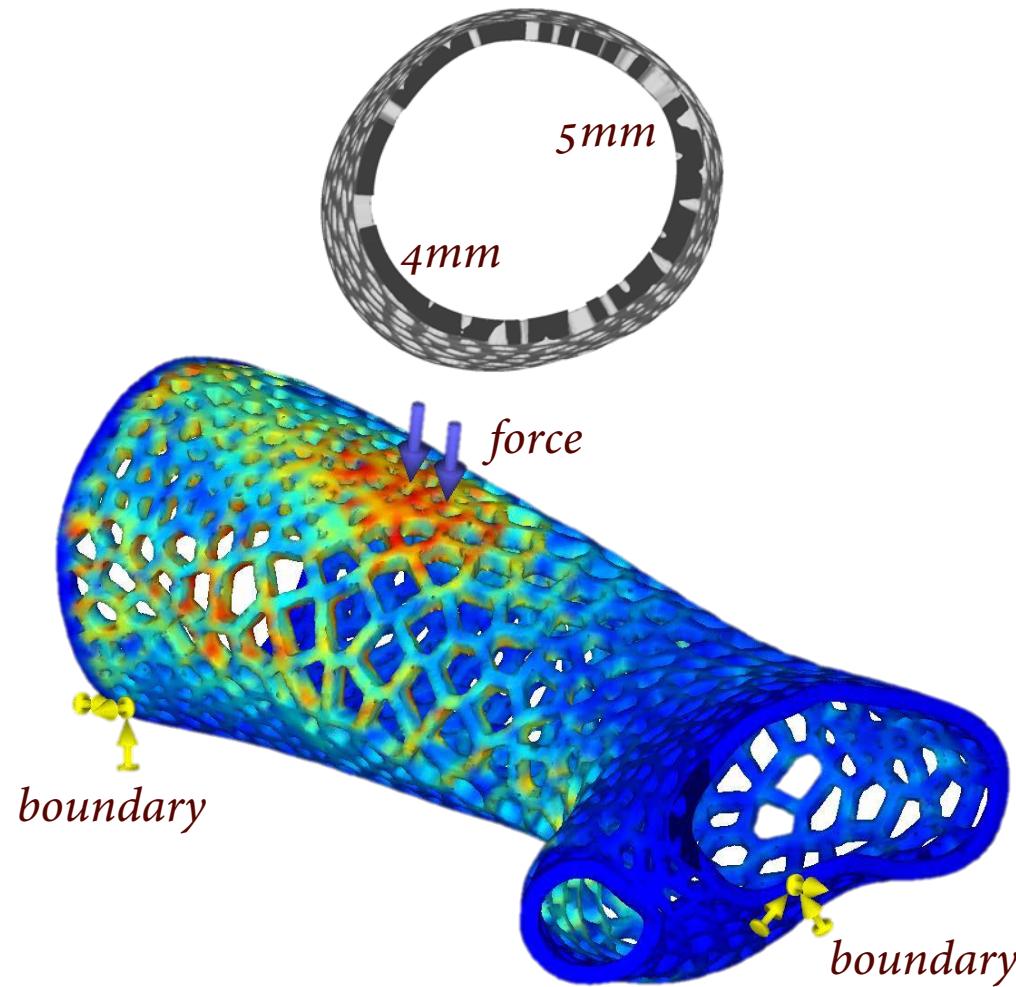


# Structural Enhancement



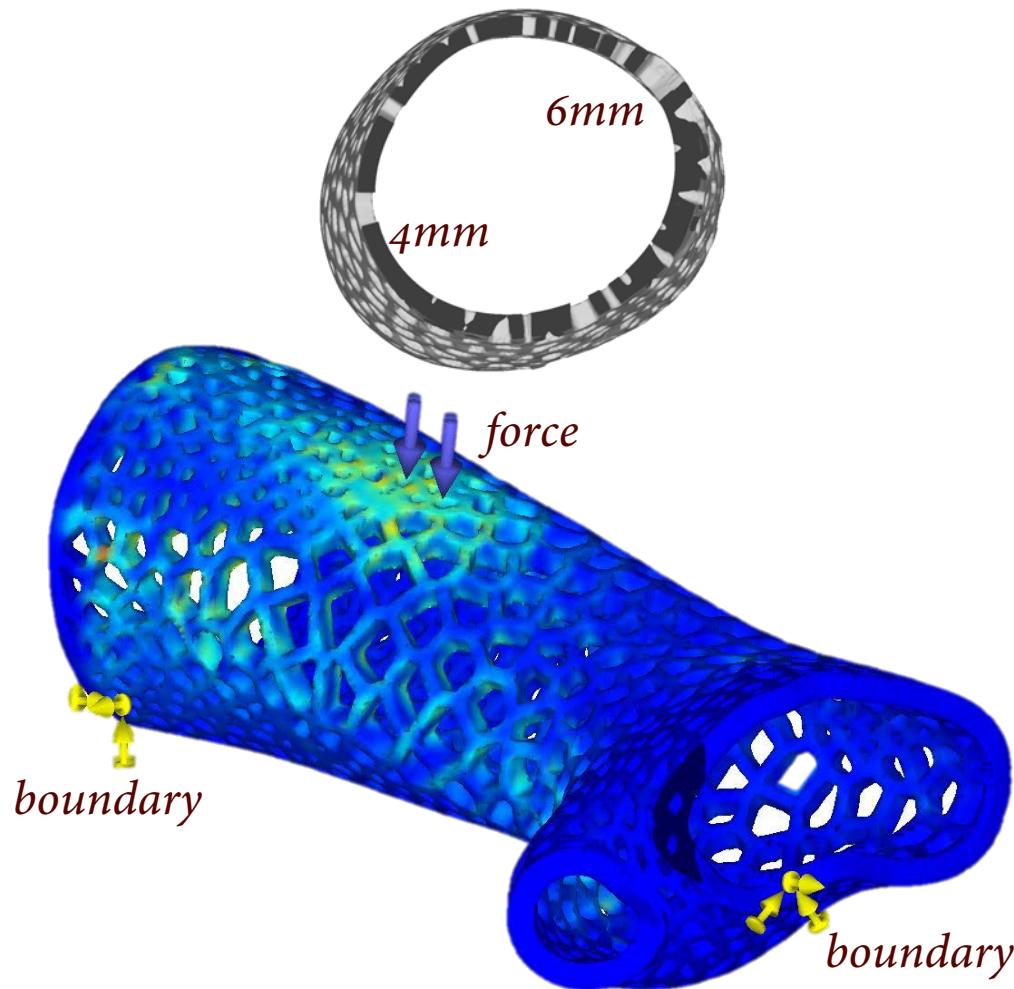
FEA result for uniform thickening (4mm)

# Structural Enhancement



FEA result for non-uniform thickening (4-5mm)

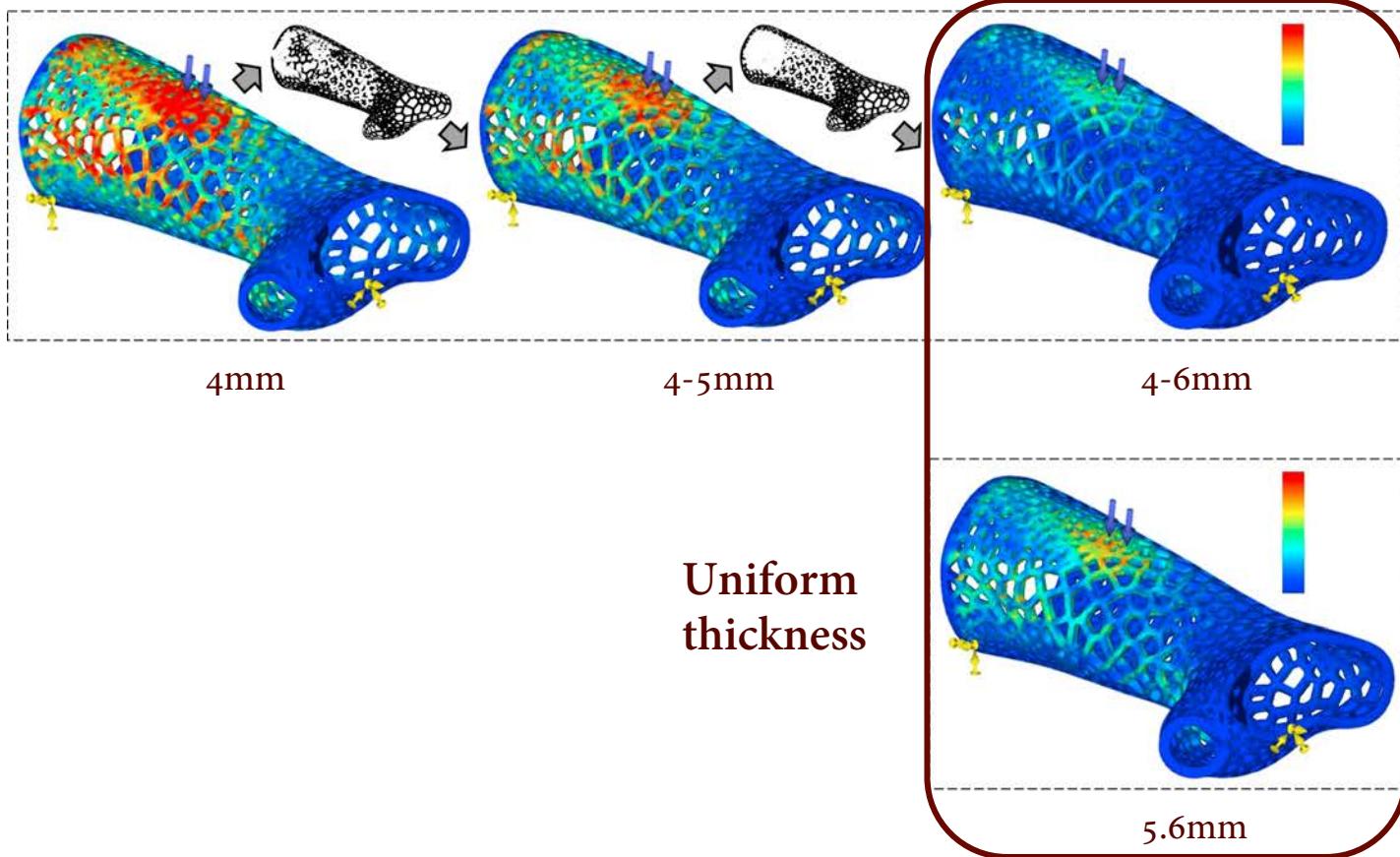
# Structural Enhancement



FEA result for non-uniform thickening (4-6mm)

# Structural Enhancement

Non-uniform thickness



# Our Casts

Prototype A



Prototype C



Prototype D



# Thermal Verification

Uniform Cast



Our Cast



## Conditions:

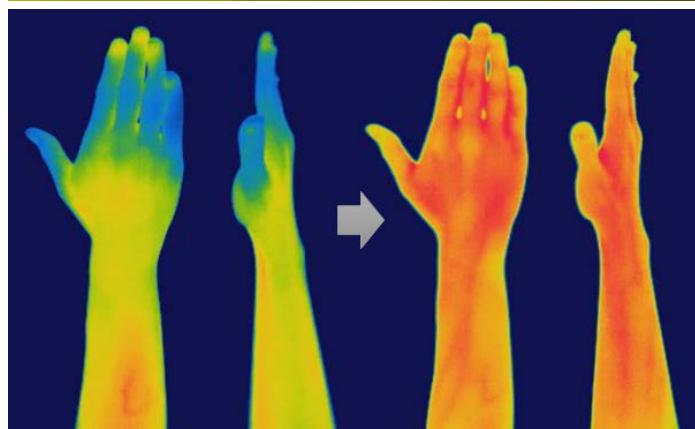
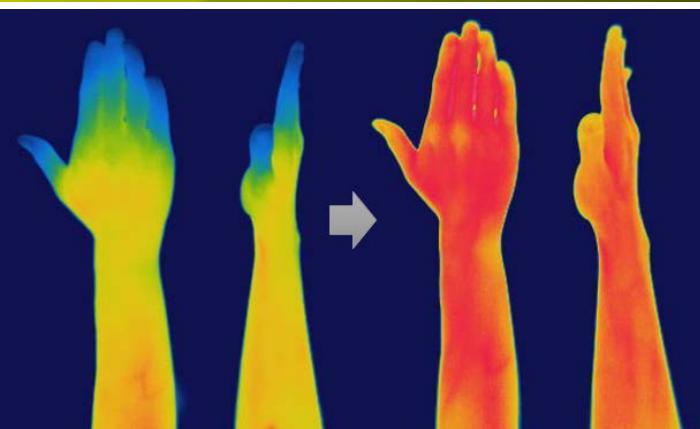
- office
- raised temperature
- 30 minutes

# Thermal Verification

Uniform Cast

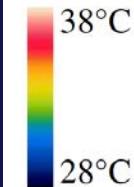


Our Cast



## Conditions:

- office
- raised temperature
- 30 minutes



# Thermal Verification

Uniform Cast



Our Cast

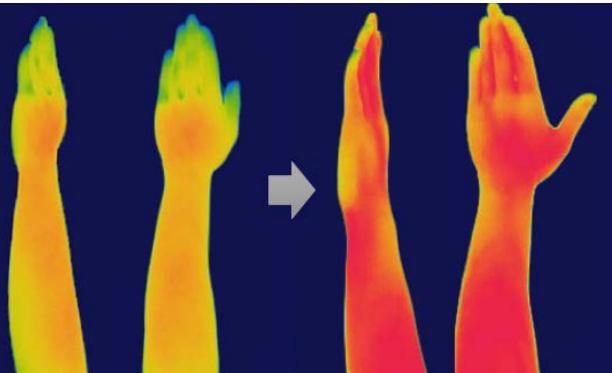


## Conditions:

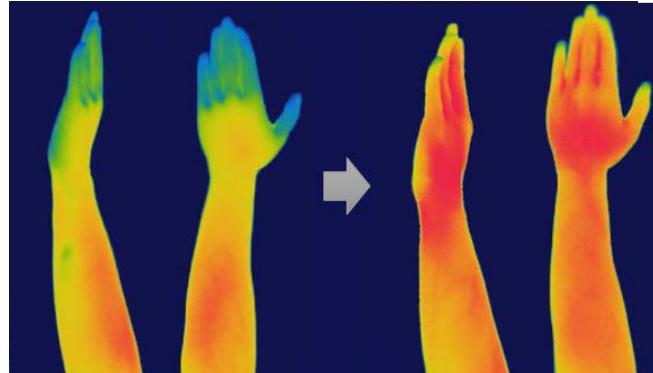
- sauna room
- raised temperature
- 30 minutes

# Thermal Verification

Uniform Cast

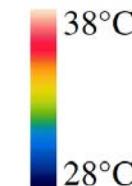


Our Cast



## Conditions:

- sauna room
- raised temperature
- 30 minutes



# Thermal Verification

Uniform Cast



Our Cast

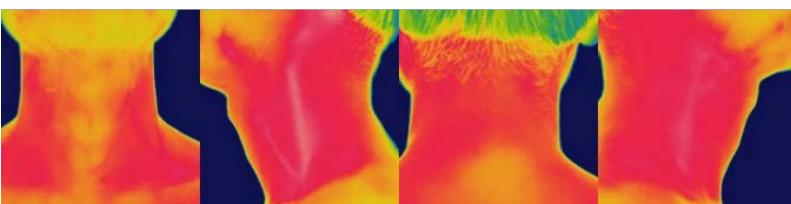
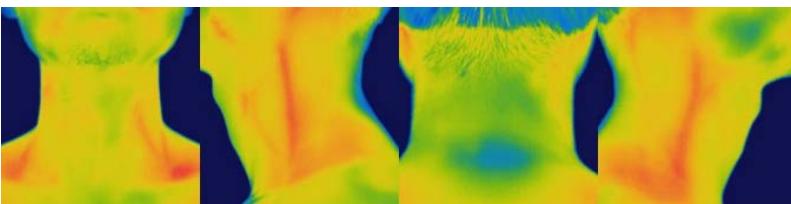


## Conditions:

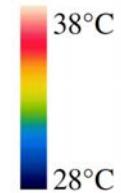
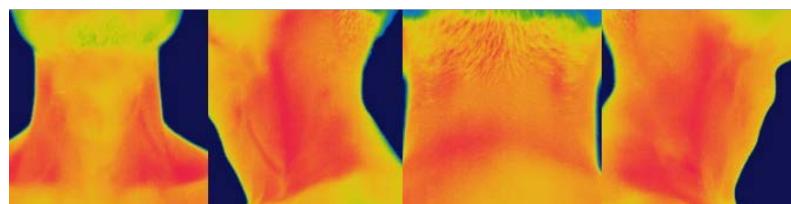
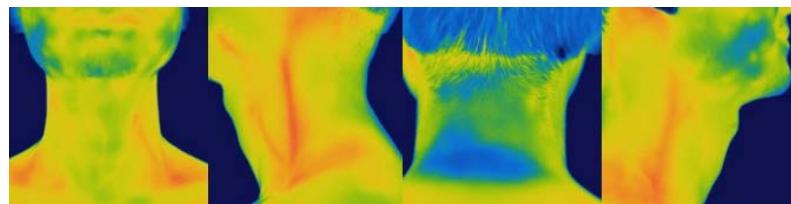
- office
- raised temperature
- 15 minutes

# Thermal Verification

Uniform Cast



Our Cast



## Conditions:

- office
- raised temperature
- 15 minutes

# Thermal Verification

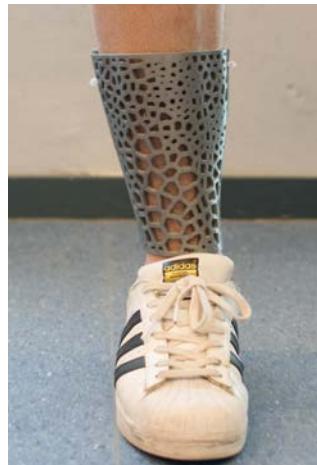
## Uniform Cast



## Conditions:

- office
- raised temperature
- 30 minutes

## Our Cast



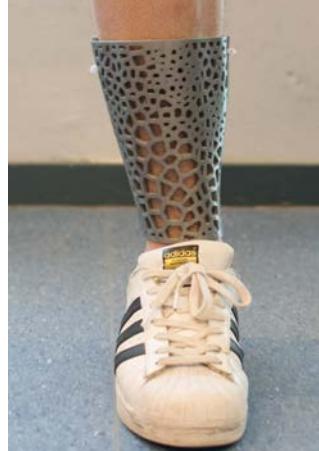
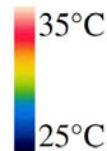
# Thermal Verification

Uniform Cast

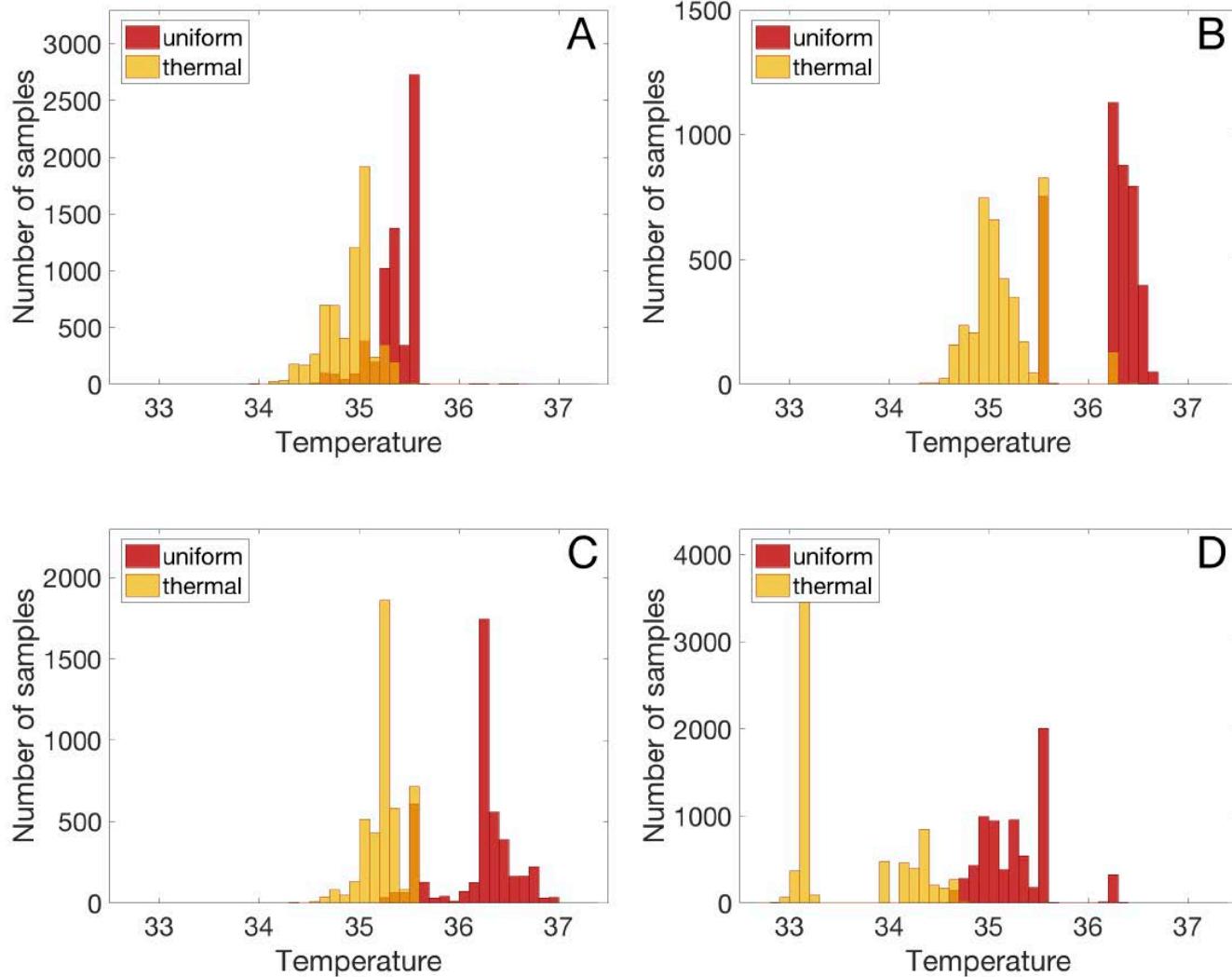


## Conditions:

- office
- raised temperature
- 30 minutes



# Thermal Verification

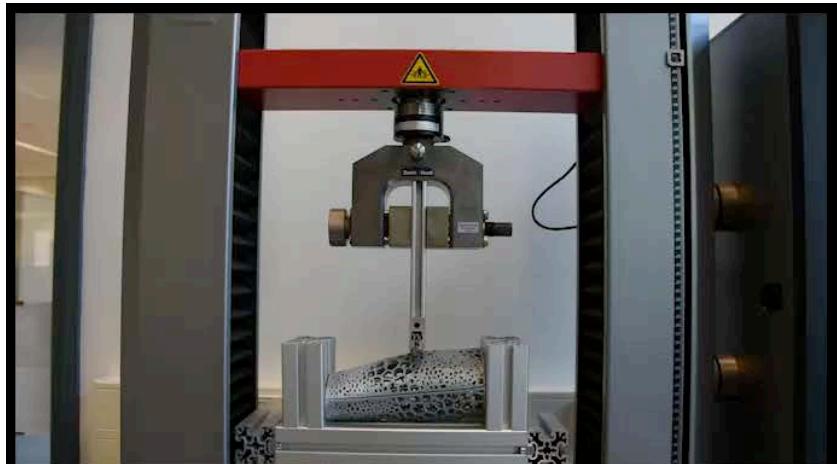


# Mechanical Verification

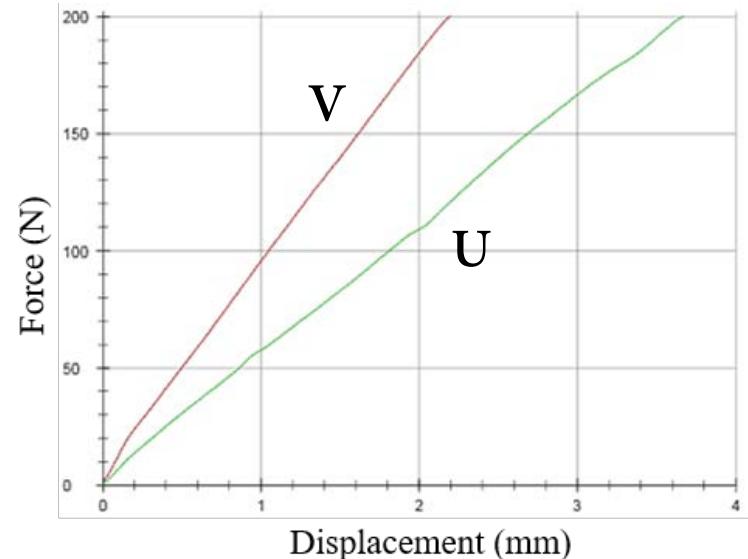
Uniform Thickness Cast (U) (4.4mm)



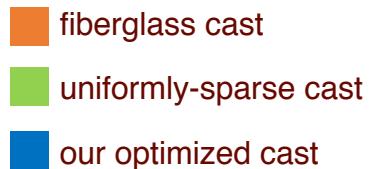
Our Cast (V) (4-6mm)



$$\text{weight(V)} = \text{weight(U)}$$



# User Feedback

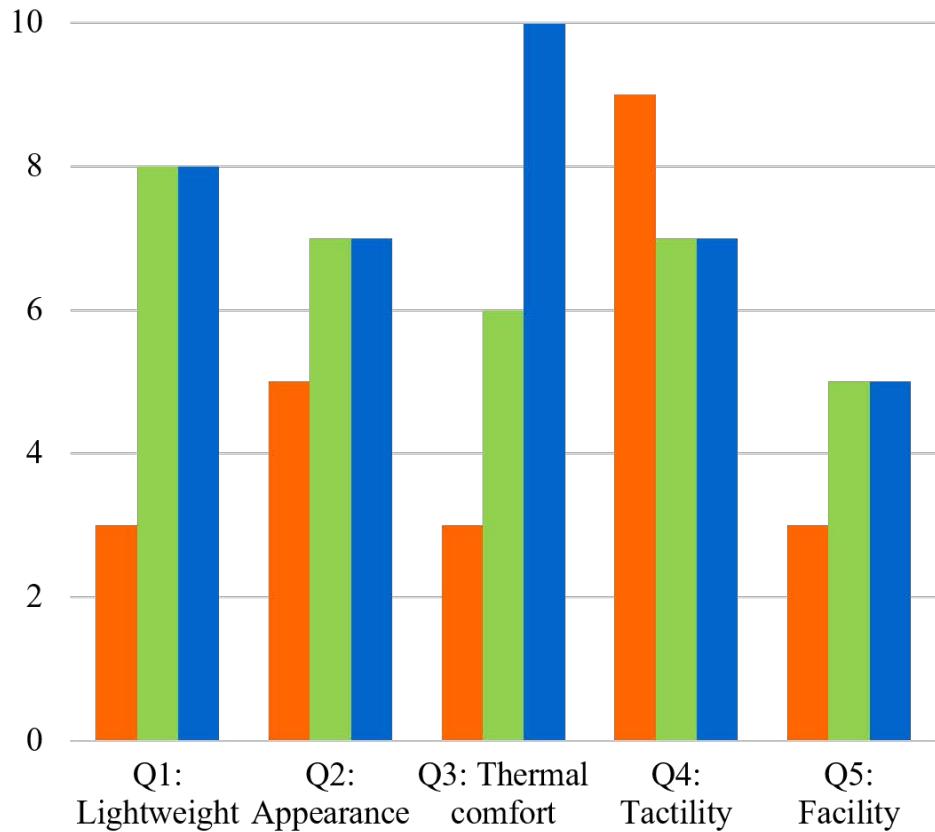


Questionnaire on 5 aspects:

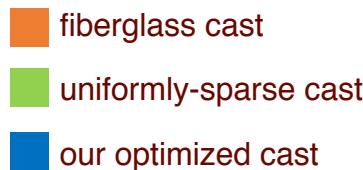
- *Q1 --- lightweight*
- *Q2 --- appearance*
- *Q3 --- thermal-comfort*
- *Q4 --- tactility*
- *Q5 --- facility*

\* *facility is an overall assessment of perception with the cast regarding regular activities, itchiness and its resistance to wear and tear*

Participant A – Right Arm



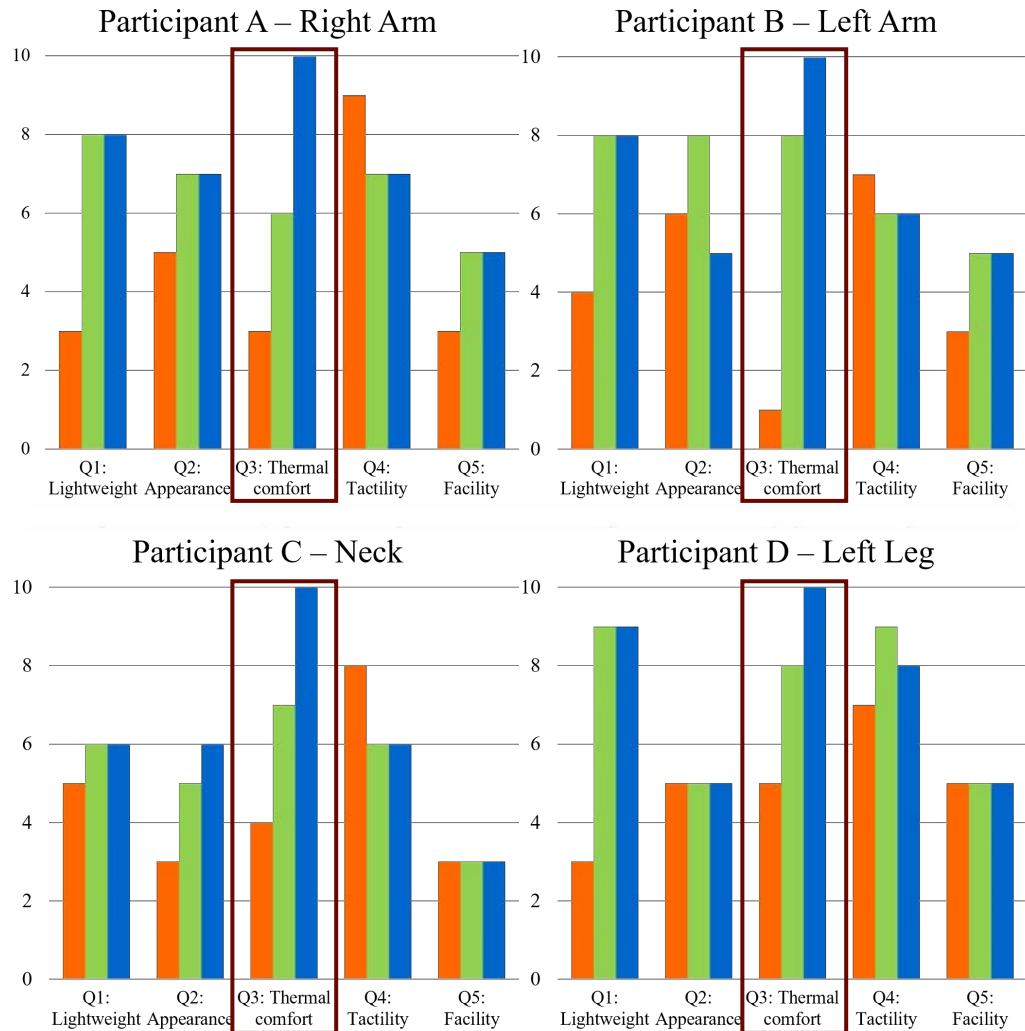
# User Feedback



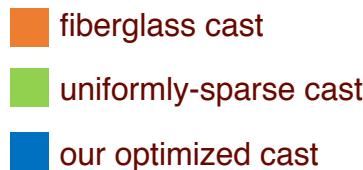
*Questionnaire on 5 aspects:*

- *Q1 --- lightweight*
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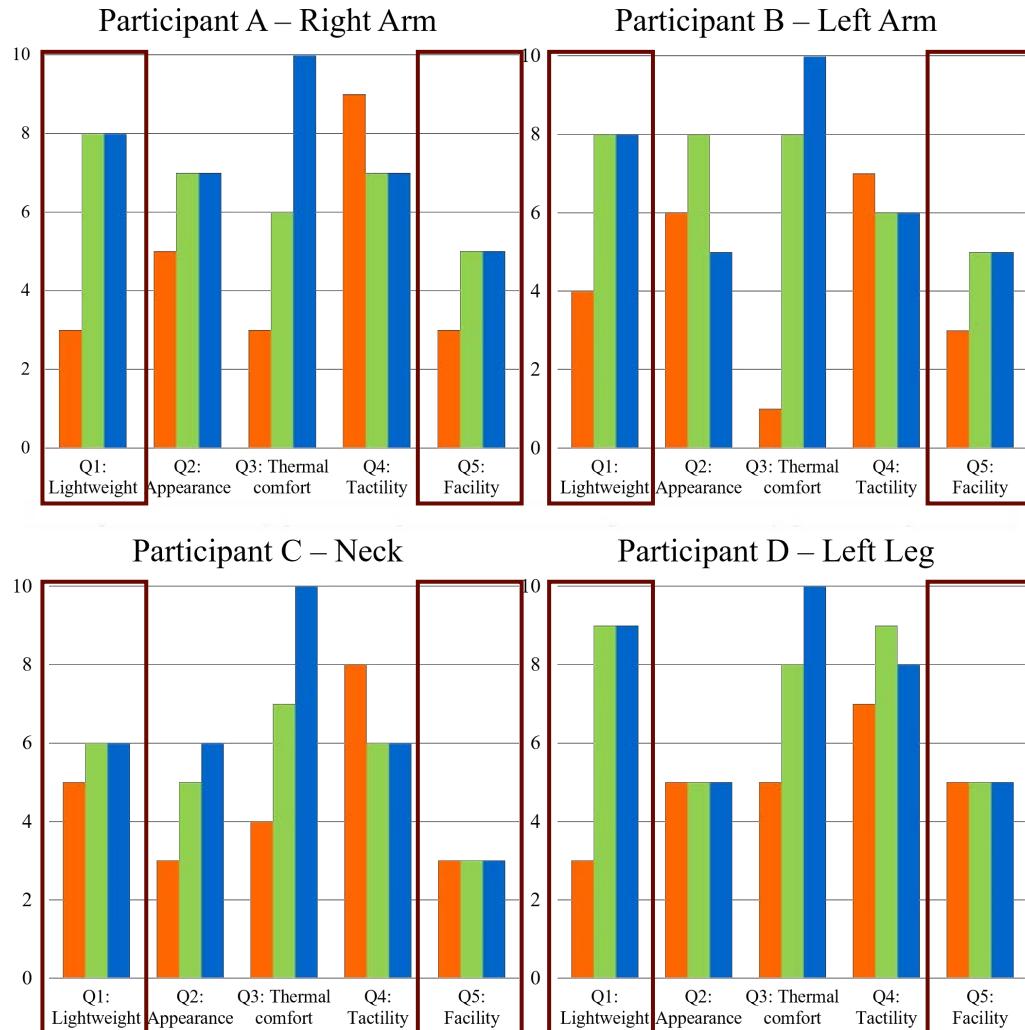
# User Feedback



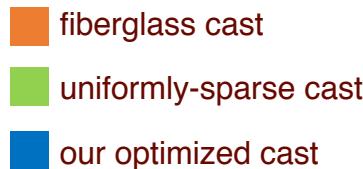
Questionnaire on 5 aspects:

- Q1 --- lightweight
- Q2 --- appearance
- Q3 --- thermal-comfort
- Q4 --- tactility
- Q5 --- facility

\* facility is an overall assessment of perception with the cast regarding regular activities, itchiness and its resistance to wear and tear



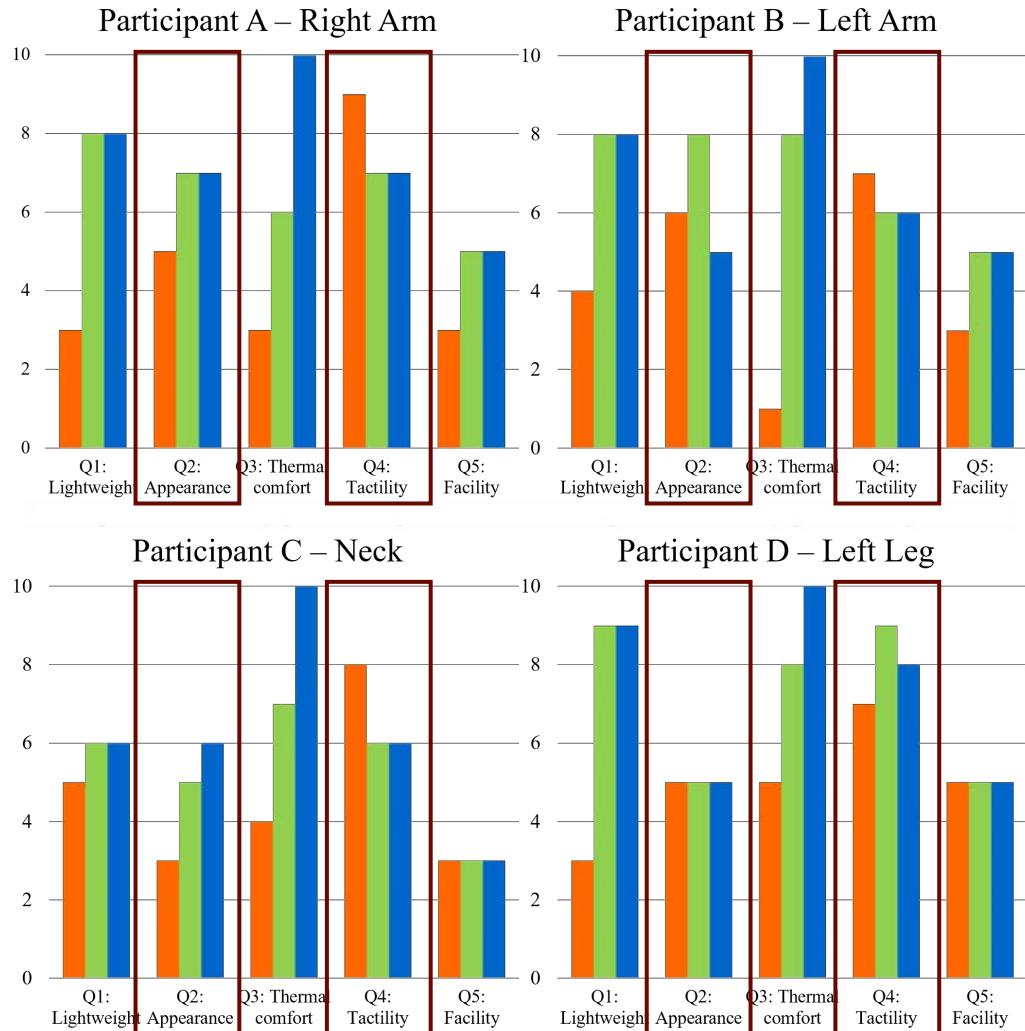
# User Feedback



*Questionnaire on 5 aspects:*

- *Q1 --- lightweight*
- *Q2 --- appearance*
- *Q3 --- thermal-comfort*
- *Q4 --- tactility*
- *Q5 --- facility*

\* *facility is an overall assessment of perception with the cast regarding regular activities, itchiness and its resistance to wear and tear*



# Heuristic Evaluation

## Interview with an orthopedic surgeon

- Improvements
  - Thermal-comfort
  - Custom-fit
- Challenges
  - 3D scanning of injured body
  - Tactile-comfort
  - Post-processing



Doctor Leon Diederix

# THANK YOU FOR YOUR ATTENTION!

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- Chinese Scholarship Council

