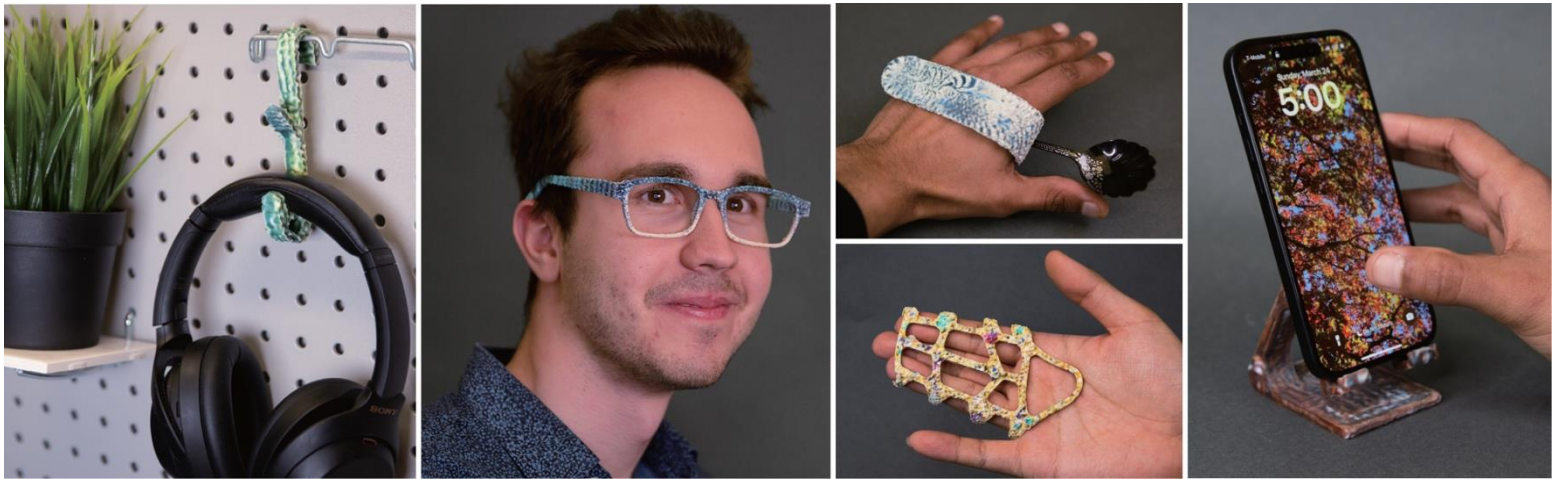
MechStyle

Augmenting Generative AI with Mechanical Simulation to Create Stylized and Structurally Viable 3D Models

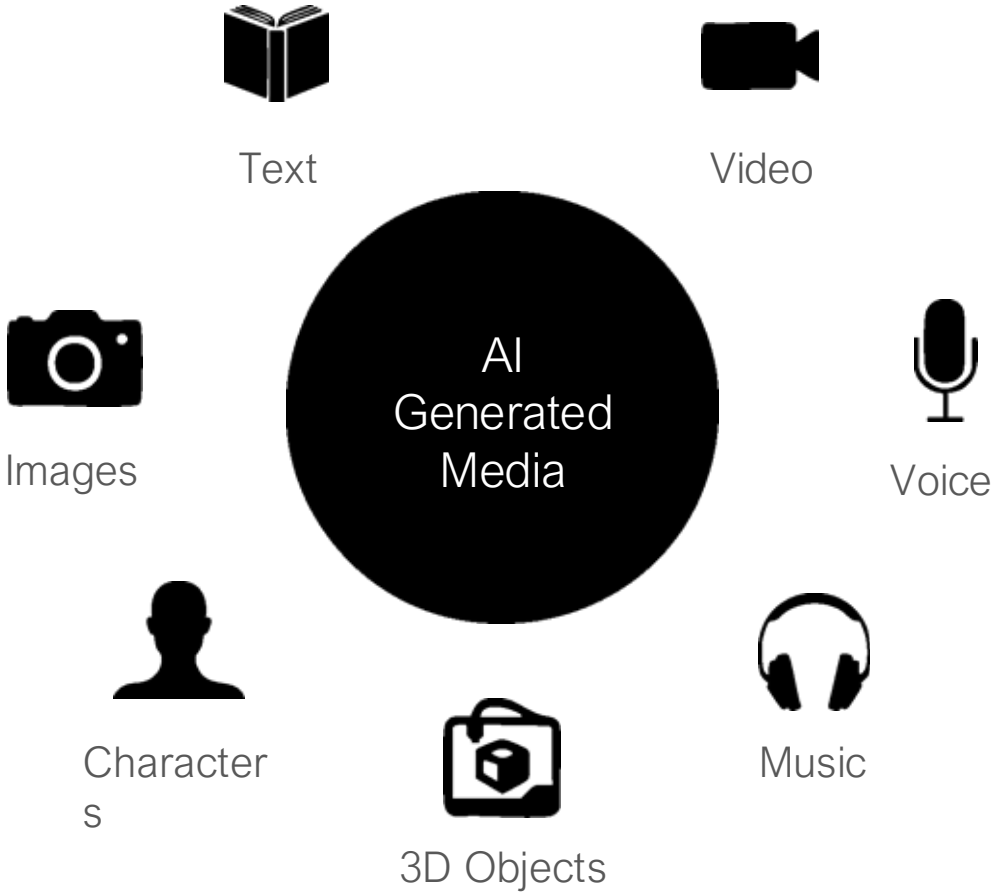


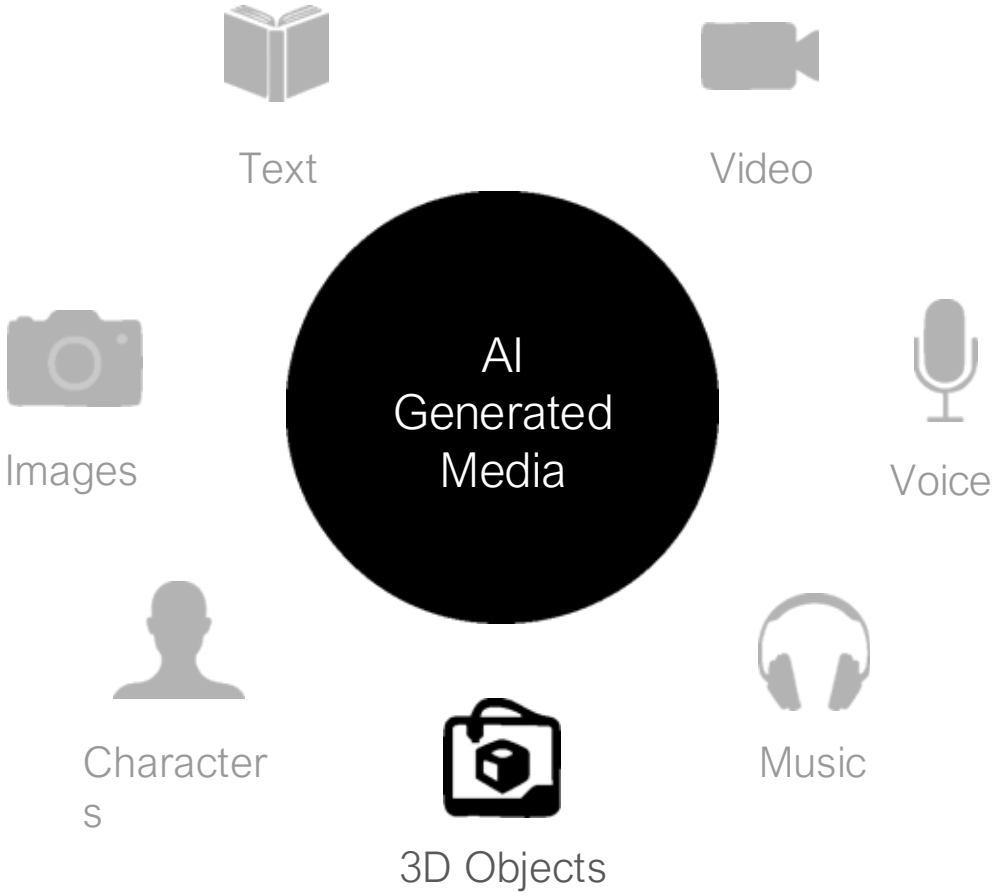
ACM SCF 2025

Faraz Faruqi, Amira Abdel-Rahman, Leandra Tejedor, Martin Nisser, Jiaji Li, Vrushank Phadnis, Varun Jampani, Neil Gershenfeld, Megan Hofmann, Stefanie Mueller

HCI ENGINEERING
MIT CSAIL
Google Research
Northeastern Khoury College of Computer and Information Sciences
The Center for Bits and Atoms Massachusetts Institute of Technology
stability.ai


AI GENERATED
DESIGN


Text
Video
AI Generated Media
Images
Voice
Characters
3D Objects
Music


Text
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Generative AI for Creating **Functional Objects**



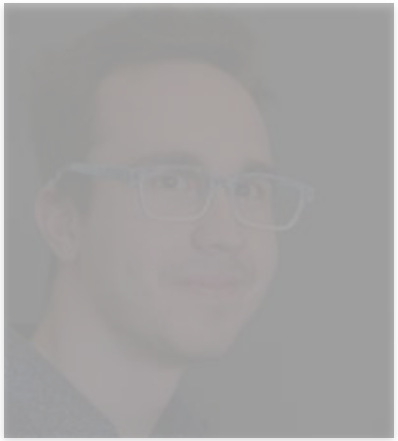





Generative AI for Creating **Home Decor Objects**

Generative AI for Creating **Personal Accessories**

Generative AI for Creating **Medical Devices**



Generative AI for Creating **Functional Objects**








BACKGROUND

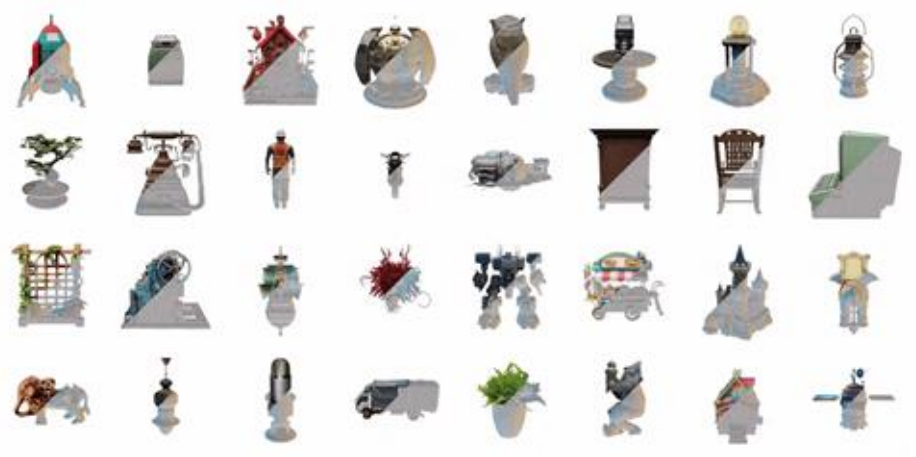
3D Model Reconstruction

DreamFusion
Poole et al. 2022

TRELLIS
Xiang et al. 2025

3D Model Reconstruction - Current Capabilities

- **Text/Image to 3D Generation**
  e.g., “a futuristic red motorcycle” → full mesh
- **Multi-view Consistency**
  Generates coherent geometry from different angles
- **Style Transfer & Remixing**
  Modify shape or texture based on visual reference
- **High-Resolution Texture Synthesis**
  Detailed surfaces for realistic rendering
- **Editable Latent Spaces**
  Latent codes allow interpolations and semantic control
- **Category-level Generalization**
  Works across all categories due to large dataset



Generative AI is great at
creating 3D models for on-screen display

Generative AI is great at
creating 3D models for on-screen display

… but those models
do not work in the real world

Some examples:

“A chair for a person to sit on” -> will break or tip over

“A toy car that can move” -> won’t move when fabricated

“A purse made from leather” -> won’t feel like leather

CHALLENGE:

How to encode physical properties into generated 3D models?

Three Dimensions of Functionality

Functional Affordance

Retaining key regions like joints, handles, or openings to ensure desired affordances.

Style2Fab

UIST 2023

Tactile Properties

Designing surface textures for touch, haptics, and contact-aware robotics.

TactStyle

CHI 2025

Mechanical Constraints

Editing shapes while preserving load-bearing performance.

MechStyle

SCF 2025

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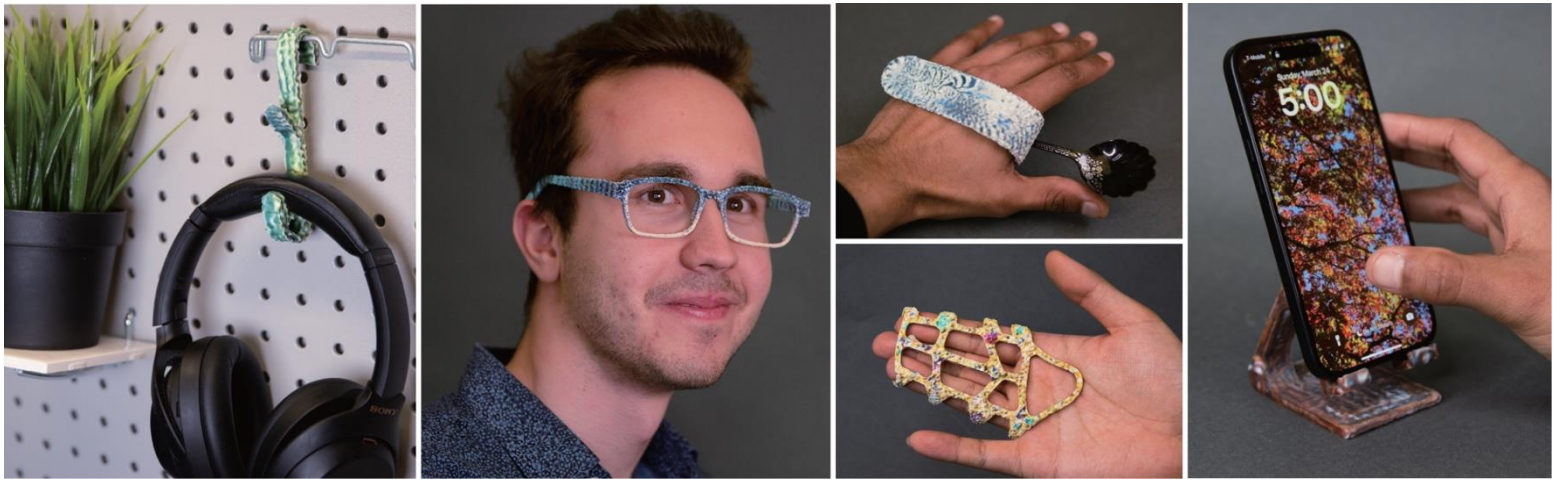

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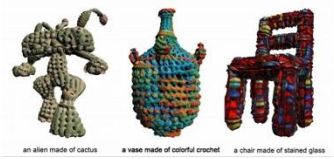
HCI ENGINEERING · MIT CSAIL · W · Google Research · Northeastern Khoury College of Computer and Information Sciences · The Center for Bits and Atoms Massachusetts Institute of Technology · stability.ai

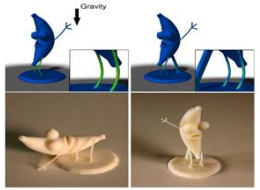
RELATED WORK

Related Work



Text2Mesh
Michel et al. 2022

Style2Fab
Faruqi et al. 2023



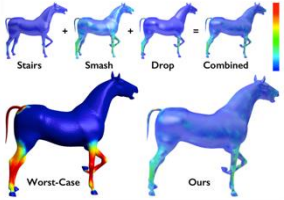
Stress Relief
Stava et al. 2012

Xmesh
Ma et al. 2023

3D Generative
AI Methods

TactStyle
Faruqi et al., 2025

Fabrication-Aware
3D Manipulation



Langlois et al., 2016

Structural Analysis and
Failure Prediction

Related Work

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3D Generative AI Methods

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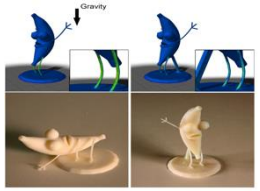

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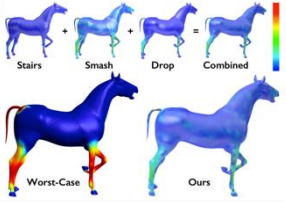

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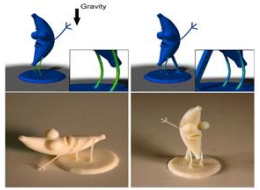

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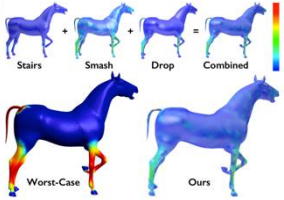

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Structural Analysis and
Failure Prediction

Original 3D Model

Original 3D Model

Stylization

Prompt: *A pair of eyeglasses in blue and green fish scale texture*

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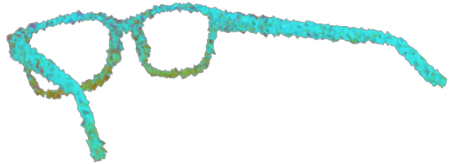

Stylized 3D Model

Original 3D Model

Stylization

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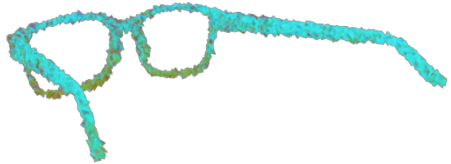

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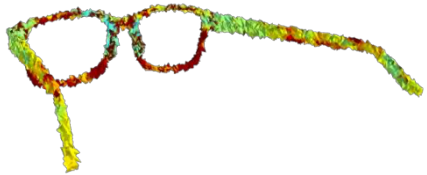
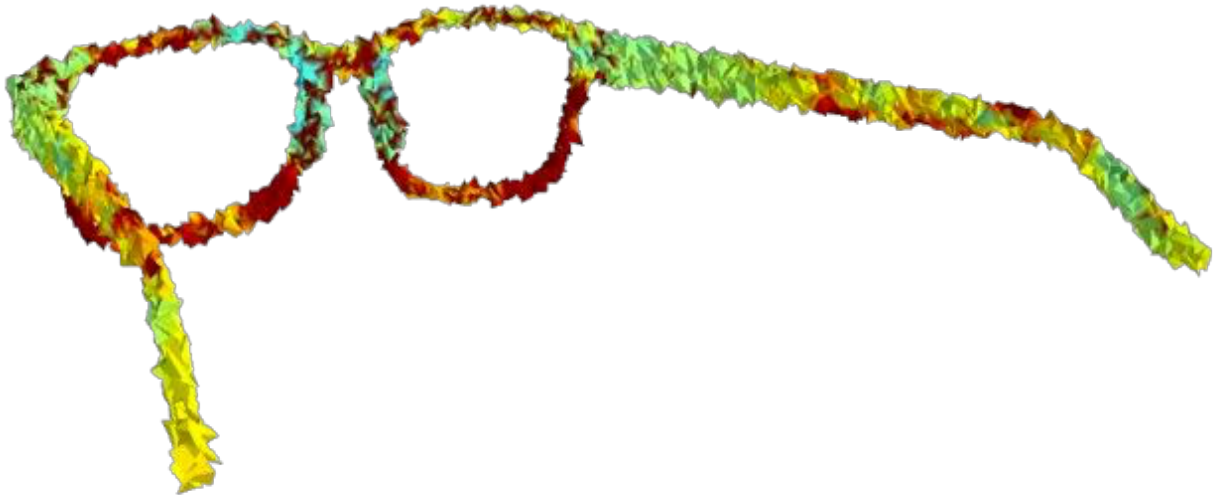
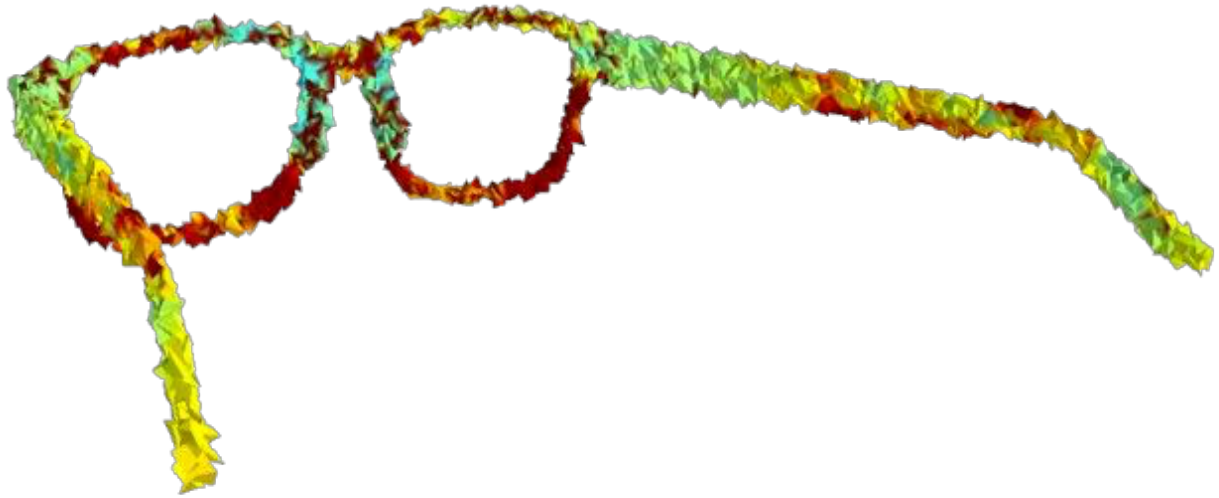


FEA Simulation Result



Region of High Stress
(High likelihood of breaking after fabrication)



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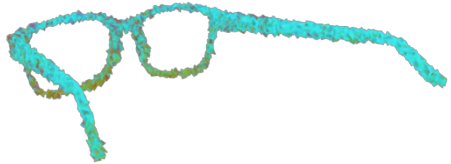
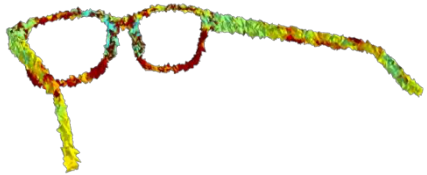


Stylized 3D Model



FEA Simulation Result

FORMATIVE STUDY

Formative Study

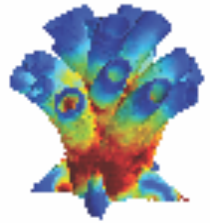
Formative Study

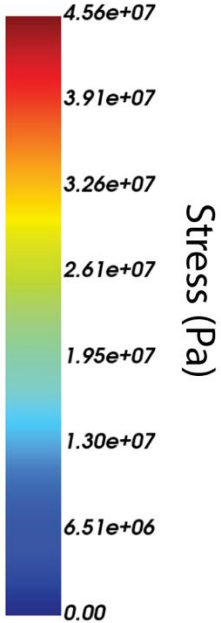
Stylized Model

Formative Study

Stylized Model

Structural Simulation





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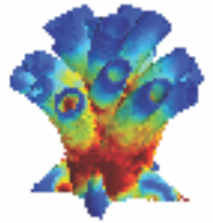

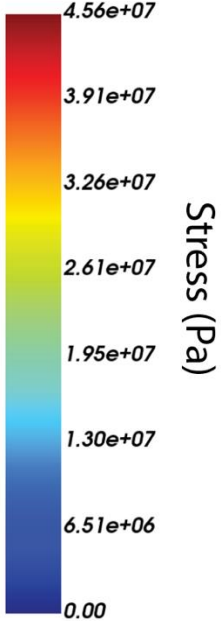

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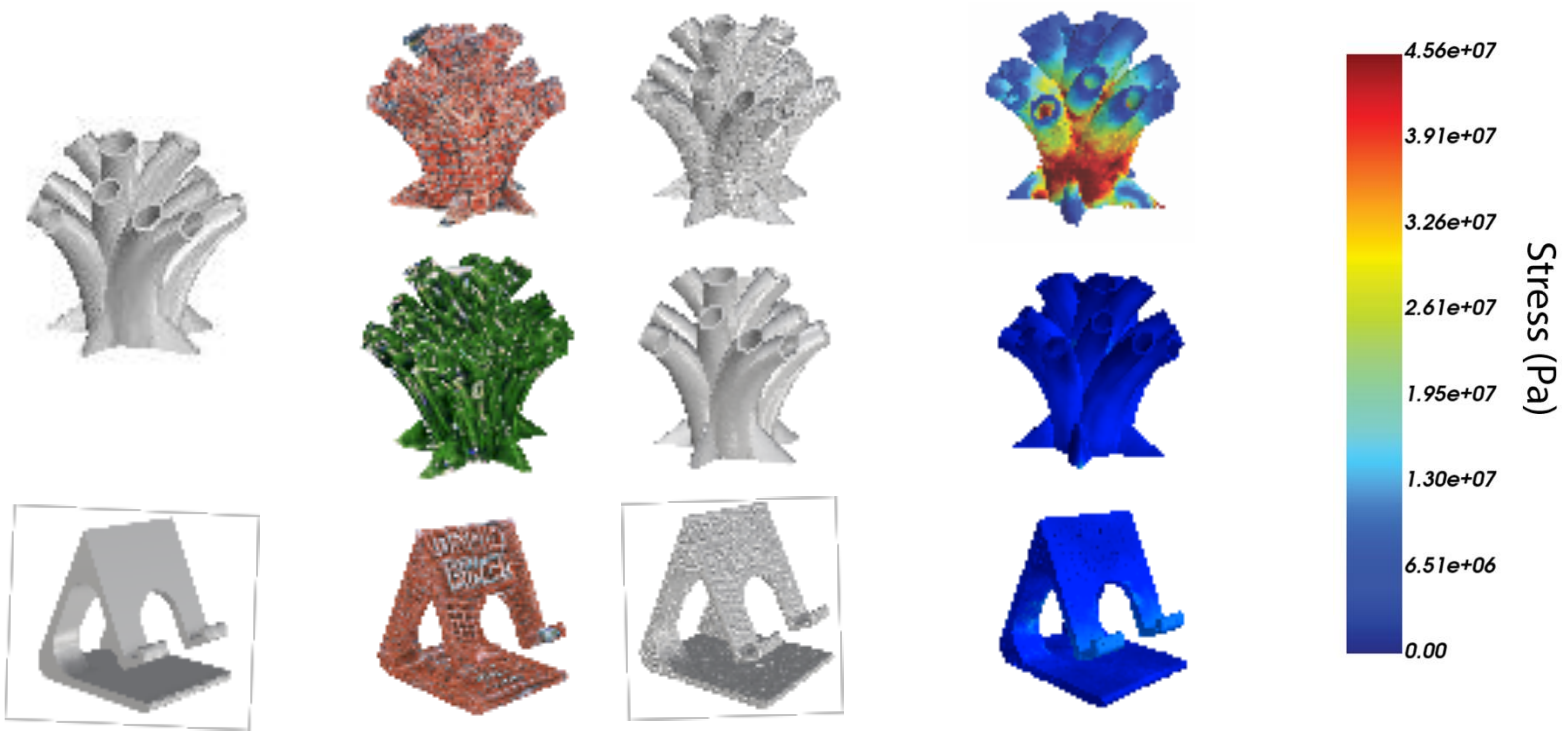

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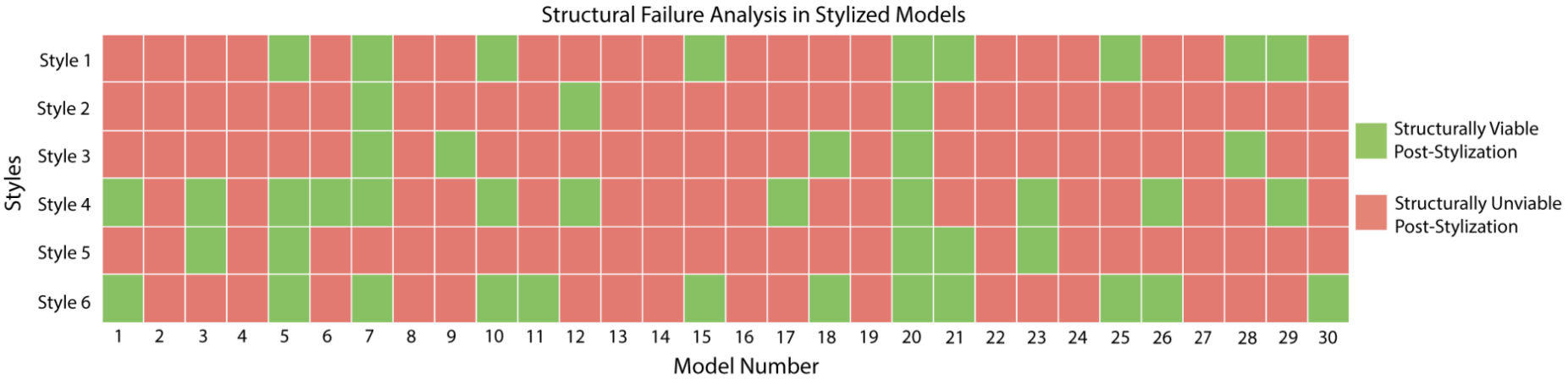


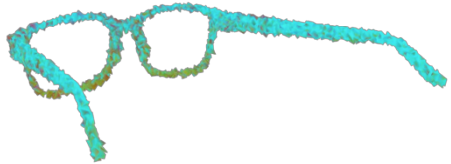
30 most popular models from Thingiverse
6 styles from XMesh dataset

Only 25.55% of models were structurally viable after being stylized.

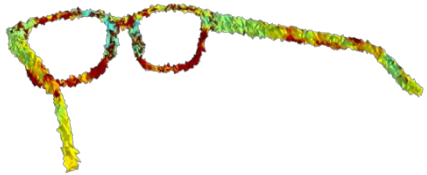
Original 3D Model

Stylization

Prompt: *A pair of eyeglasses in blue and green fish scale texture*



Stylized 3D Model



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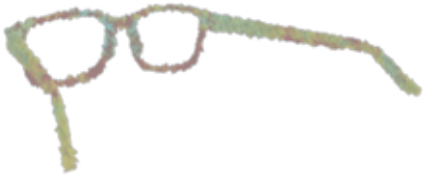

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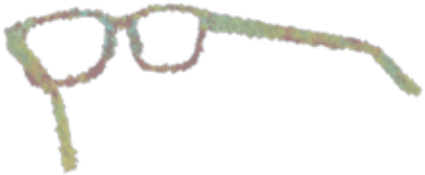

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Original 3D Model

MechStyle

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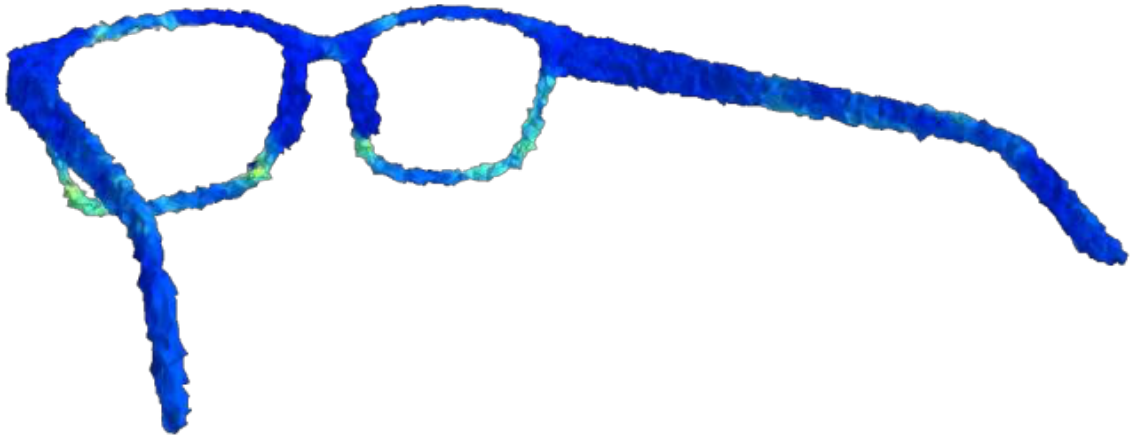
Stylized 3D Model

FEA Simulation Result

Region of Low Stress
(Low likelihood of breaking after fabrication)



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Stylization

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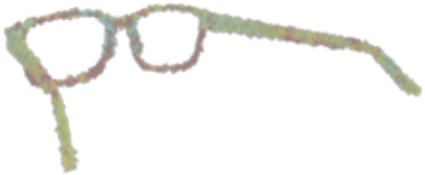
Stylized 3D Model



FEA Simulation Result

Original 3D Model

MechStyle

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Stylized 3D Model

FEA Simulation Result

SYSTEM DESIGN

GenAI Model

GenAI Model

Generative AI
3D Modification

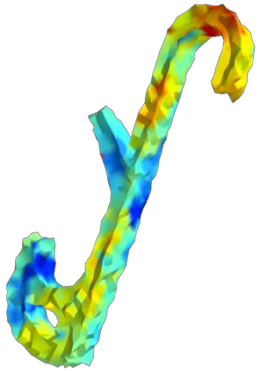
Intermediate Geometry

GenAI Model

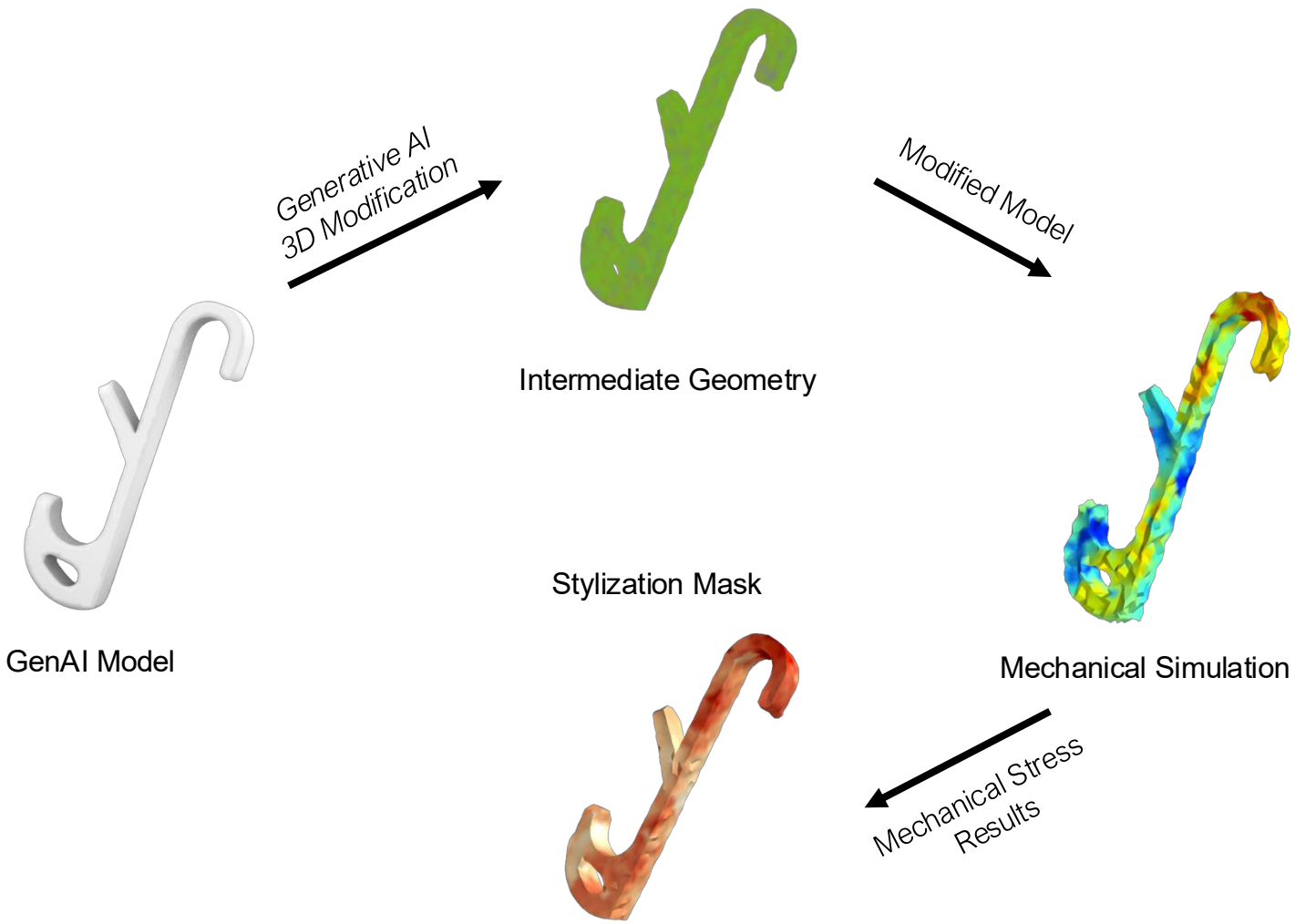
Generative AI
3D Modification

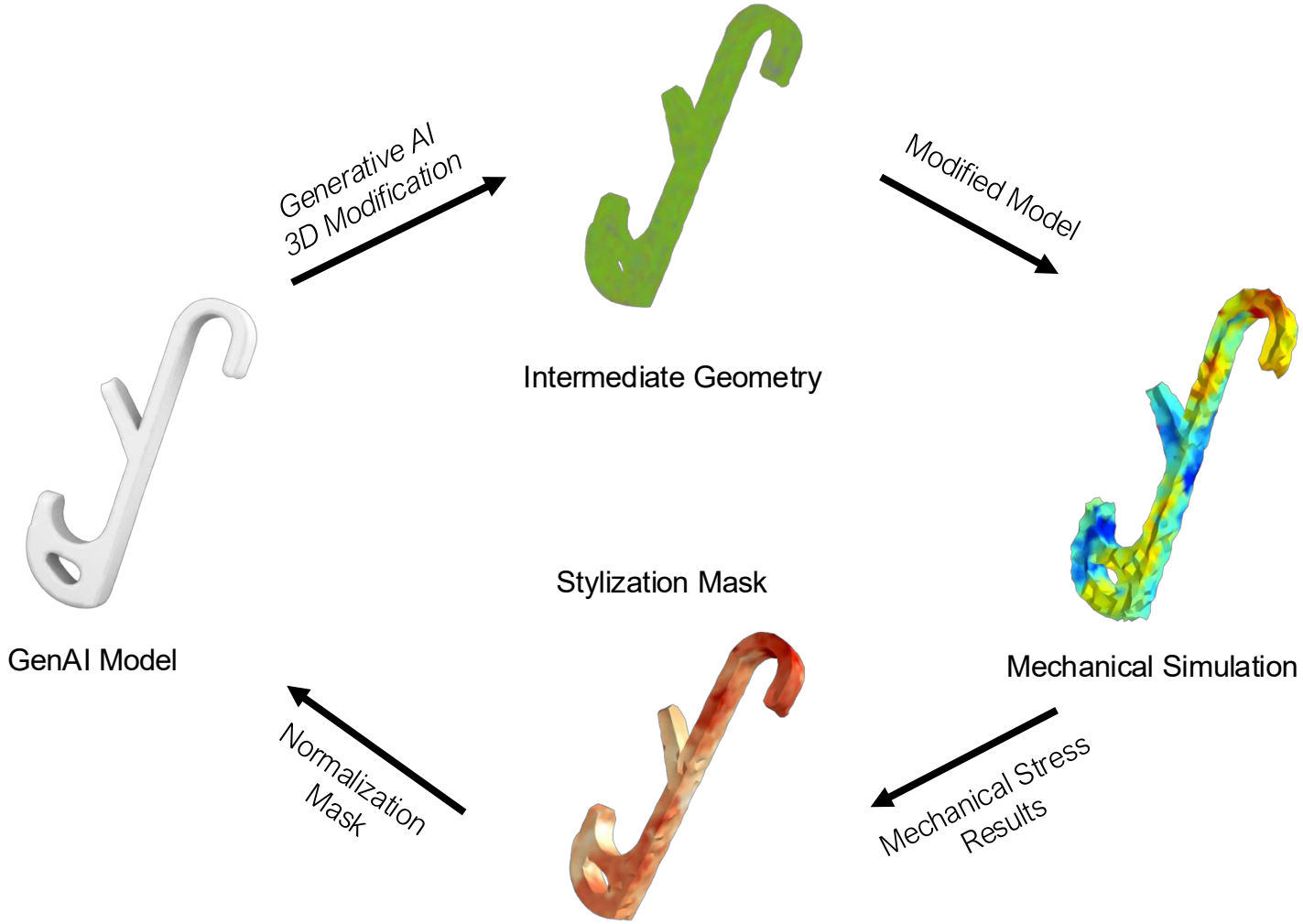
Intermediate Geometry

Modified Model



Mechanical Simulation


Generative AI
3D Modification
Intermediate Geometry
Modified Model
GenAI Model
Stylization Mask
Mechanical Simulation
Mechanical Stress
Results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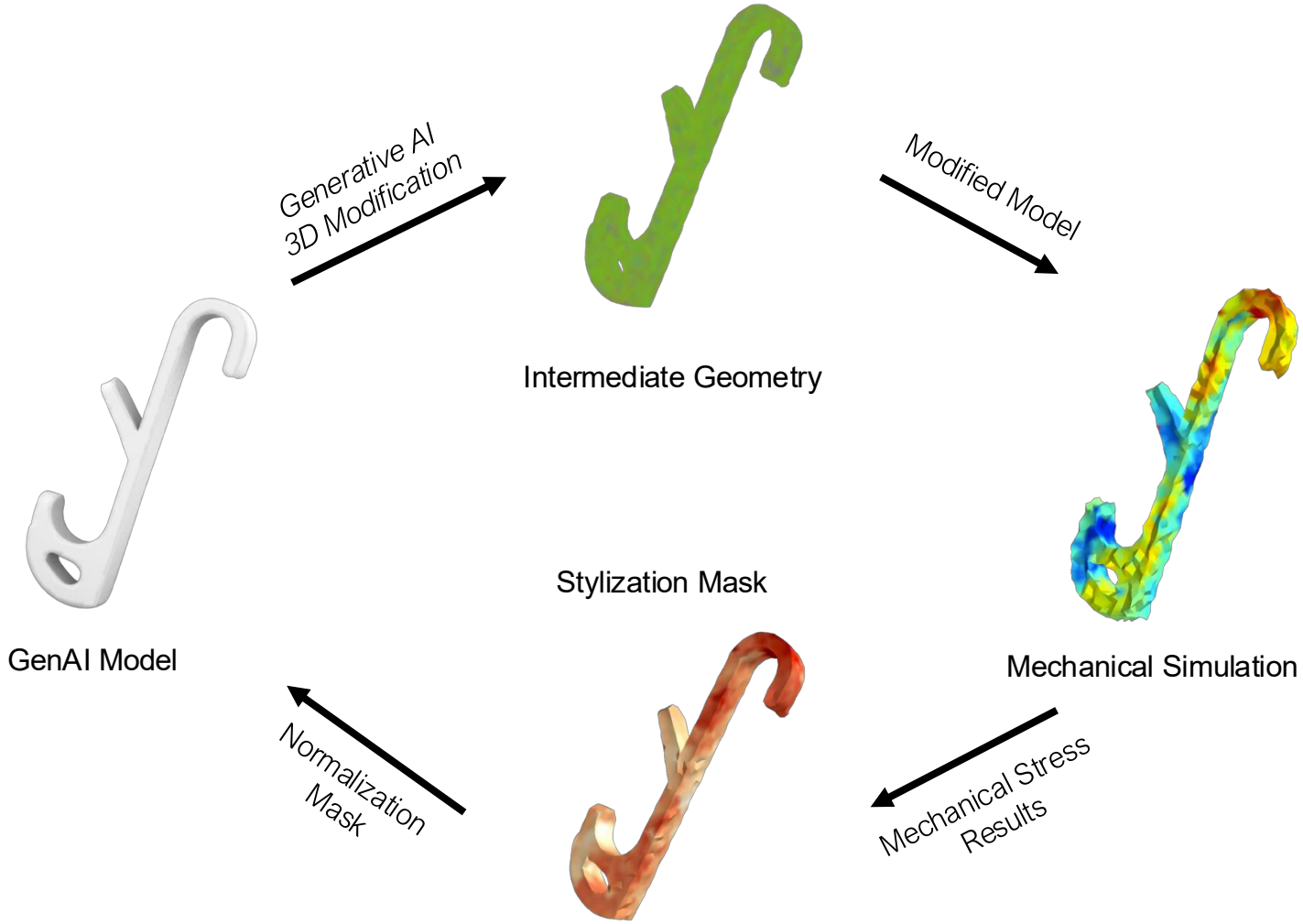
Mechanical Stress
Results
Stylization Mask
Normalization
Mask
GenAI Model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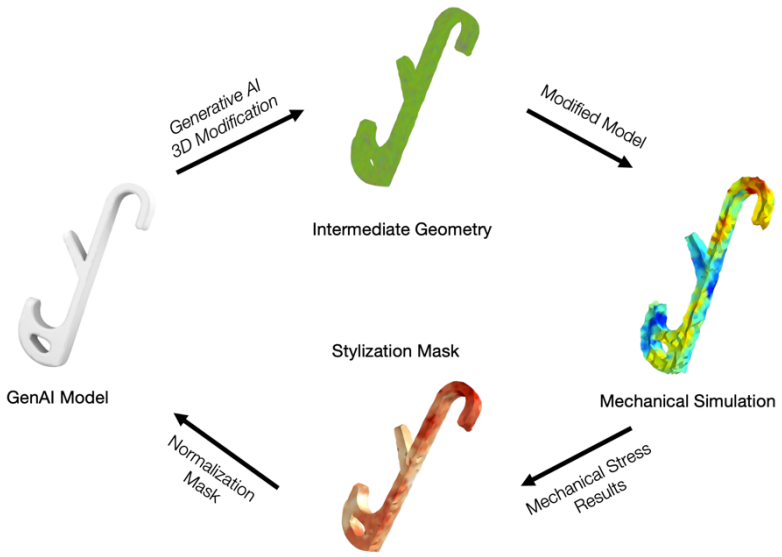
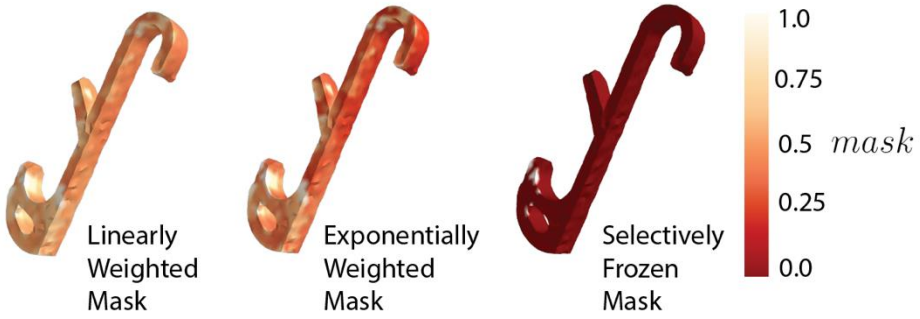
Two Design Questions

Two Design Questions

- Stylization Control Strategy
- Adaptive Scheduling Strategy



Stylization Control Strategies



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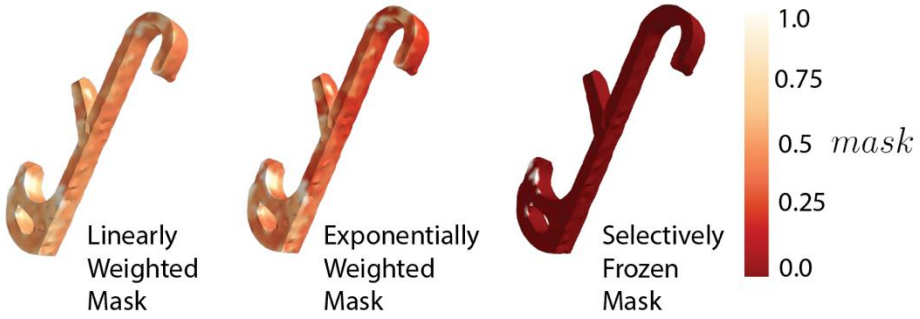
$mask_{v_i} = e^{-\left(\frac{s_{norm}(v_i)}{1-s_{norm}(v_i)}\right)}$

$mask_{v_i} = \begin{cases} 0 & \text{if } s_{v_i} \geq max(\mathbb{S}_{M_0}) \\ 1 & \text{if } s_{v_i} < max(\mathbb{S}_{M_0}) \end{cases}$

Stylization Control Strategies



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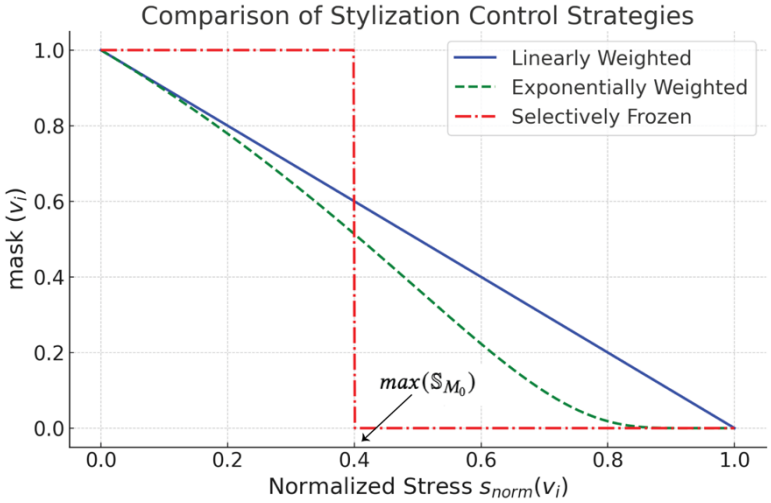

Adaptive Scheduling Strategies

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Generative manipulation: 2.67 seconds (avg)
FEA simulation: 4.61 minutes (avg)

200 iterations: 15.4 hours

Adaptive Scheduling Strategies

Generative manipulation: 2.67 seconds (avg)
FEA simulation: 4.61 minutes (avg)

200 iterations: 15.4 hours

Scheduling Challenge: Keep runtime low, while preserving structural viability

Adaptive Scheduling Strategies

Three Types of Strategies:

- Temporal Scheduling
- Geometry based Scheduling
- Stress based Scheduling

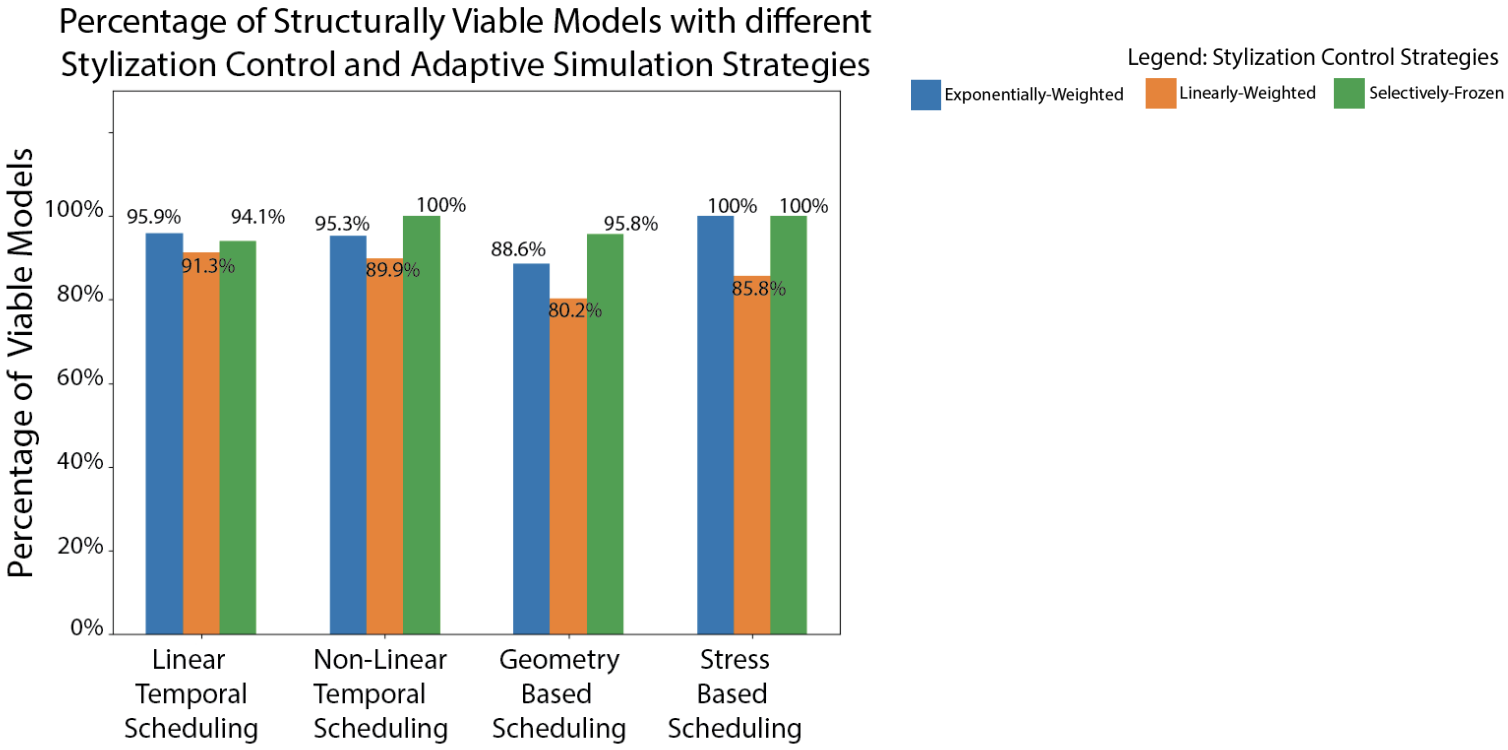
TECHNICAL EVALUATION

Technical Evaluation

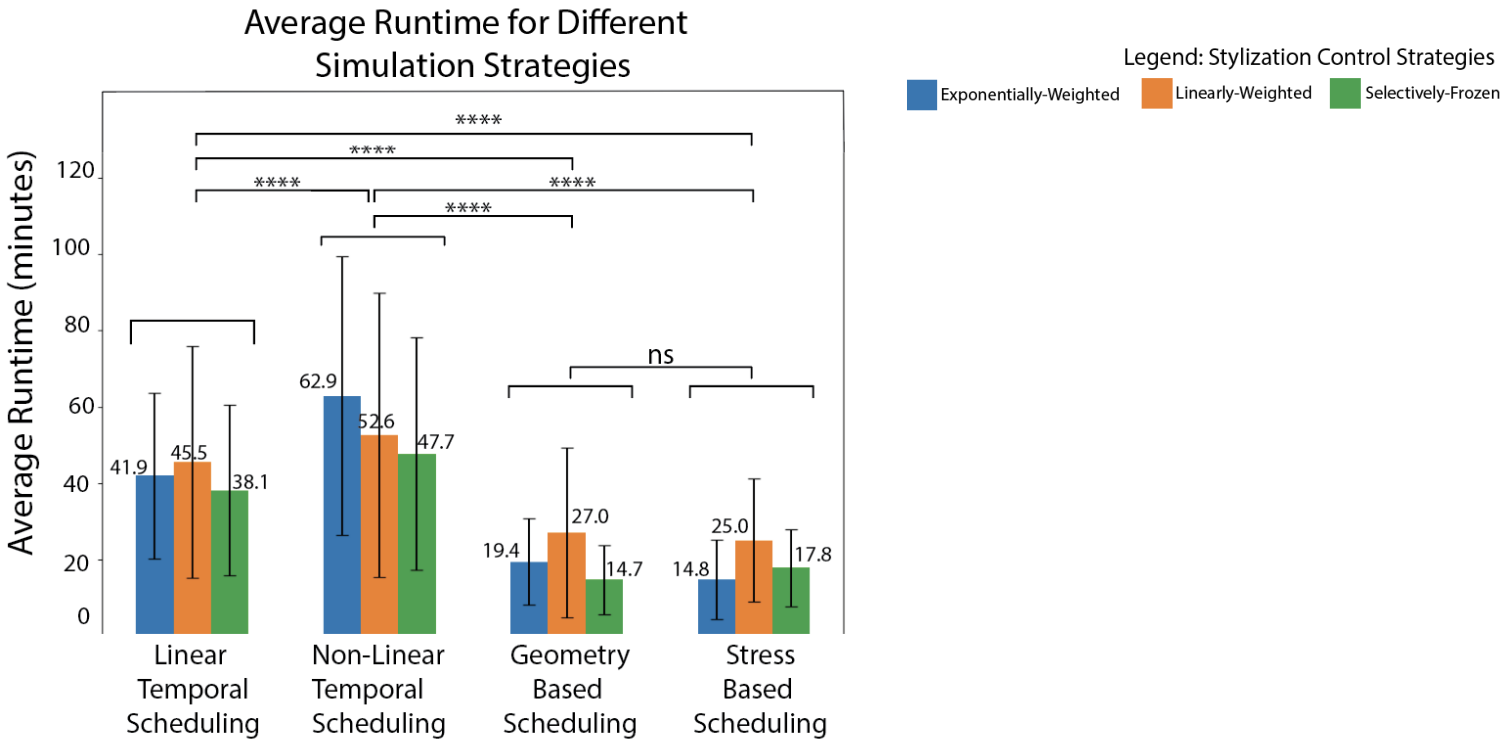
- 30 3D models
- 6 styles
- 3 stylization control strategies
- 4 adaptive scheduling strategies

- **Grid search**: 2,160 total configurations

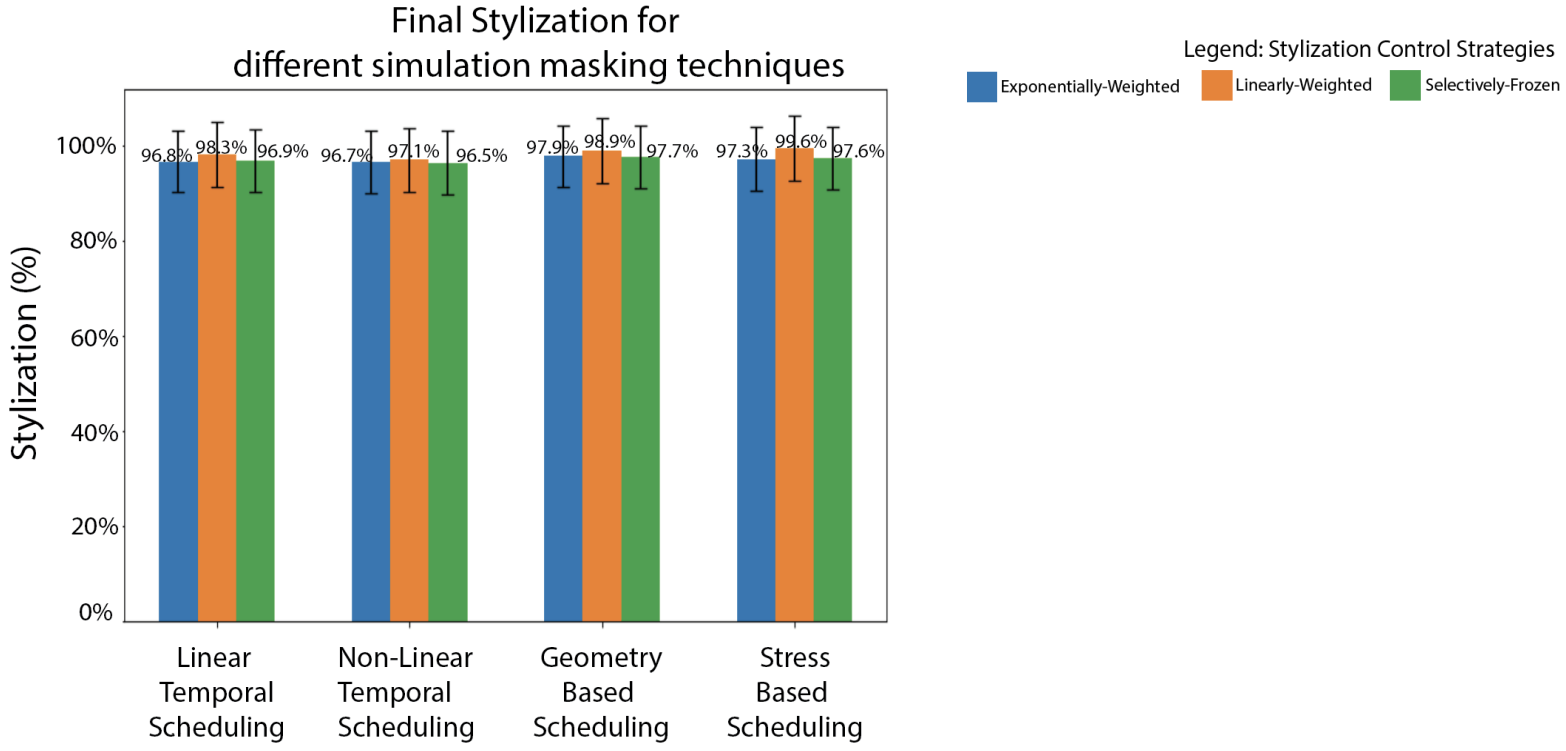
Technical Evaluation



Technical Evaluation

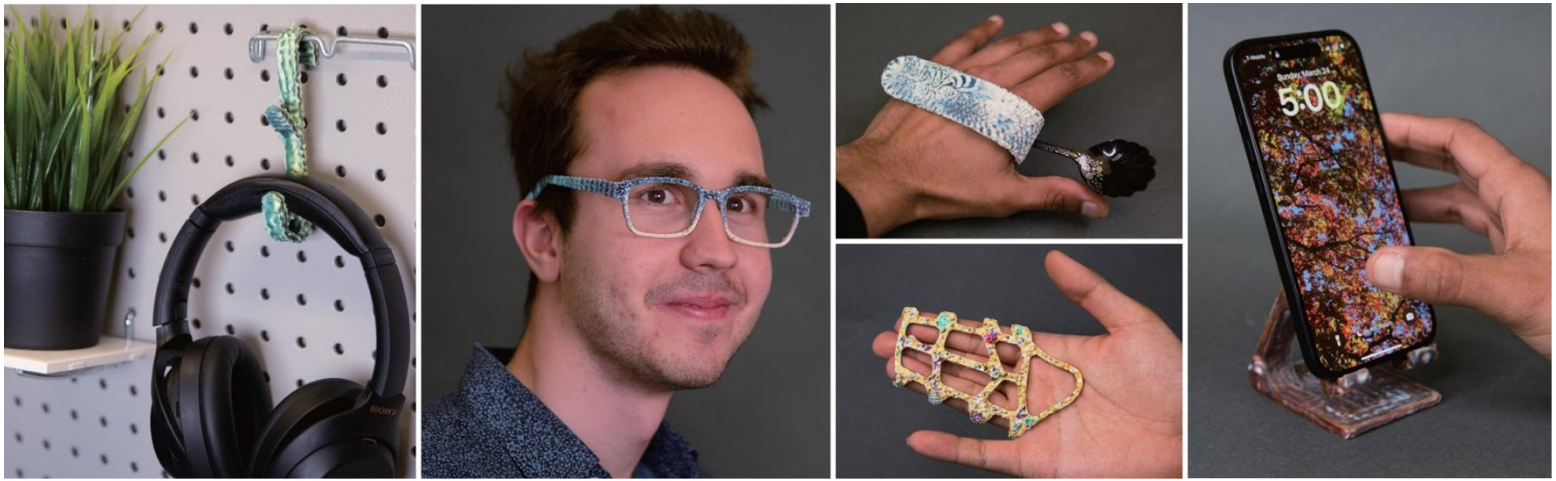


Technical Evaluation



MechStyle

Augmenting Generative AI with Mechanical Simulation to Create Stylized and Structurally Viable 3D Models



ACM SCF 2025

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