Physically Compatible 3D Object Modeling from a Single Image

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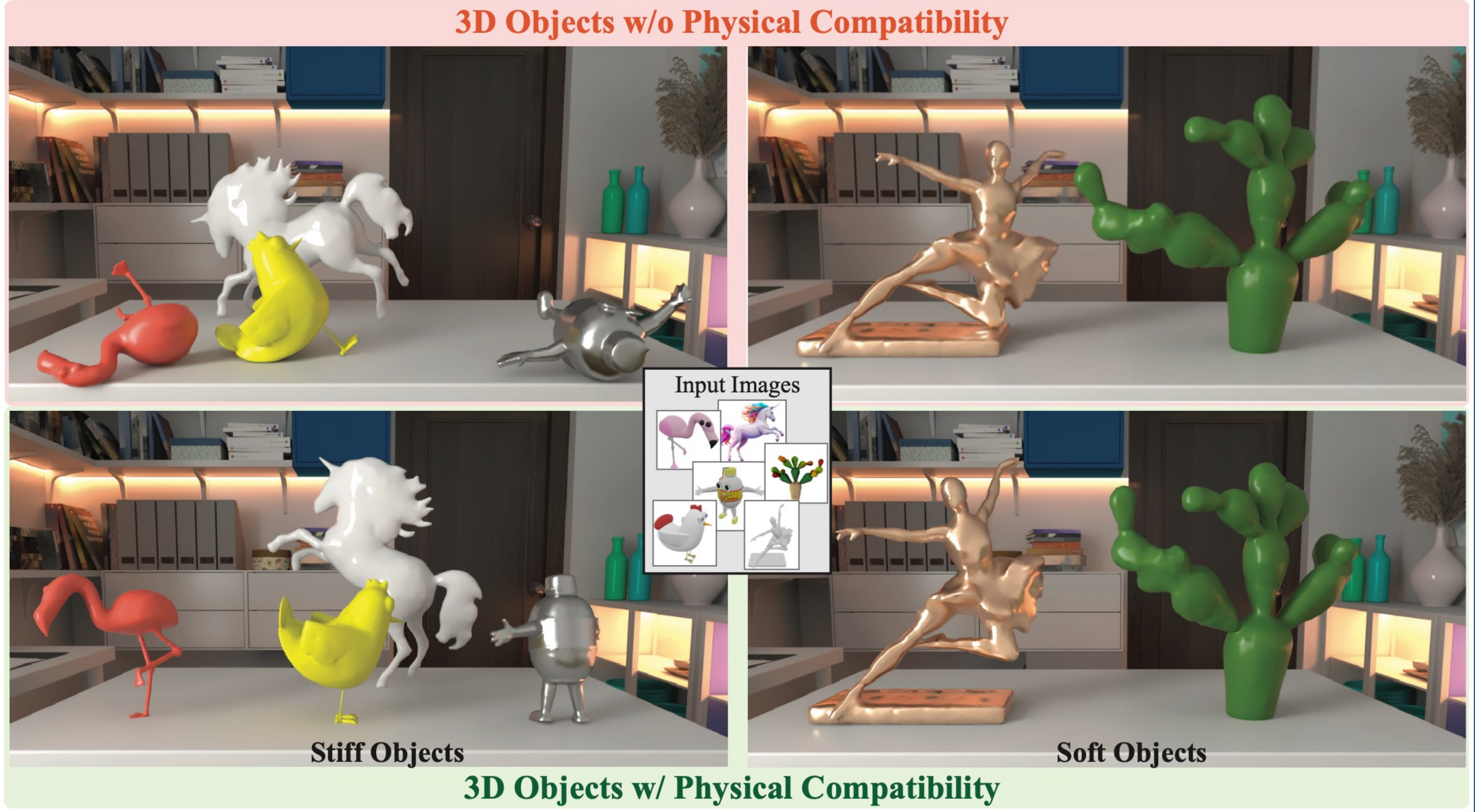
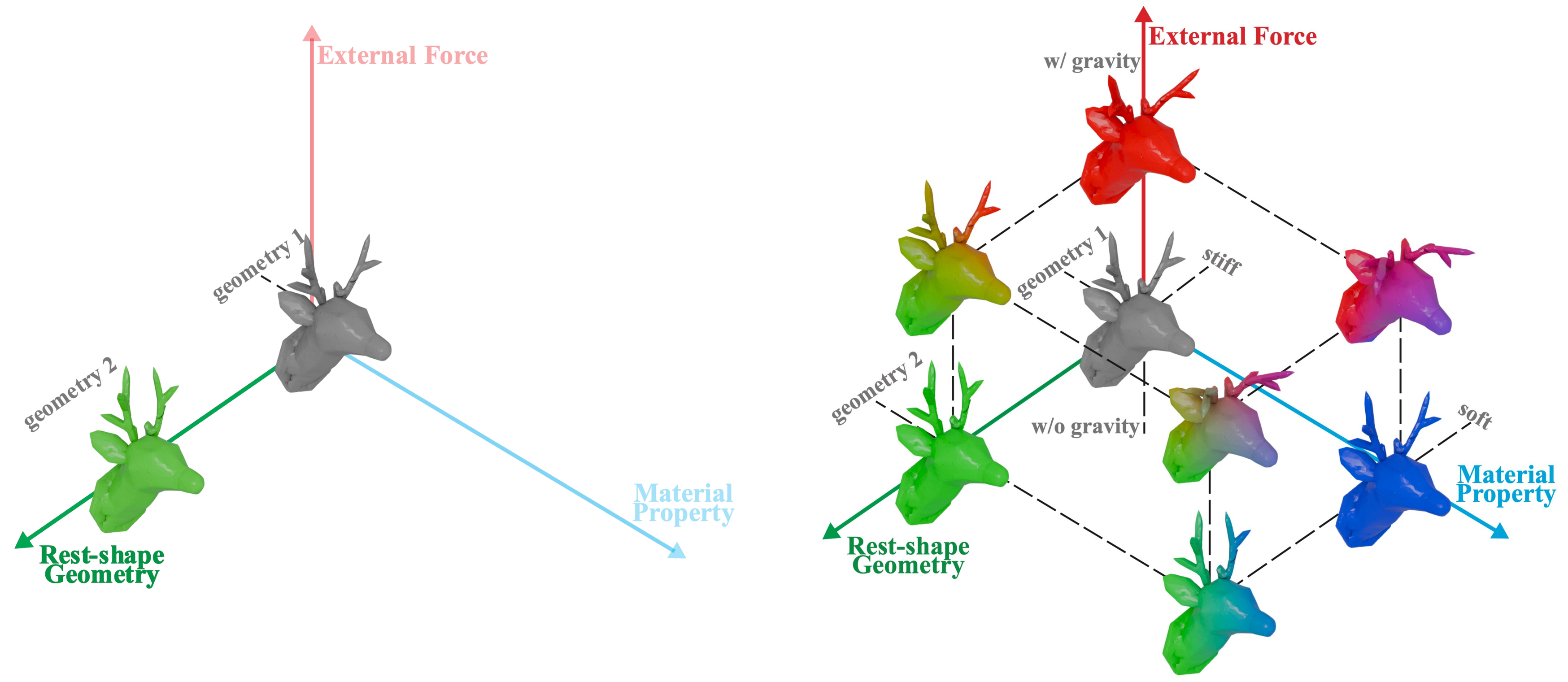
Motivation

- Existing single-view reconstruction methods output 3D objects failing to withstand real-world physical forces.
- We propose **physical compatibility optimization**, ensuring that the optimized physical shapes exhibit desired physical behavior.



An Image is a **Physical Snapshot** of an Object

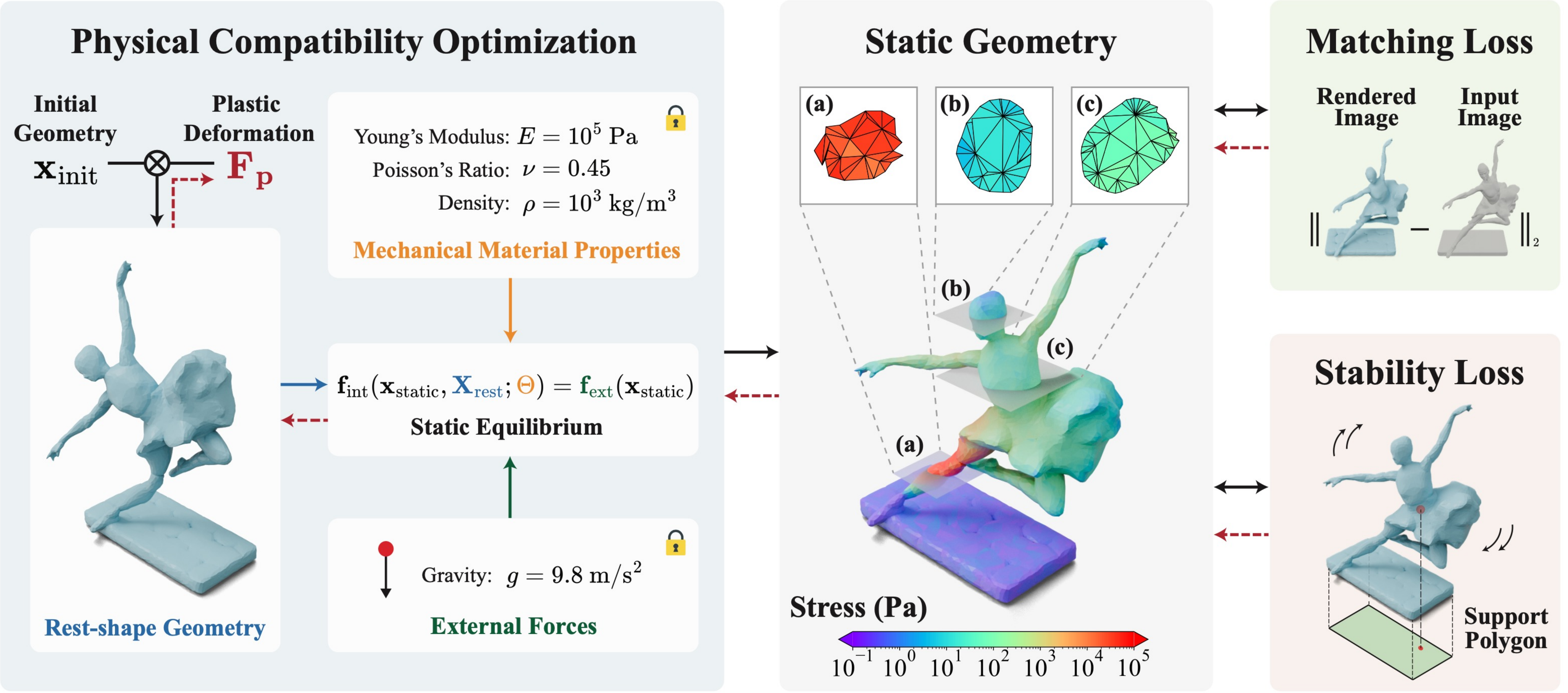
- The object in an image is in a state of **static equilibrium**, under the influence of real-world forces.



Current Methods

Ours

Formulation of Physical Compatibility



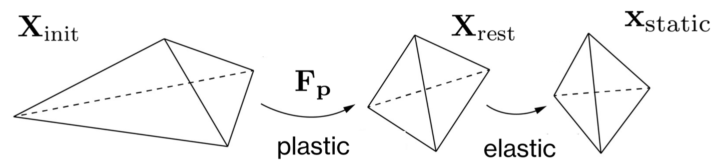
- **Optimization Objective:**

$$\min_{\mathbf{X}_{\text{rest}}, \mathbf{x}_{\text{static}}} \quad \mathcal{J}(\mathbf{X}_{\text{rest}}, \mathbf{x}_{\text{static}}) = \mathcal{L}(\mathbf{x}_{\text{static}}) + \mathcal{L}_{\text{reg}}(\mathbf{X}_{\text{rest}})$$
$$\text{s.t.} \quad \mathbf{f}_{\text{int}}(\mathbf{x}_{\text{static}}, \mathbf{X}_{\text{rest}}; \Theta) = \mathbf{f}_{\text{ext}}(\mathbf{x}_{\text{static}}).$$

Parameterization of Rest Geometry

- **Plastic Deformation:**

$$\mathbf{X}_{\text{rest}} := \phi(\mathbf{F}_{\text{p}}; \mathbf{X}_{\text{init}}),$$
$$\text{with} \quad \mathbf{f}_{\text{int}}(\mathbf{X}_{\text{rest}}, \mathbf{X}_{\text{init}}; \Theta) = \mathbf{0}.$$



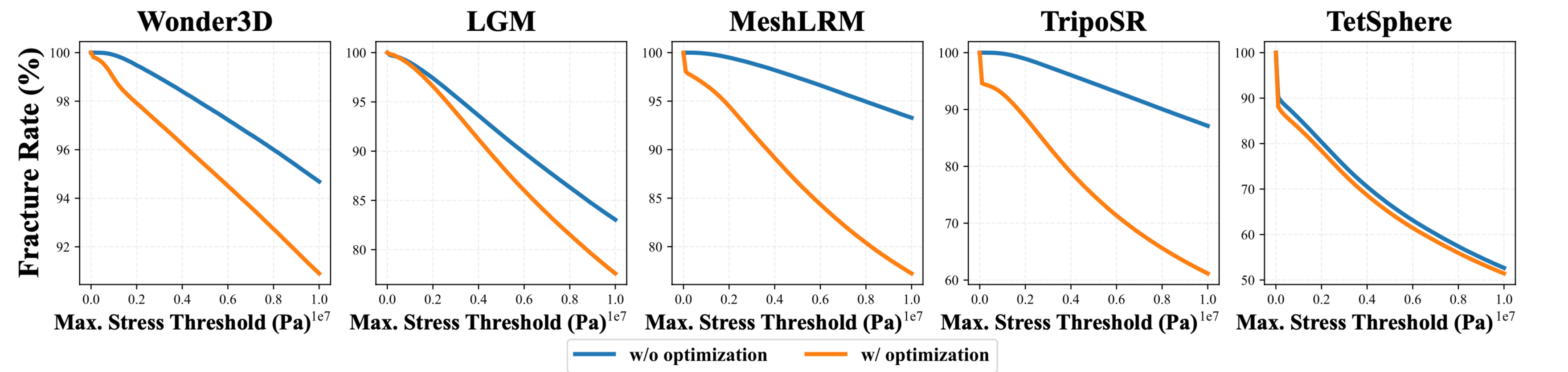
- **Implicit Differentiation-based Optimization:**

$$\min_{\mathbf{F}_{\text{p}}, \mathbf{x}_{\text{static}}} \quad \mathcal{J}(\mathbf{F}_{\text{p}}, \mathbf{x}_{\text{static}}) = \mathcal{L}(\mathbf{x}_{\text{static}}) + \mathcal{L}_{\text{reg}}(\mathbf{F}_{\text{p}})$$
$$\text{s.t.} \quad \mathbf{f}_{\text{int}}(\mathbf{x}_{\text{static}}, \phi(\mathbf{F}_{\text{p}}; \mathbf{X}_{\text{init}}); \Theta) = \mathbf{f}_{\text{ext}}(\mathbf{x}_{\text{static}}).$$

$$\frac{\partial \mathcal{J}}{\partial \mathbf{F}_{\text{p}}} = -\left(\frac{\partial \mathcal{L}}{\partial \mathbf{x}_{\text{static}}}\right)\left[\frac{\partial \mathbf{f}_{\text{net}}}{\partial \mathbf{x}_{\text{static}}}\right]^{-1} \frac{\partial \mathbf{f}_{\text{net}}}{\partial \mathbf{F}_{\text{p}}} + \frac{\partial \mathcal{L}_{\text{reg}}}{\partial \mathbf{F}_{\text{p}}}$$

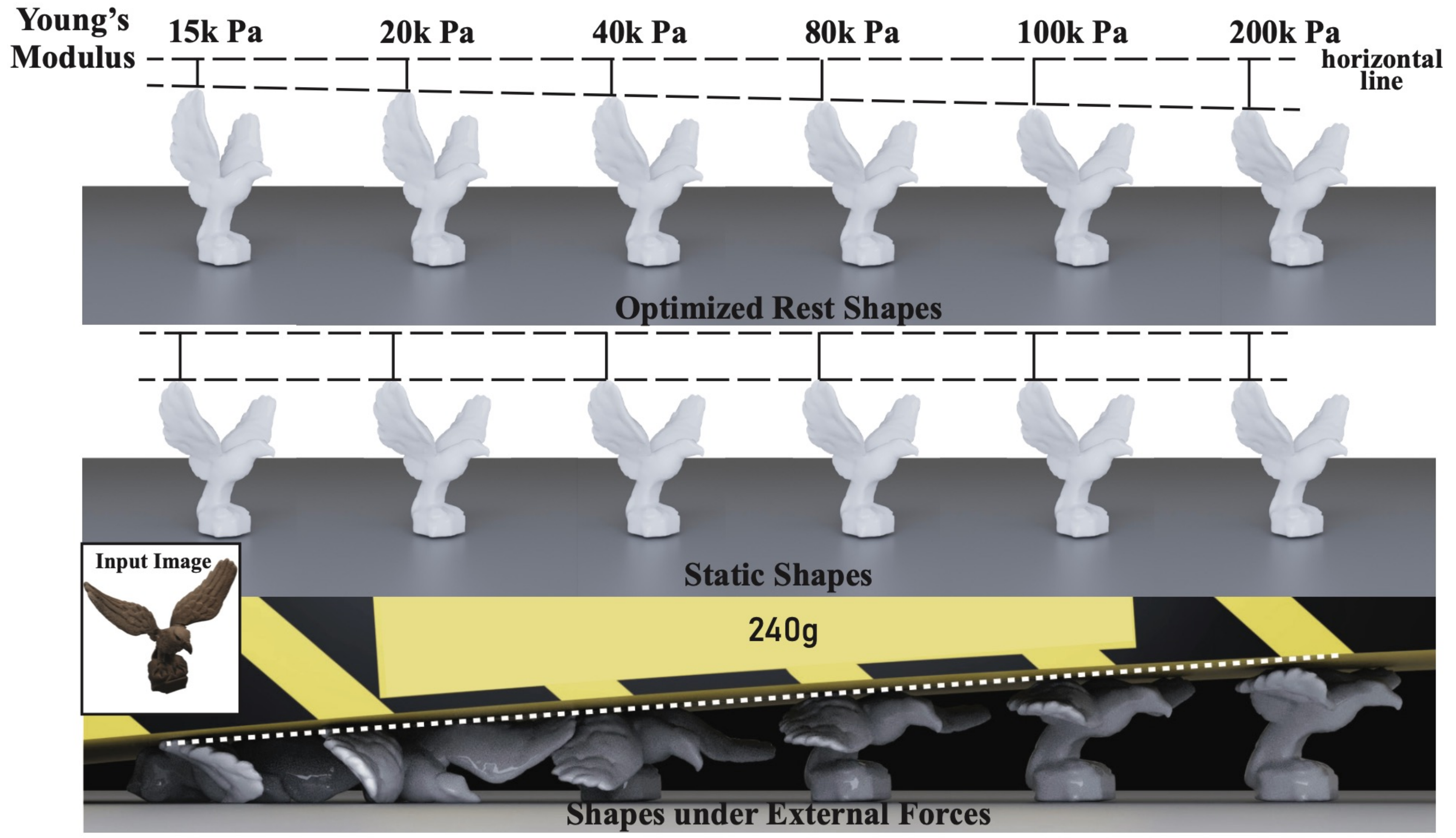
Experimental Results

- **Main Results**



Method		Init. Geo.	#CC. ↓	Mean Stress ↓ (kPa)	Standable. ↑ (%)	Img. Loss ↓
Wonder3D	Baseline	NeuS	2.54 ± 2.64	10.68 ± 17.47	6.9	0.073 ± 0.063
	Ours			0.45 ± 0.96	72.4	0.069 ± 0.048
LGM	Baseline	Gaussian splatting	2.67 ± 2.13	1.14 ± 2.03	20.3	0.121 ± 0.091
	Ours			1.01 ± 1.34	<u>85.9</u>	0.116 ± 0.065
MeshLRM	Baseline	surface mesh	1.55± 2.13	0.54 ± 1.41	28.6	0.065 ± 0.042
	Ours			0.38 ± 1.05	73.8	0.064 ± 0.042
TripoSR	Baseline	NeRF	1.43 ± 1.12	0.29 ± 1.28	24.2	0.066 ± 0.047
	Ours			<u>0.22 ± 0.94</u>	80.6	<u>0.059 ± 0.039</u>
TetSphere	Baseline	tet-sphere	**1.00 ± 0.00**	<u>0.22 ± 0.51</u>	32.8	0.061 ± 0.045
	Ours			**0.19 ± 0.78**	**92.4**	**0.057 ± 0.040**

- **Ablation Study on Young's Modulus**



- **Applications on Dynamic Simulation and Fabrication**