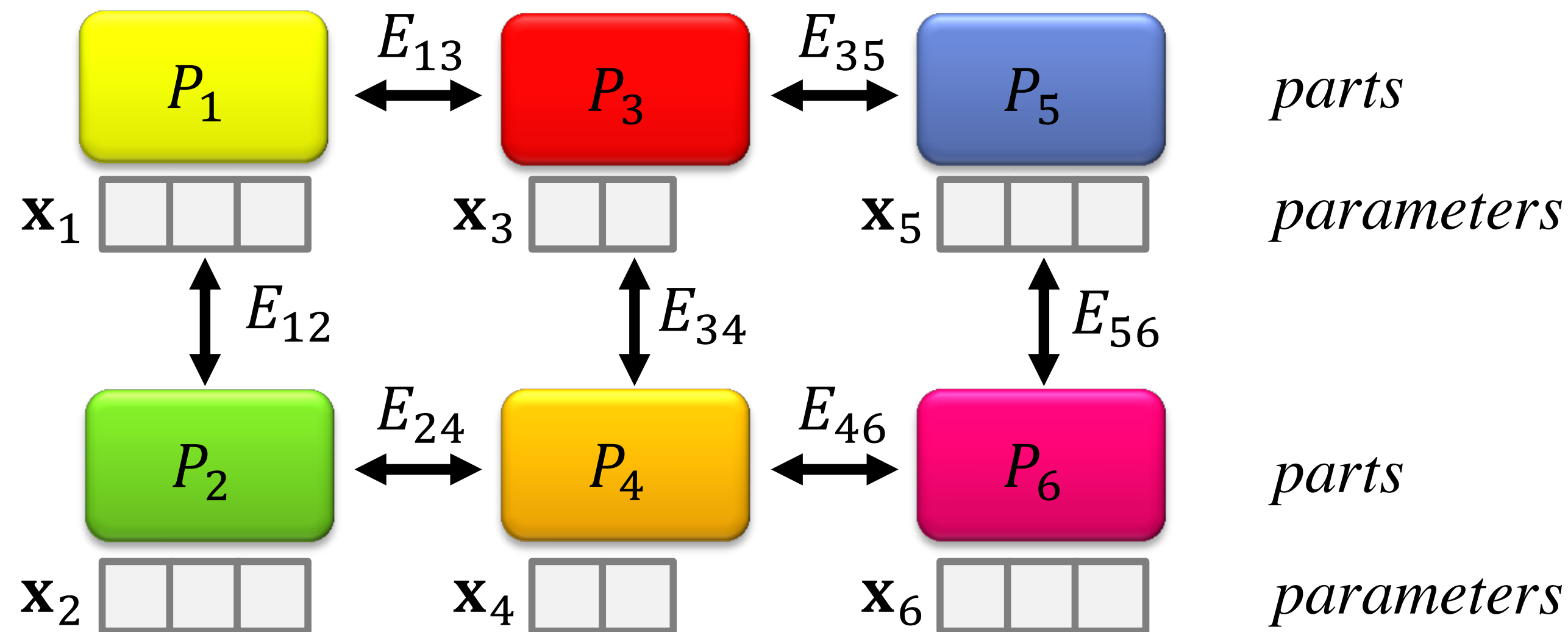


Structure-Aware Shape Processing



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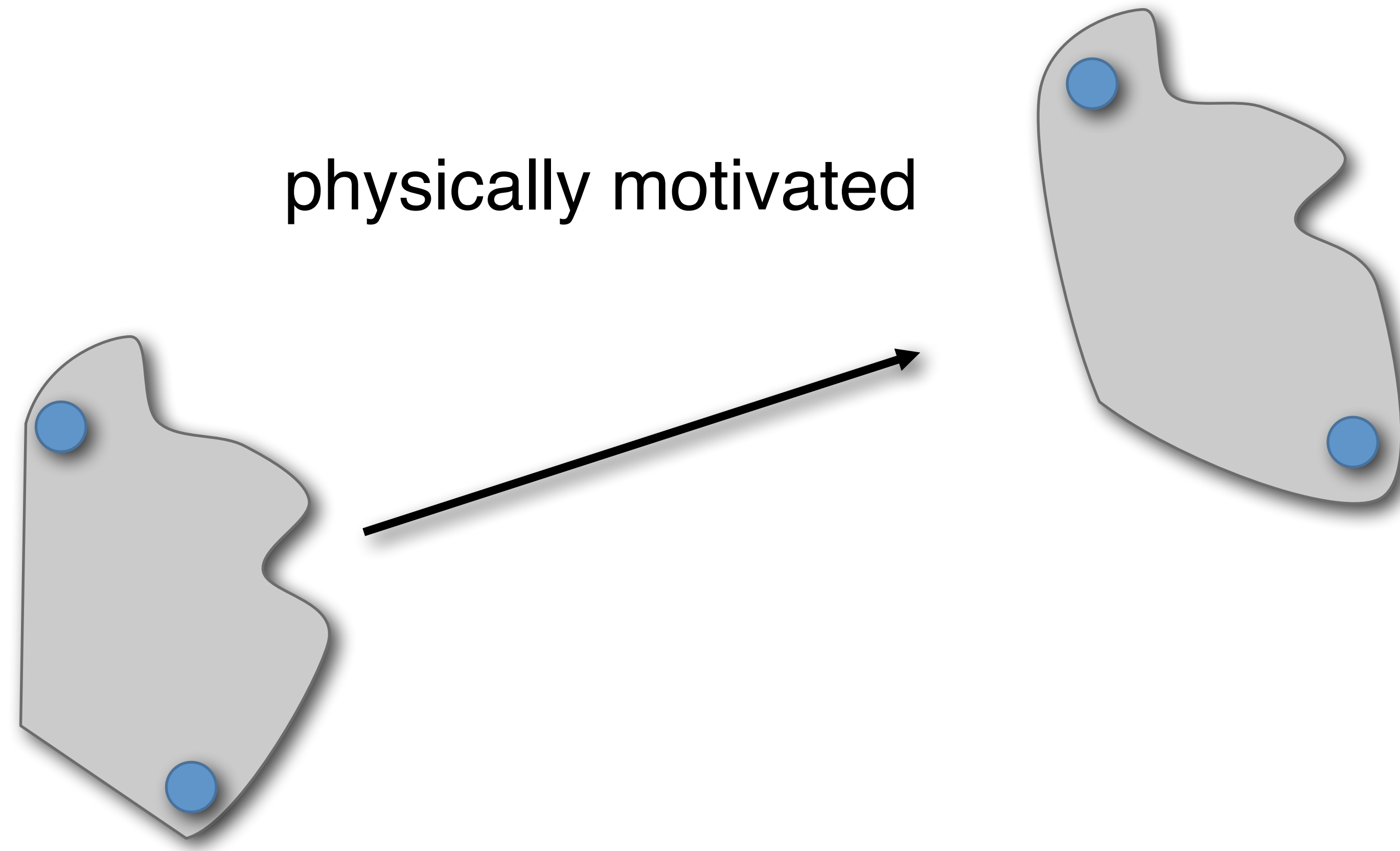


- **Introduction to Geometric ‘Structure’**
- **Extracting Structures**
 - analysis of Individual Models
 - analysis of Shape Collections (co-analysis)
 - encoding Structural Hierarchy
- **Manipulating Structures**
 - Modeling as Structural Variations
 - ***Structure-guided Design***
 - Organization + Exploration of Shape Collections
- **Future Directions**

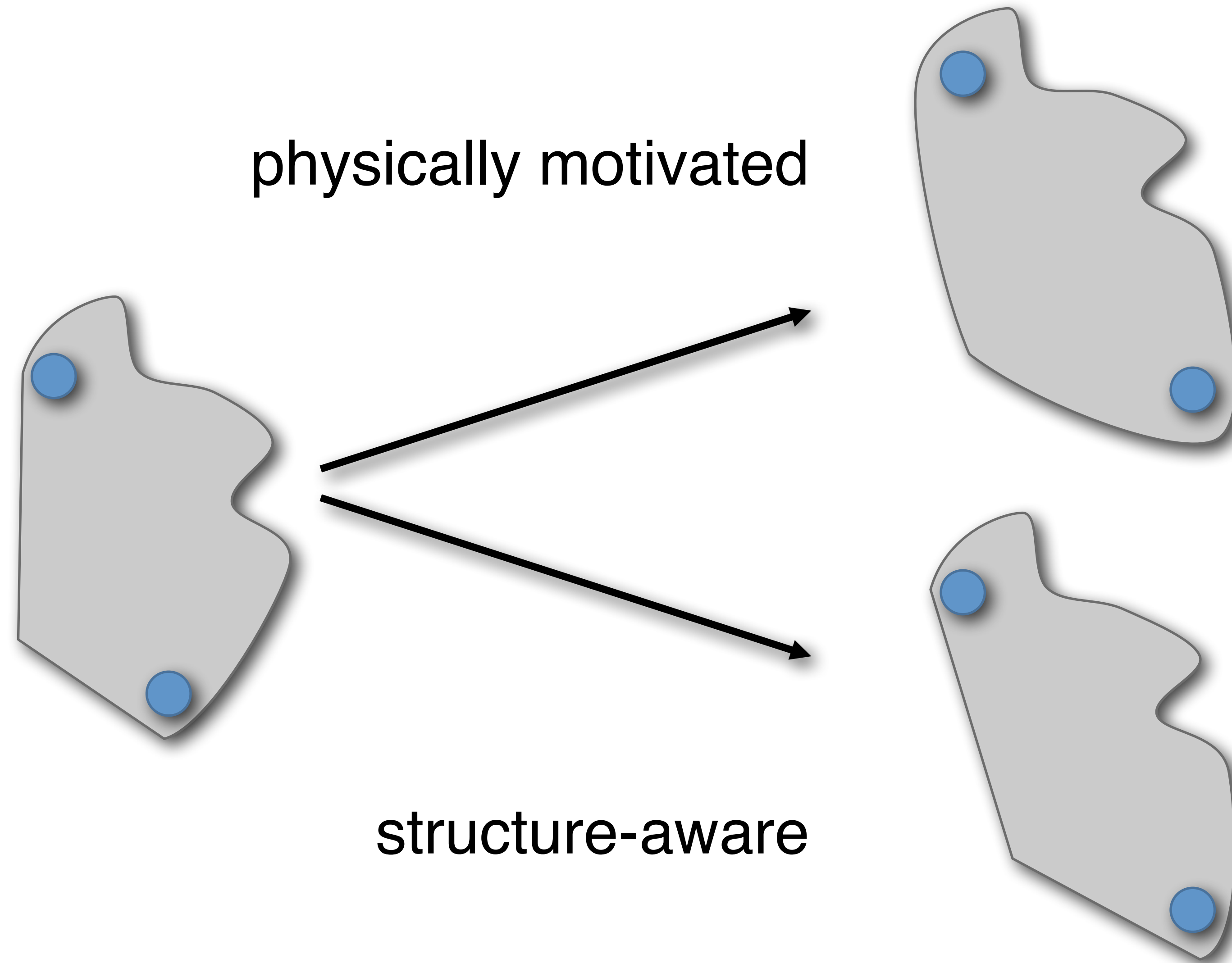
Manipulating Structures

Structure-guided Design

Structure-Aware Deformation

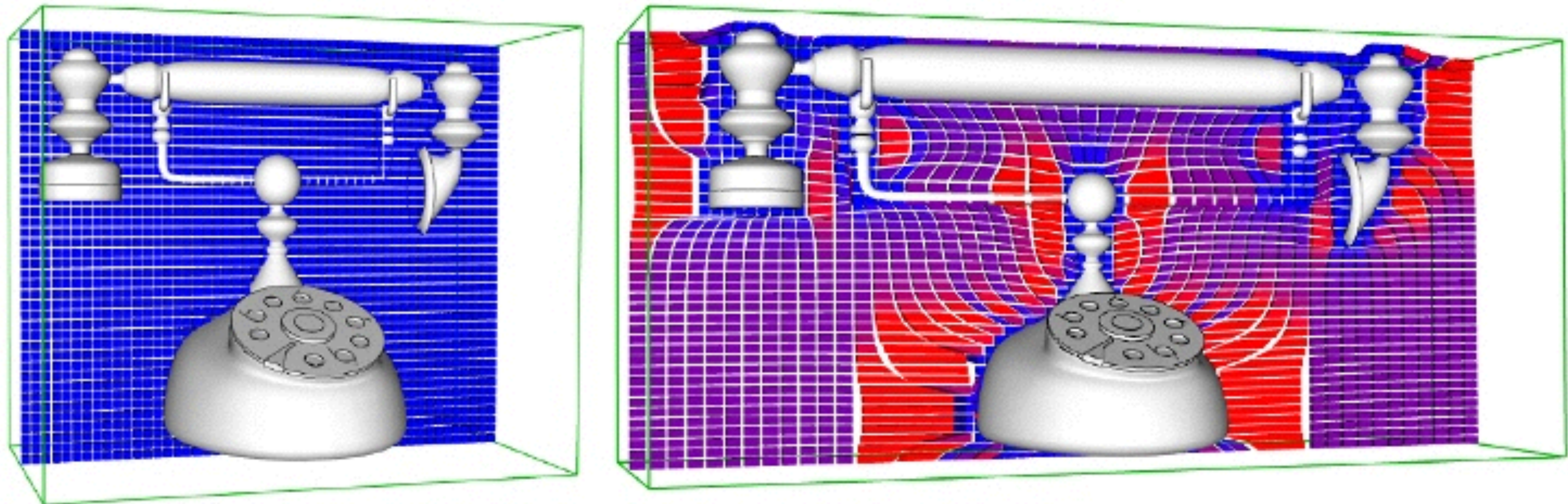


Structure-Aware Deformation



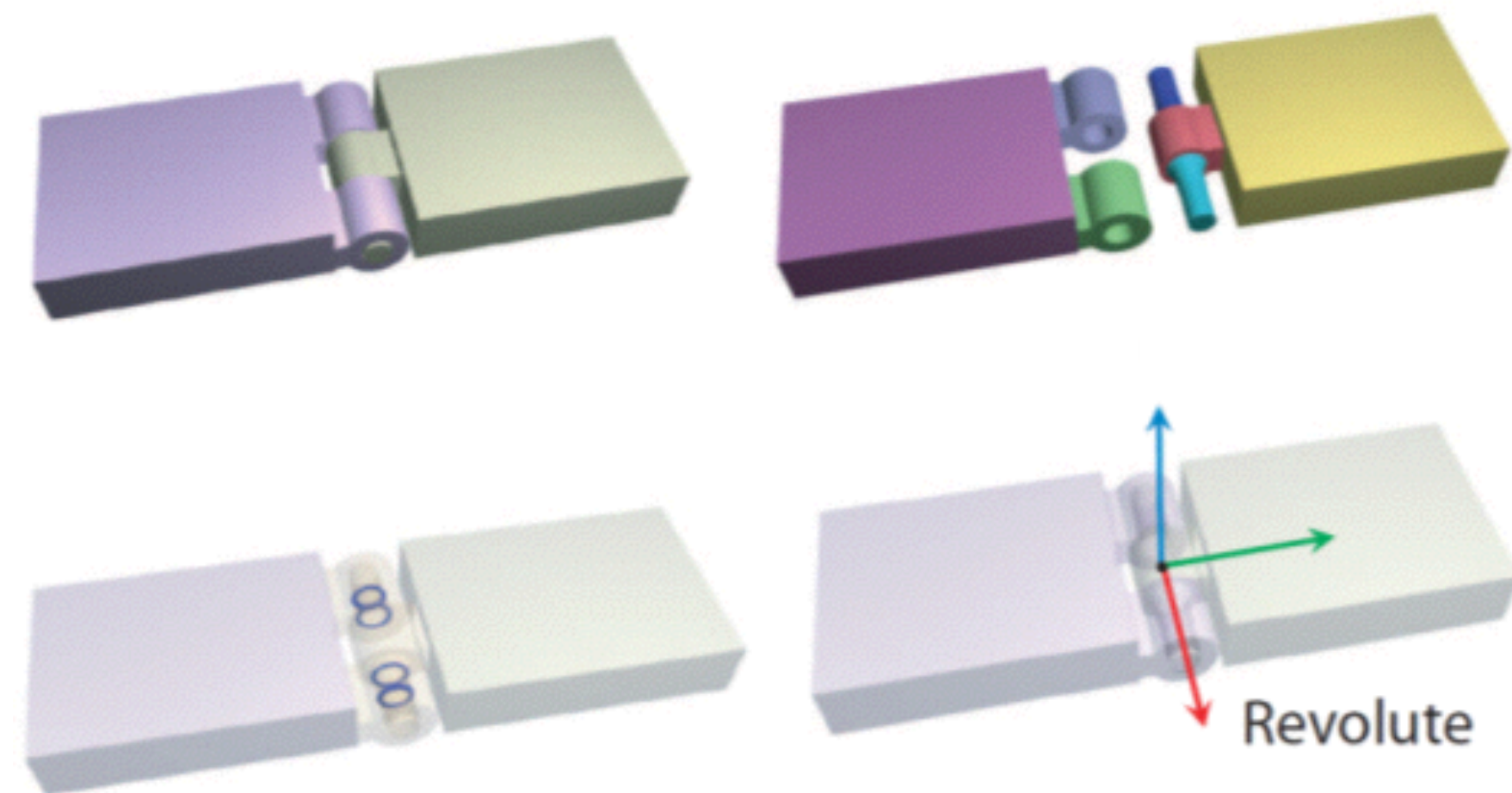
Local Adaptivity

- Non-homogeneous resizing
 - Elastic deformation model
 - Introduce local ‘vulnerability’ term (parameters)



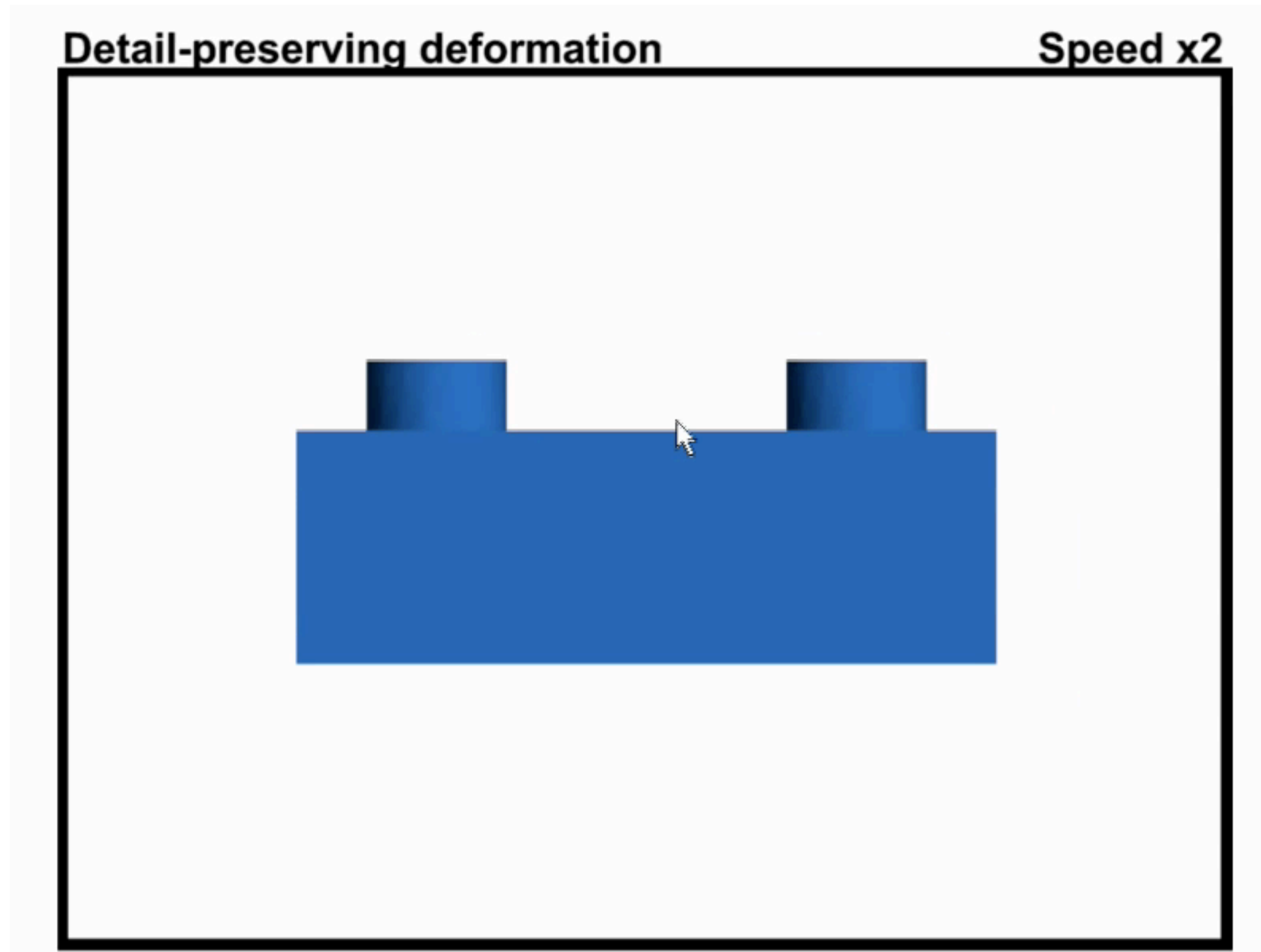
[Non-homogeneous Resizing of Complex Models, Kraevoy et al. 2008]

- Joint-aware deformation
 - Joint-analysis using slippage direction
 - Setup deformation cells (**parts**)
 - Prefer motions along joints in deformation (**parameters**)



[Joint-aware Manipulation of Deformable Models, Xu et al. 2009]

Relations across Features



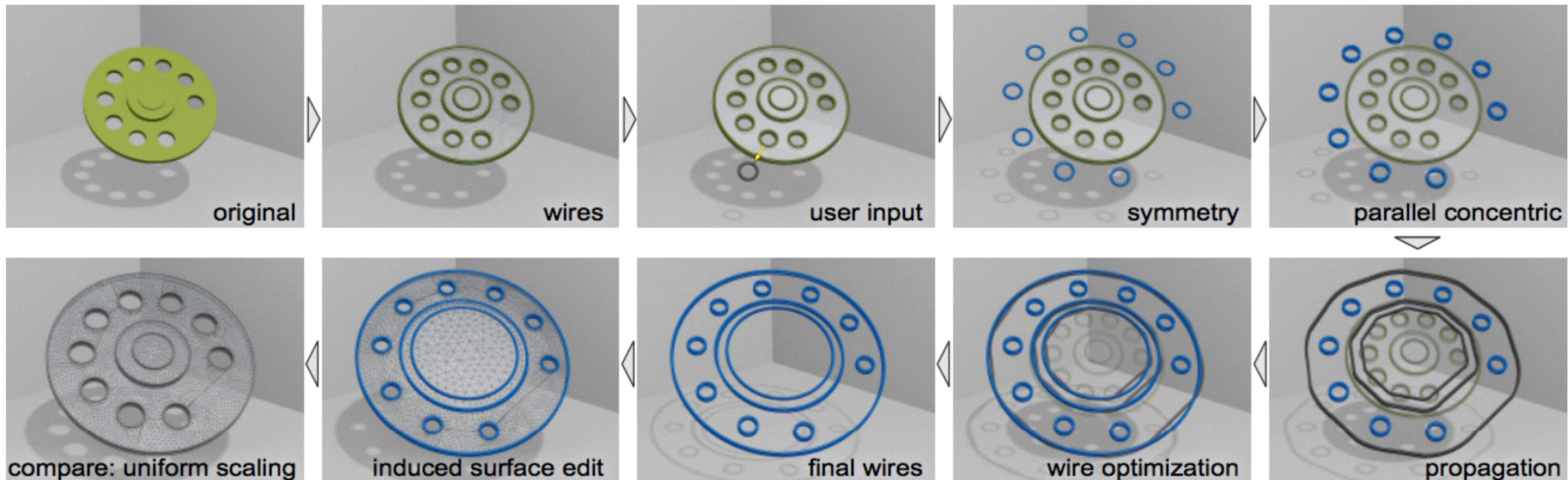
[iWIRES: An Analyze-and-Edit Approach to Shape Manipulation, Gal et al. 2009]

Parts and their Relations

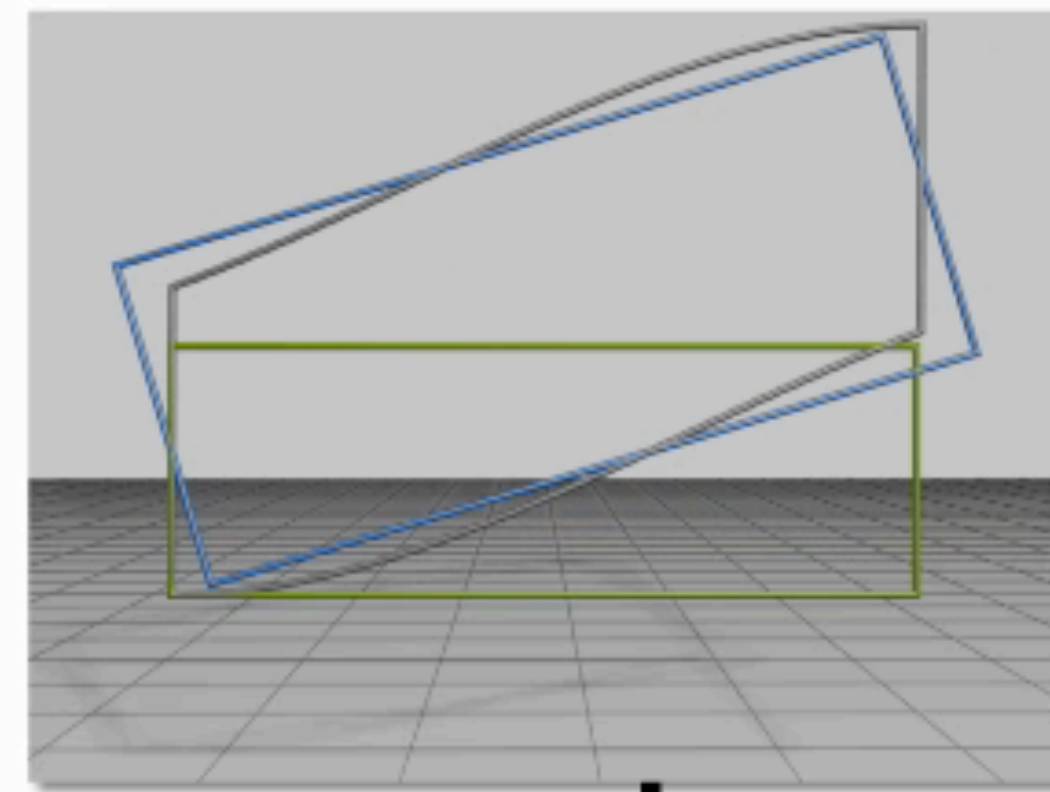
- **Primitives:**
 - wires, i.e., sharp-edge **curves**
- **Relations:**
 - **individual** relations (single wires)
 - planarity, straight line, circle, etc.
 - **mutual** relations (pair of wires)
 - parallel, orthogonal, concentric, etc.

Non-local Relations

- iWires



Algorithm

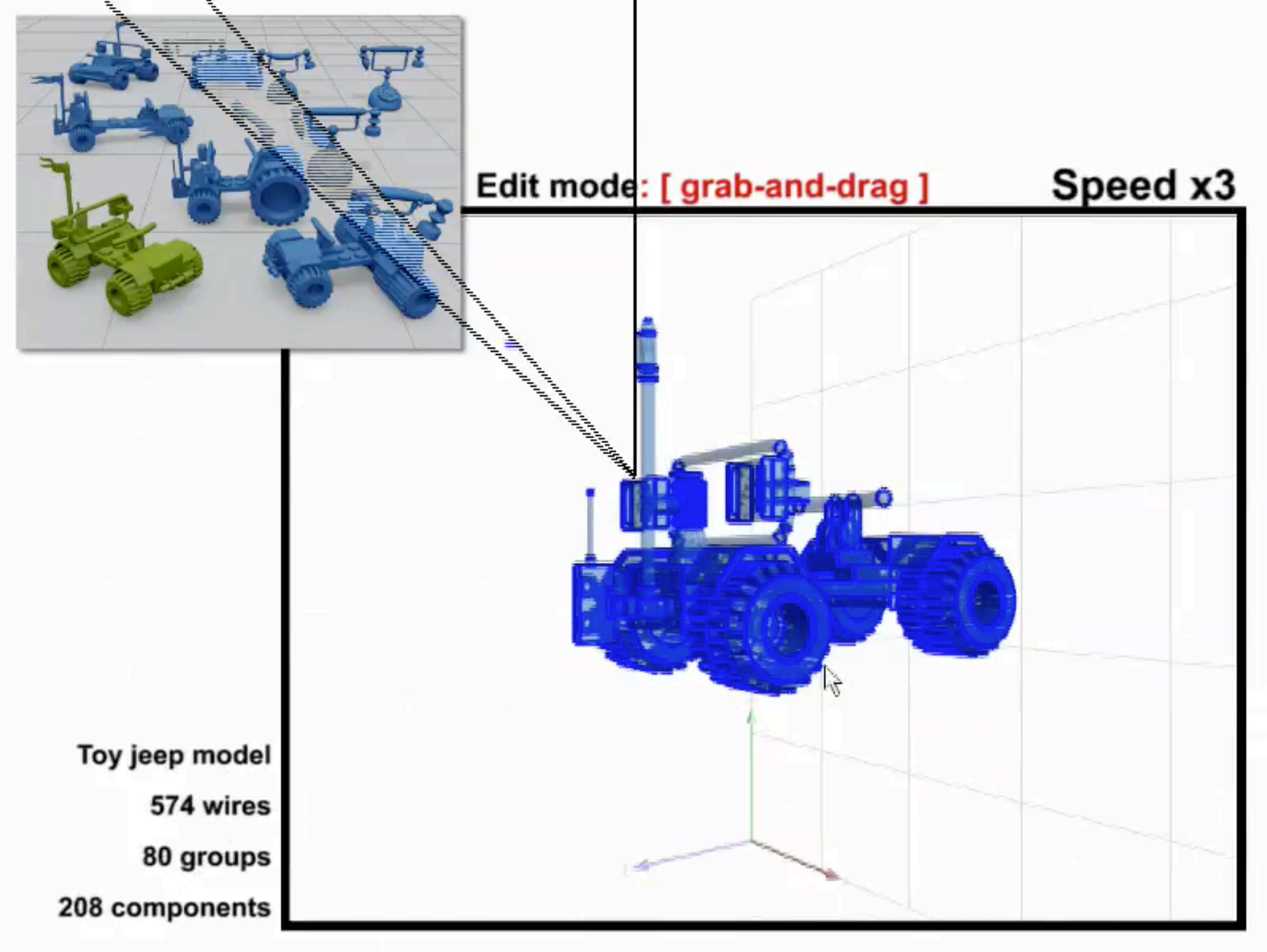


Speed x2

Compound wire
4 sub-wires
planar
4 equal angles
2 pairs of equal
lengths segments

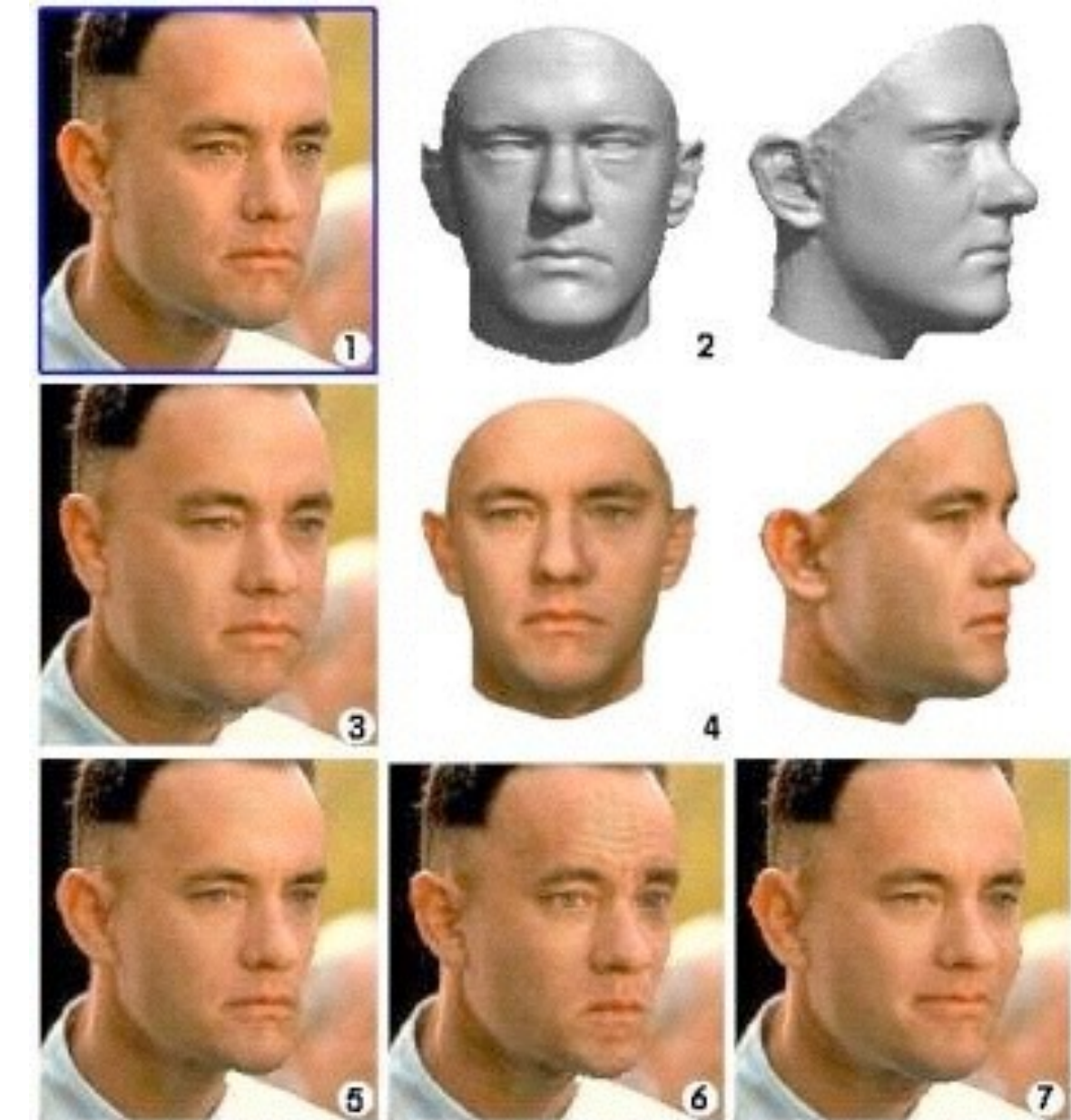
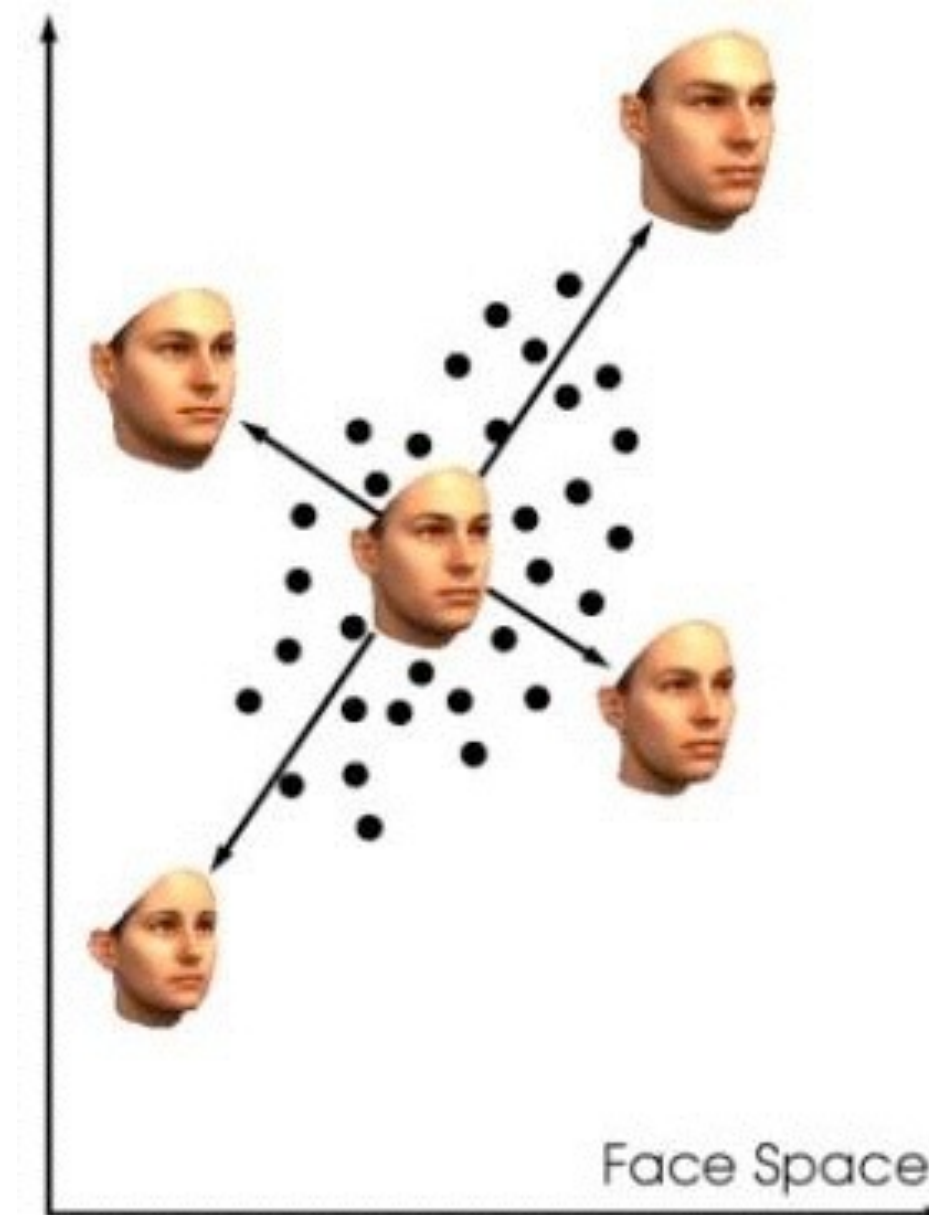


Editing Sessions



Learning Deformations

- PCA-based models
 - Establish *dense correspondences* between shapes from a database and a template shape
 - Fit *linear generative model* to data
 - Assume low-dimensional linear subspace



[A Morphable Model for Synthesis of 3D Faces, Blanz and Vetter 1999]

Modeling by Example

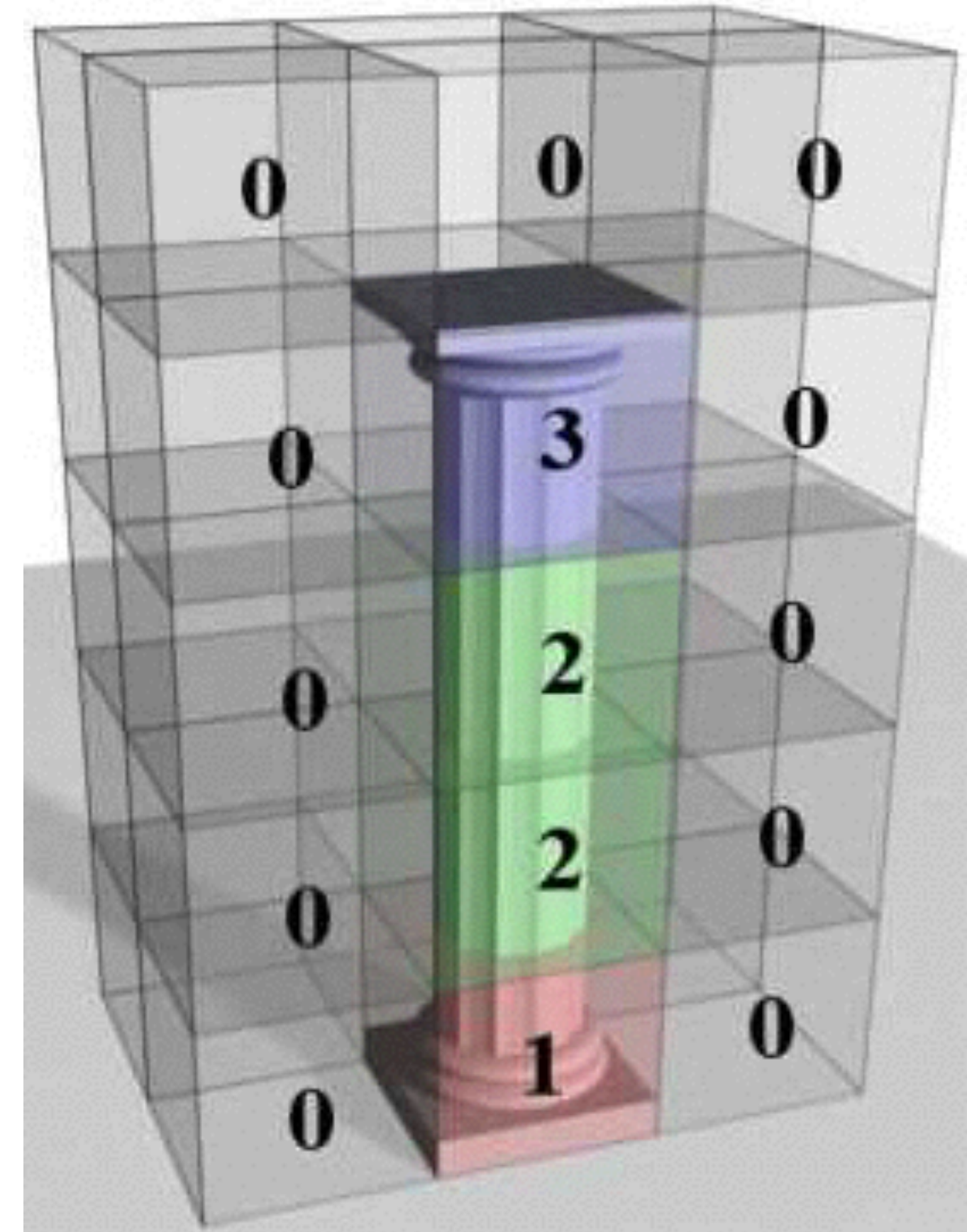
- User focused method
 - User defines parts and accepts suggestions from the database
- Method assists in composition



[Modeling by Example, Funkhouser et al. 2004]

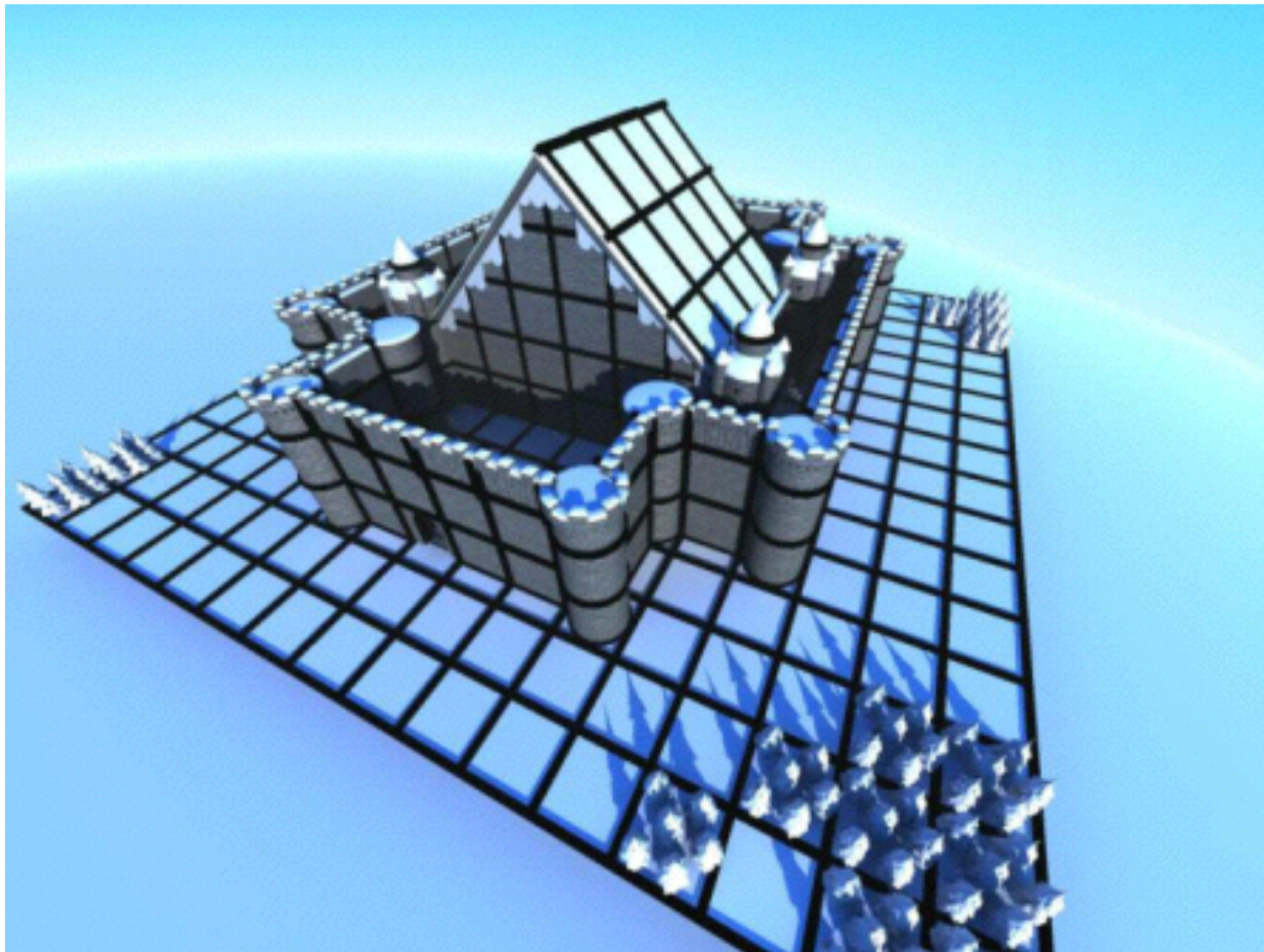
Fixed-sized Tiles

- Provide parts
- Find compatible boundaries
- MRF-based reassembling

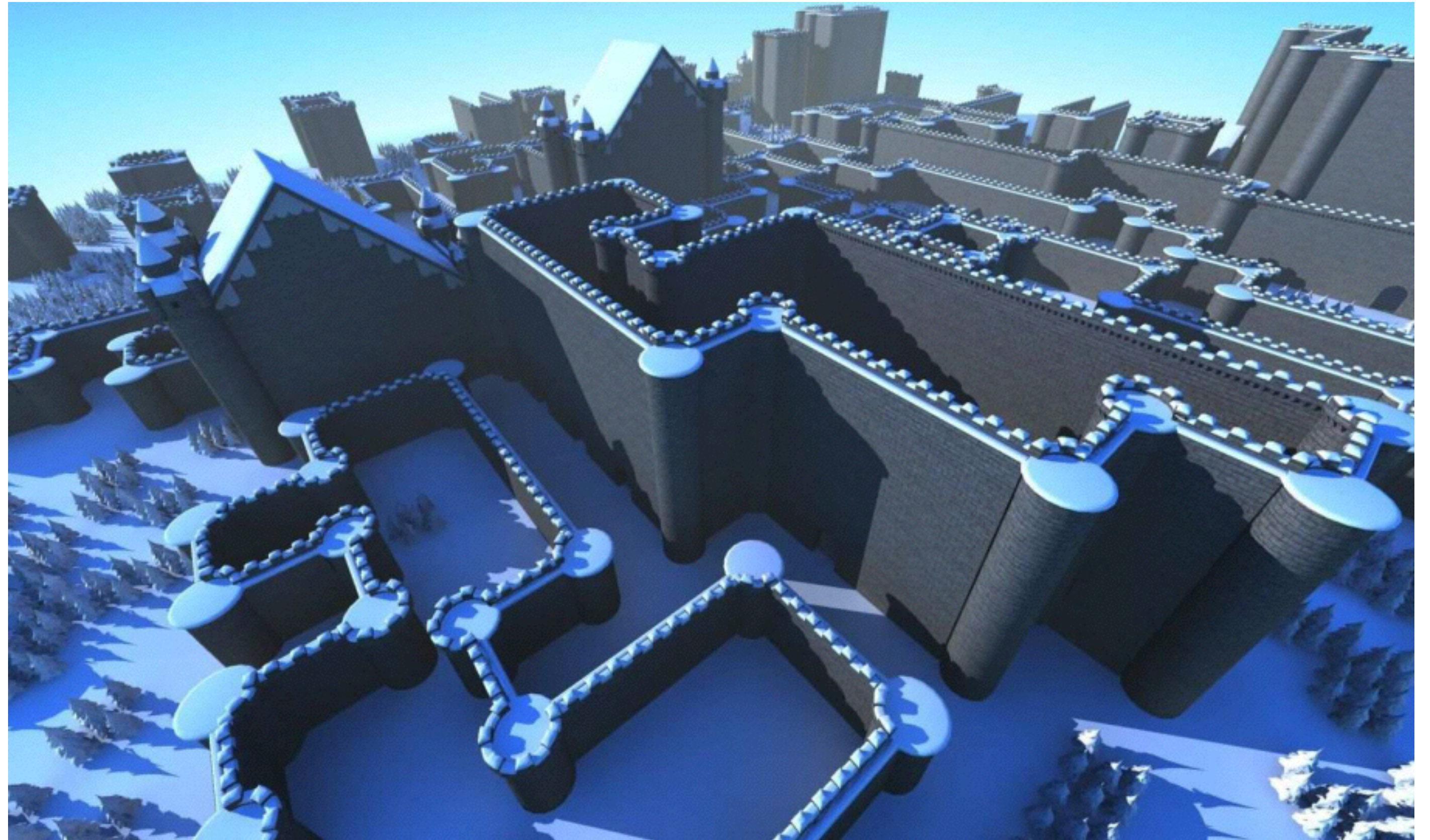


[Example-based Model Synthesis, Merrell 2007]

Fixed-sized Tiles



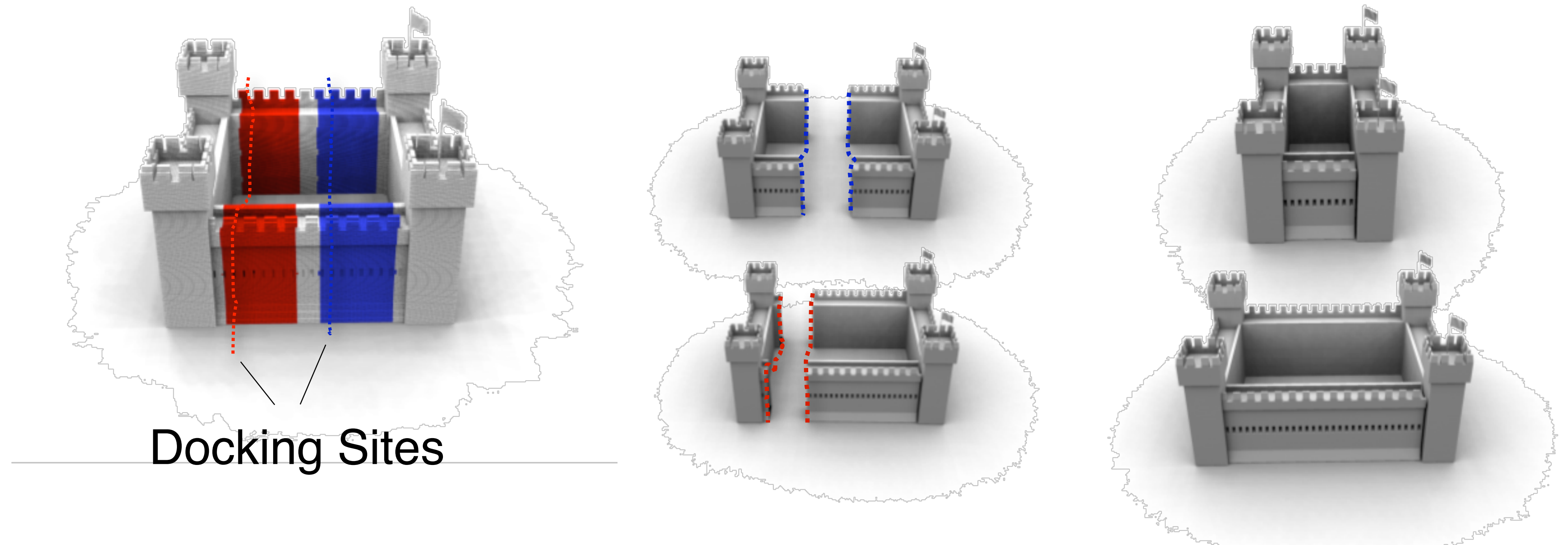
input



synthesized

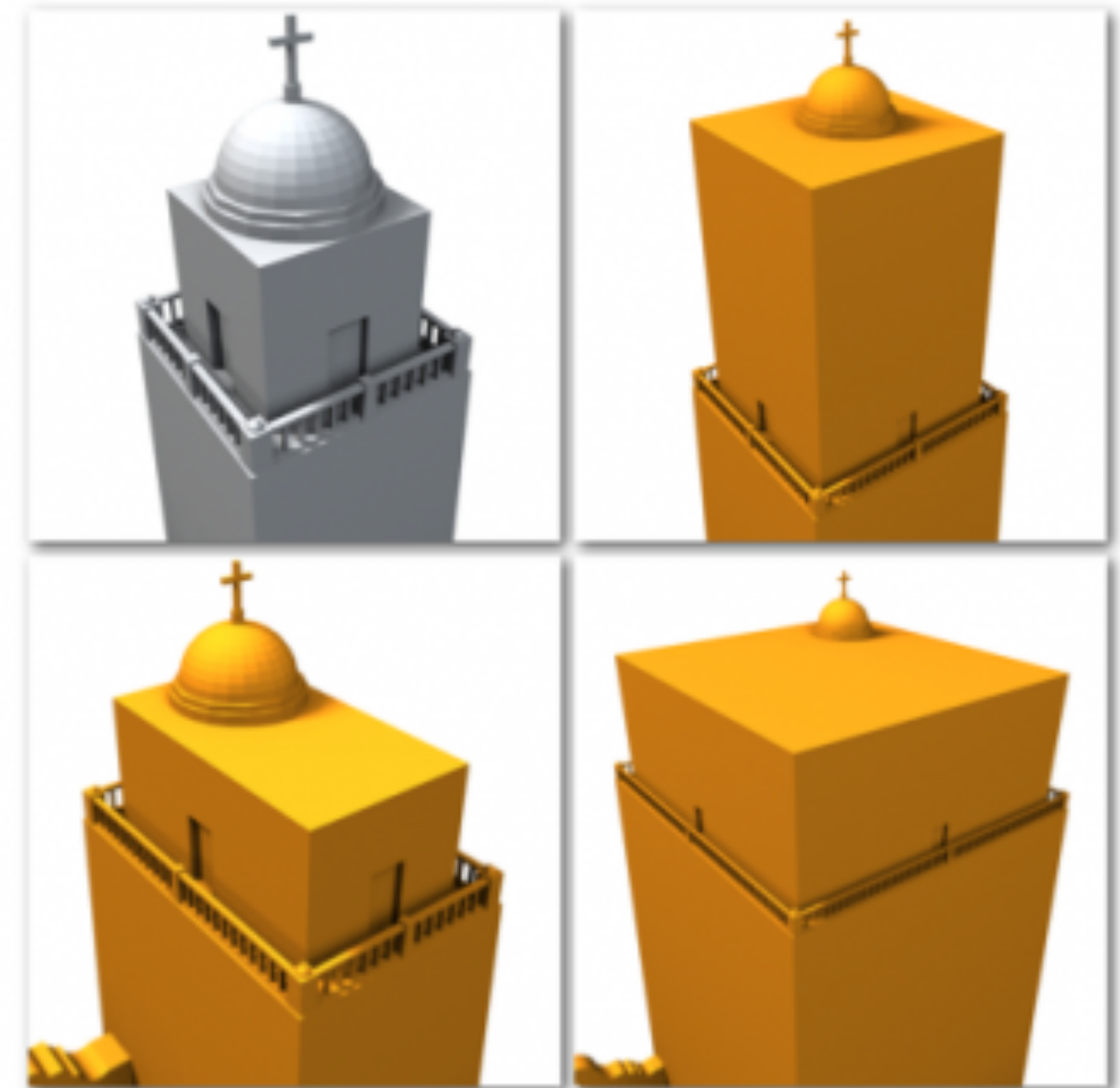
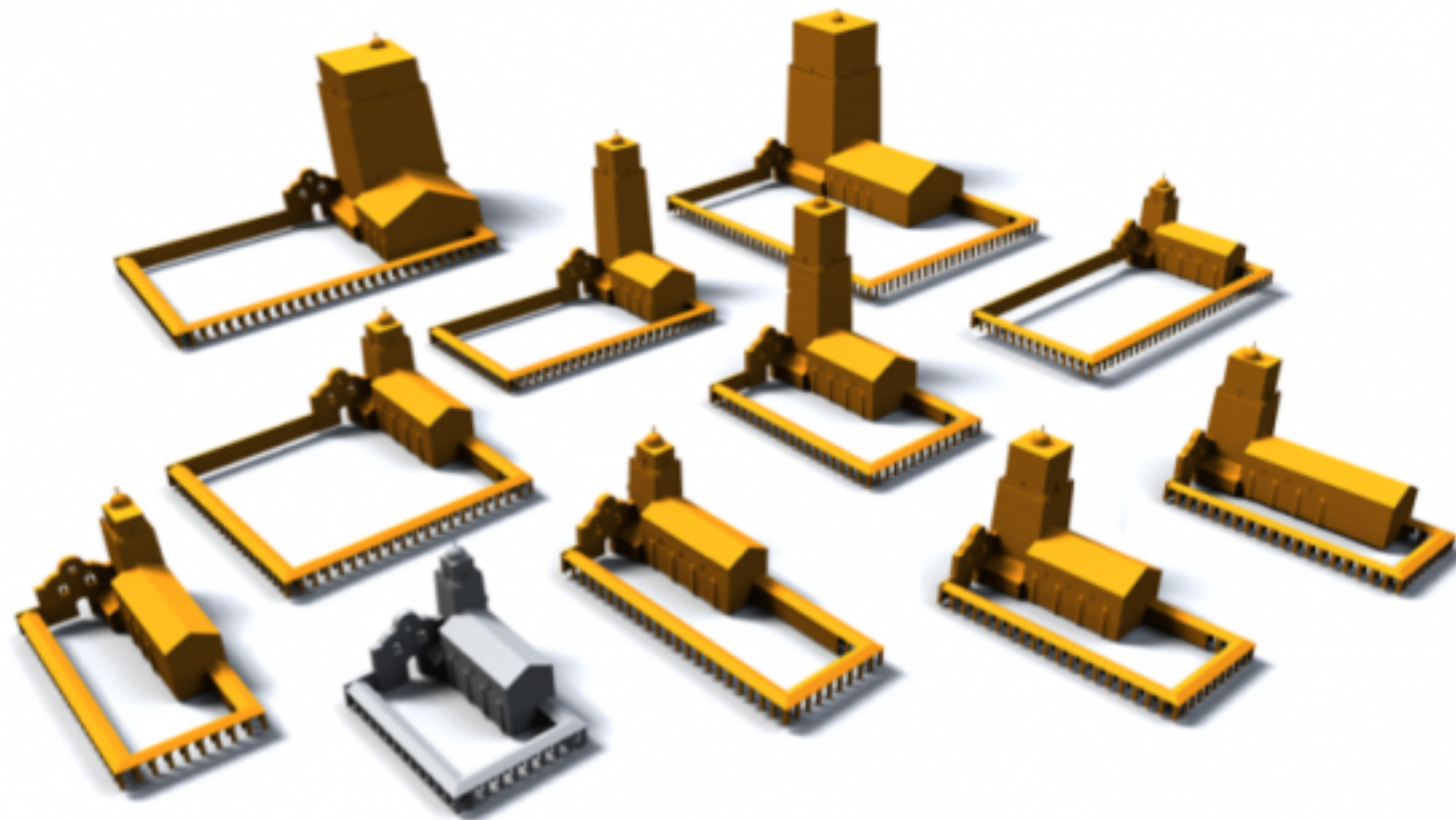
Docking Sites

- **Cut** model at symmetry boundaries
- Symmetric boundaries yield **replacement rules**
- **Precompute** shape grammar



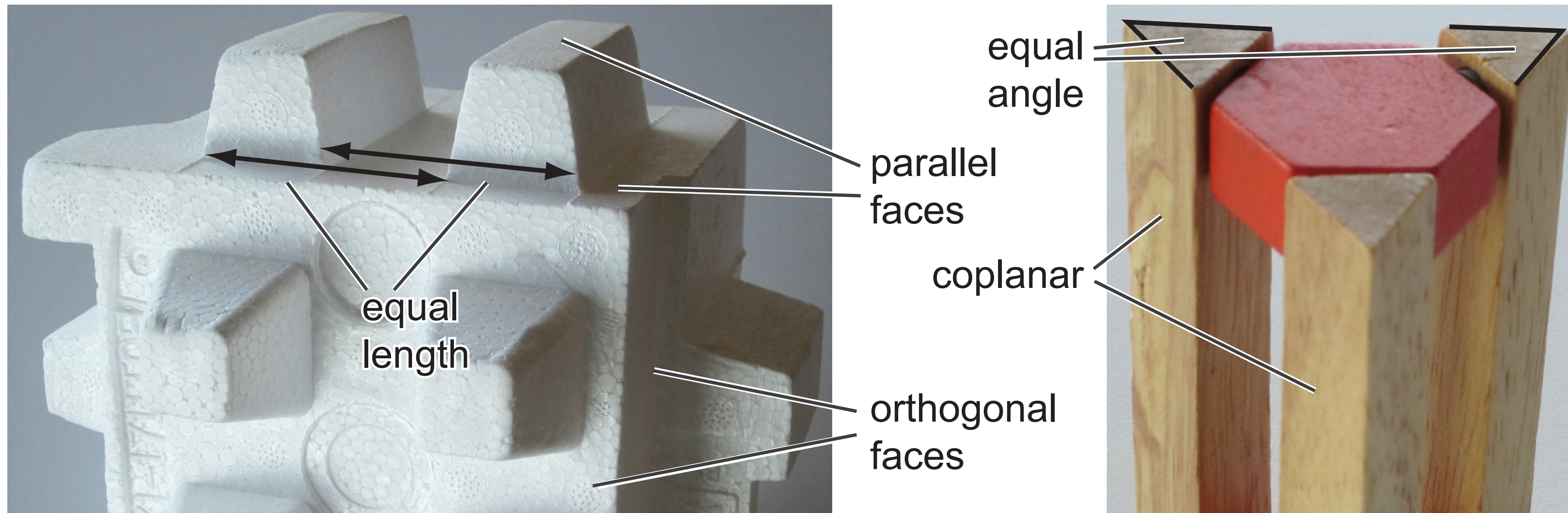
[A Connection between Partial Symmetry and Inverse Procedural Modeling, Bokeloh et al., 2010]

Deformation Null Space



[An Algebraic Model for Parameterized Shape Editing, Bokeloh et al. 2012]

Relations in Scanned Objects



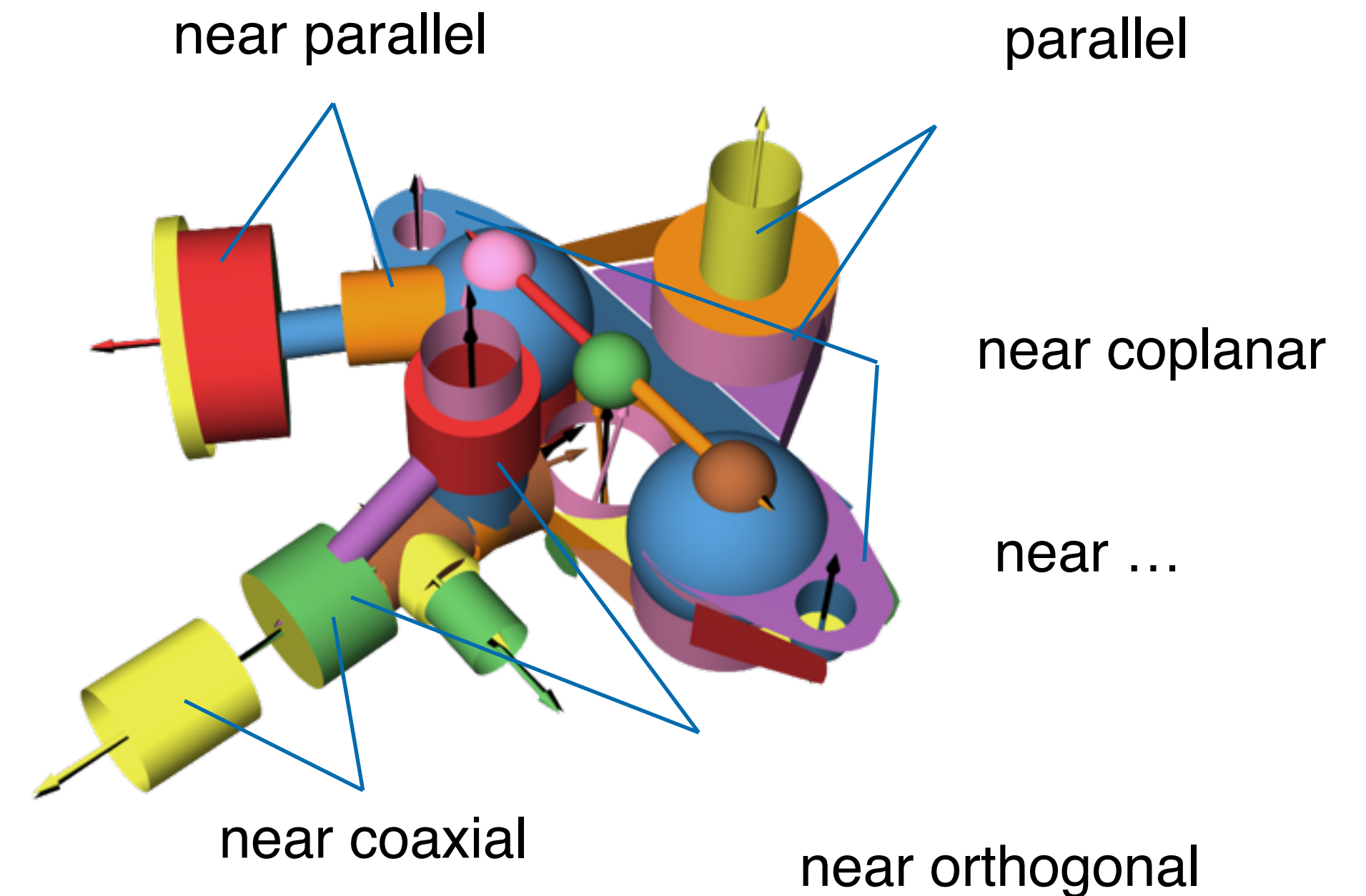
- i) orthogonal/parallel relations, equal angle
- ii) placement relation, e.g., coplanar, coaxial
- iii) equal length/radii relations

[GlobFit: Consistently Fitting Primitives by Discovering Global Relations, Li et al. 2011]



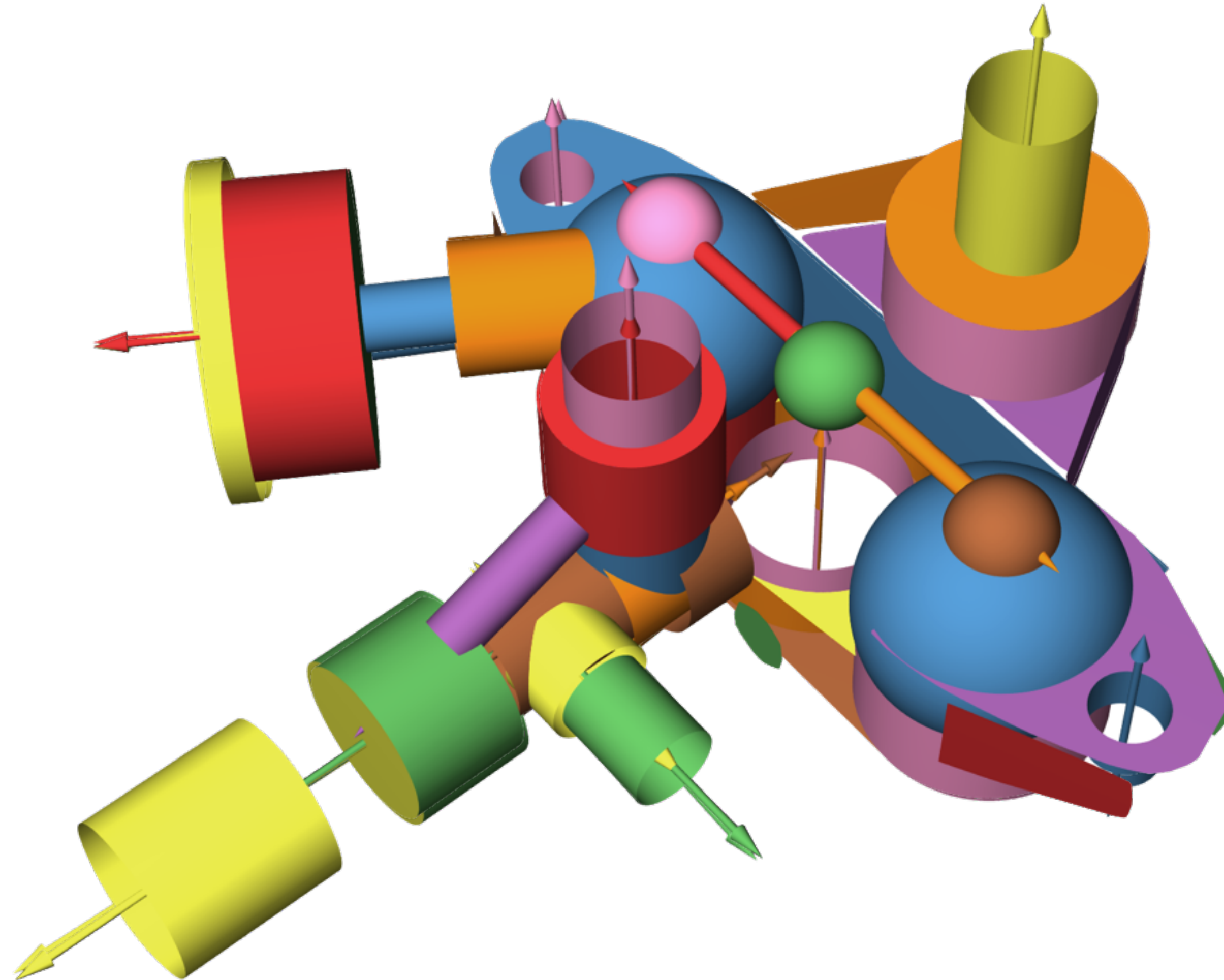
point cloud

RANSAC

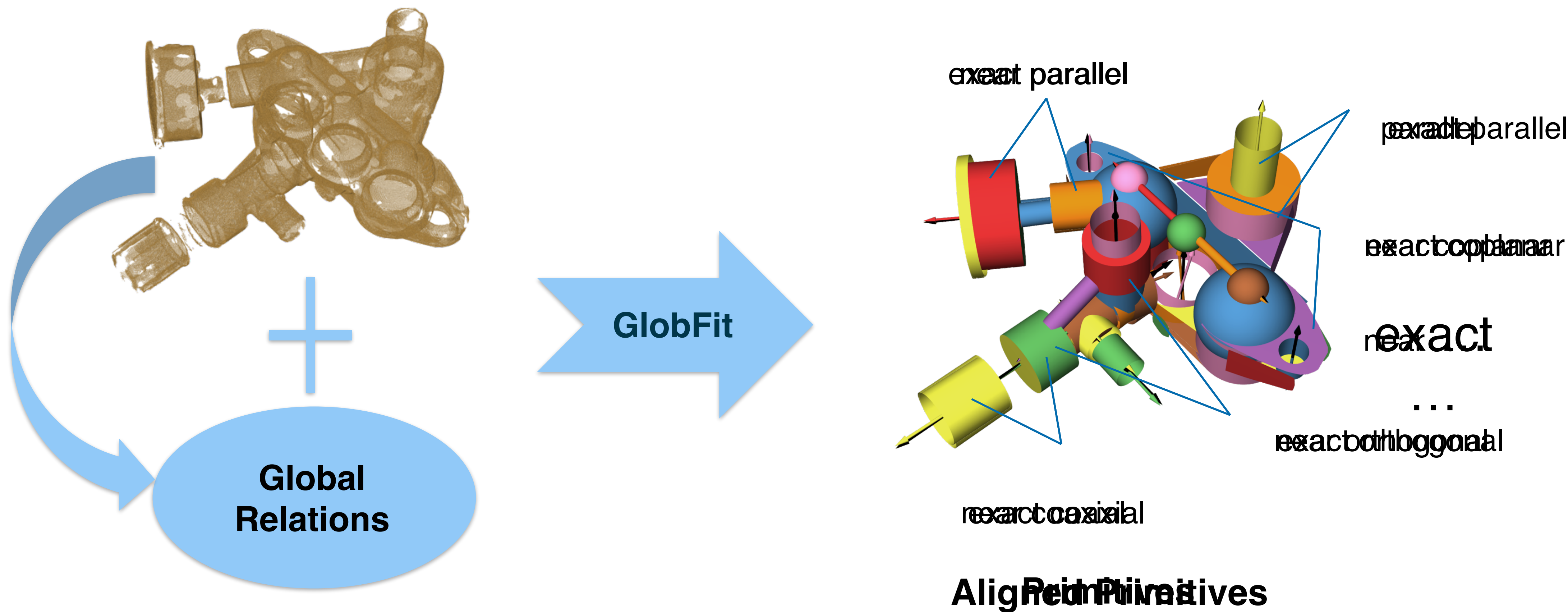


primitives

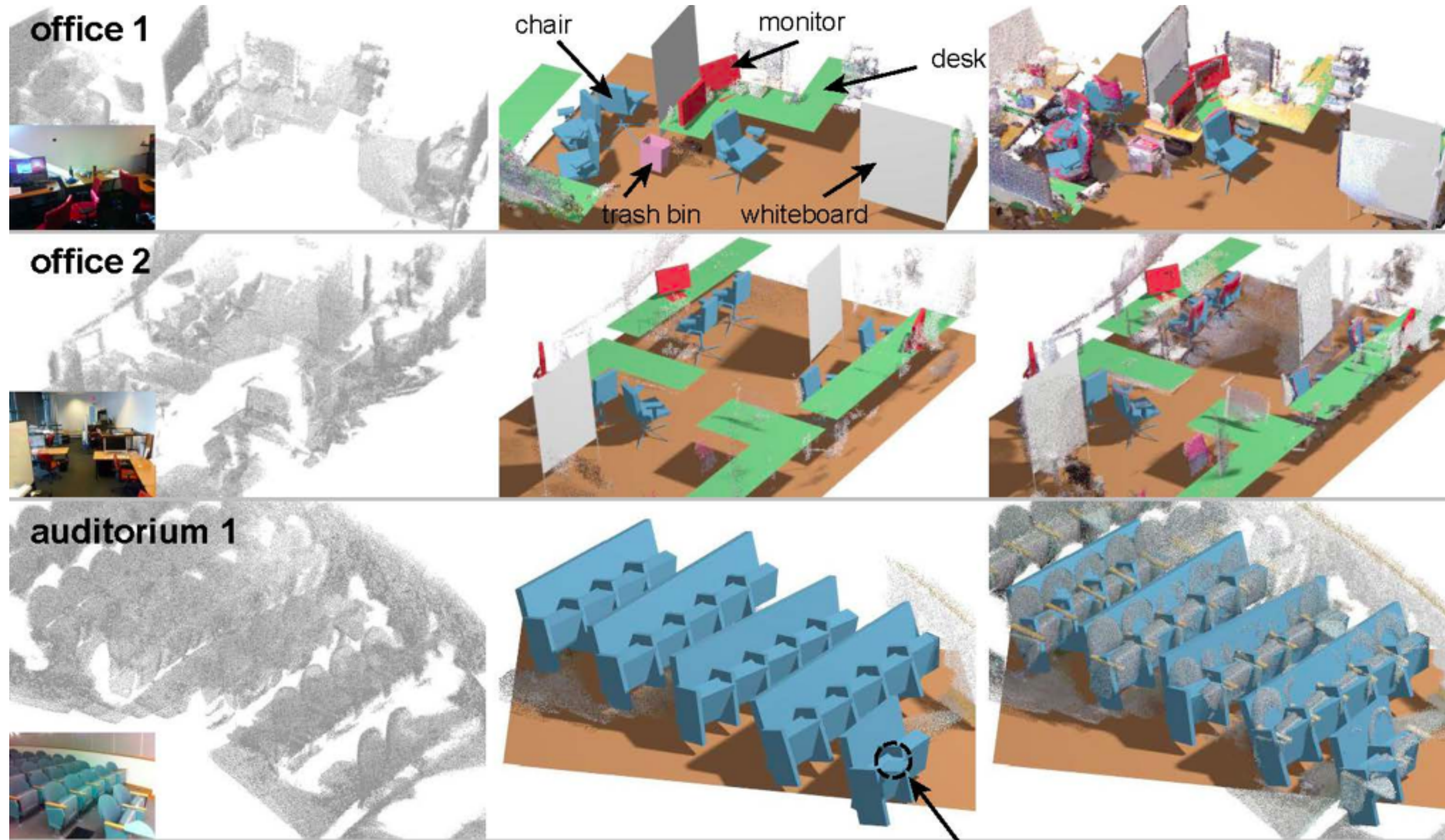
Consistent Primitive Fitting



Primitive Fitting with Global Relations



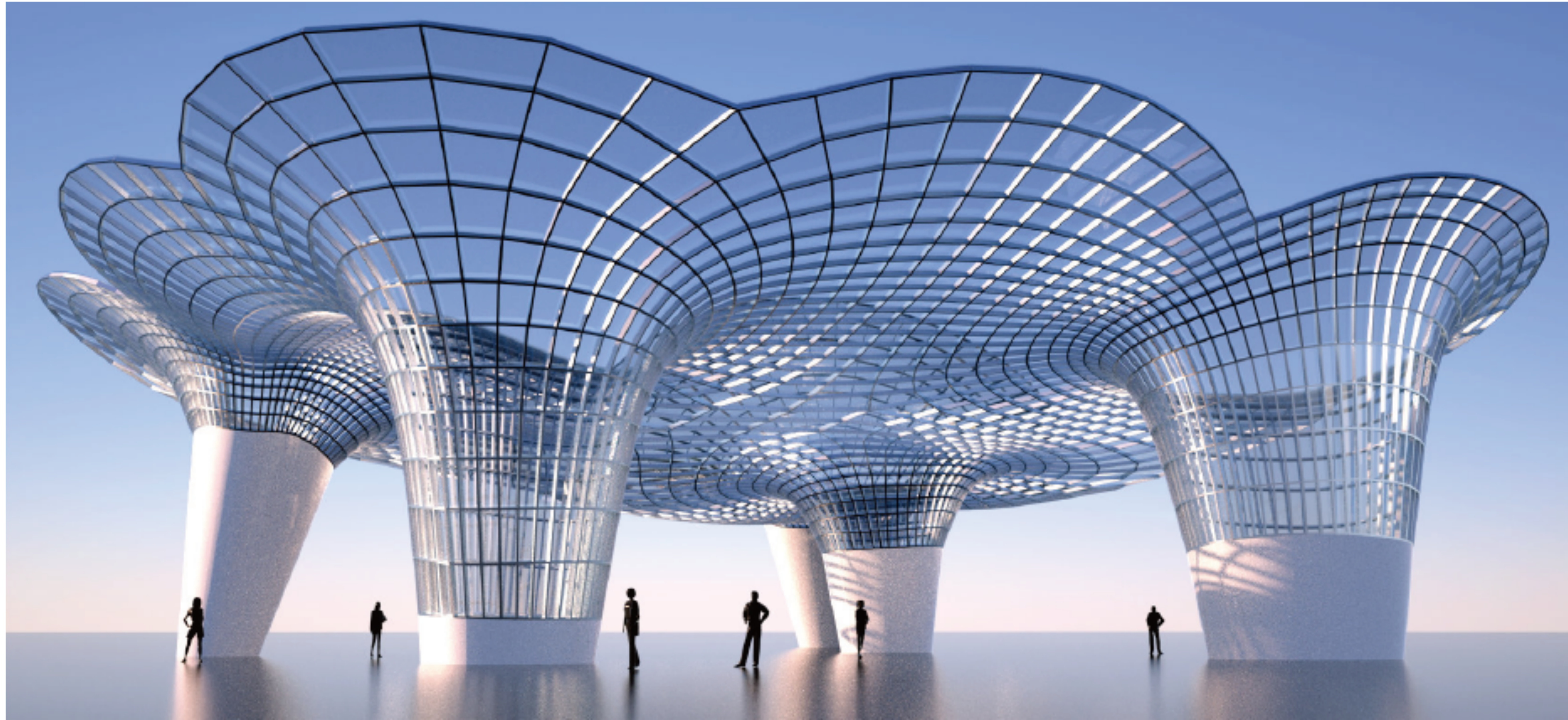
Structures as Features



[Acquiring 3D Indoor Environments with Variability and Repetition, Kim et al. 2012]

Constrained Meshes

- Explore shape space w.r.t. specific constraints (implicit non-linear constraints)



[Shape Space Exploration of Constrained Meshes, Yang et al. 2011]

Constrained Shape Space

- mesh \rightarrow point $\mathbf{x} = (v_1, \dots, v_n) \in \mathbb{R}^D$
- combinatorics remain fixed
- starting mesh \mathbf{x}_0 satisfies (nonlinear) constraints

Each (face) constraint/relation

$$\Gamma_i := \{\mathbf{x} \in \mathbb{R}^D : E_i(\mathbf{x}) = 0\} \quad \forall \quad i = 1, \dots, m$$
$$\mathbf{d} \Rightarrow \mathbf{x}_0 + \mathbf{d}$$

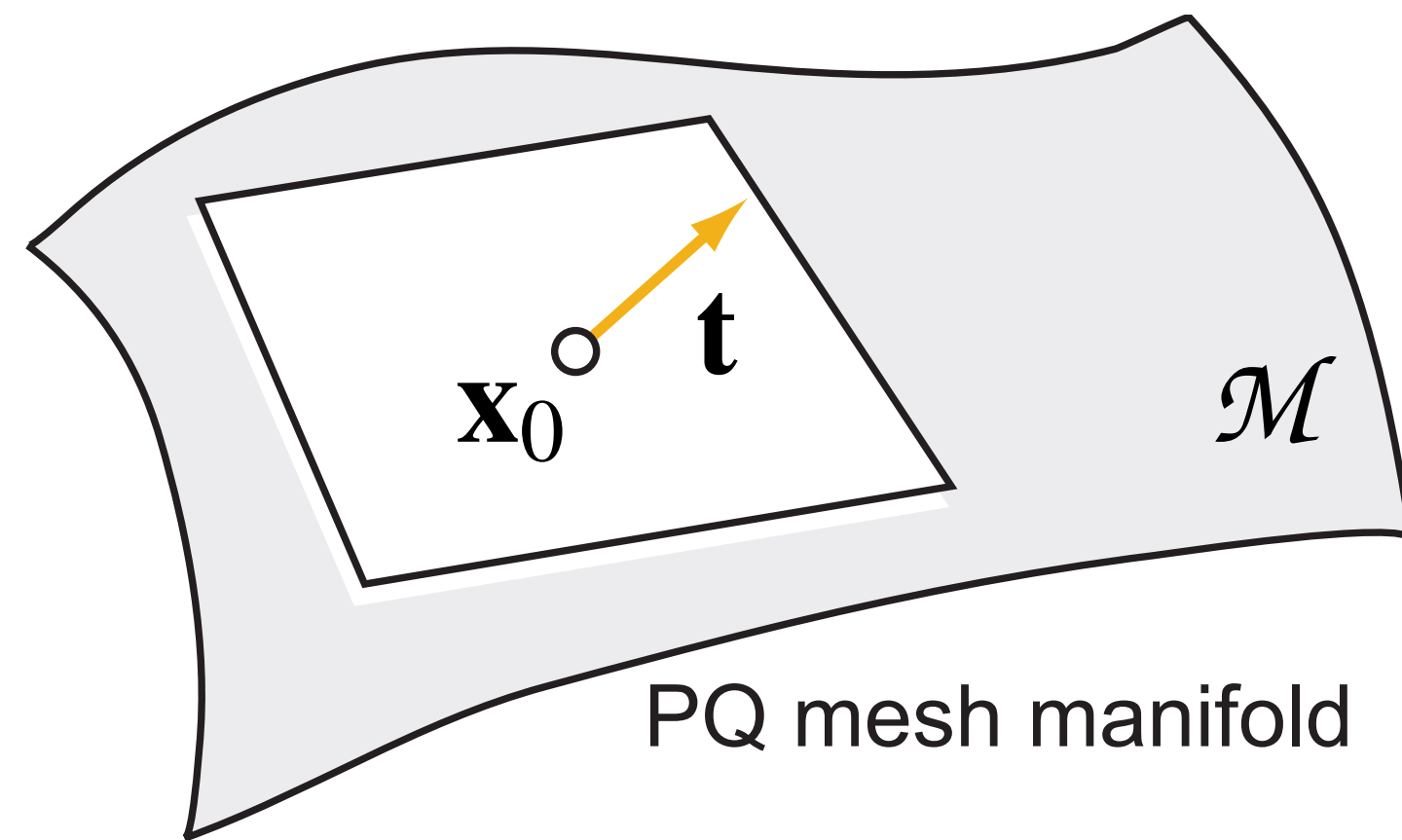
$$d(\mathbf{x}_1, \mathbf{x}_2) = \|\mathbf{x}_1 - \mathbf{x}_2\|$$

$$\mathbf{S}(\mathbf{u}) = \mathbf{x}_0 + \sum_{i=1}^{D-m} u_i \mathbf{e}_i + \frac{1}{2} \sum_{j=1}^m (\mathbf{u}^T \cdot A_j \cdot \mathbf{u}) \mathbf{n}_j$$

$$\begin{aligned} E_i(\mathbf{x}) &= E_i(\mathbf{x}_0) + \nabla E_i^T \cdot (\mathbf{x} - \mathbf{x}_0) + \frac{1}{2} (\mathbf{x} - \mathbf{x}_0)^T \cdot H_i \cdot (\mathbf{x} - \mathbf{x}_0) \\ &\quad + o(\|\mathbf{x} - \mathbf{x}_0\|^2) \end{aligned}$$

$$E_i(\mathbf{u}) = E_i(\mathbf{x}_0)$$

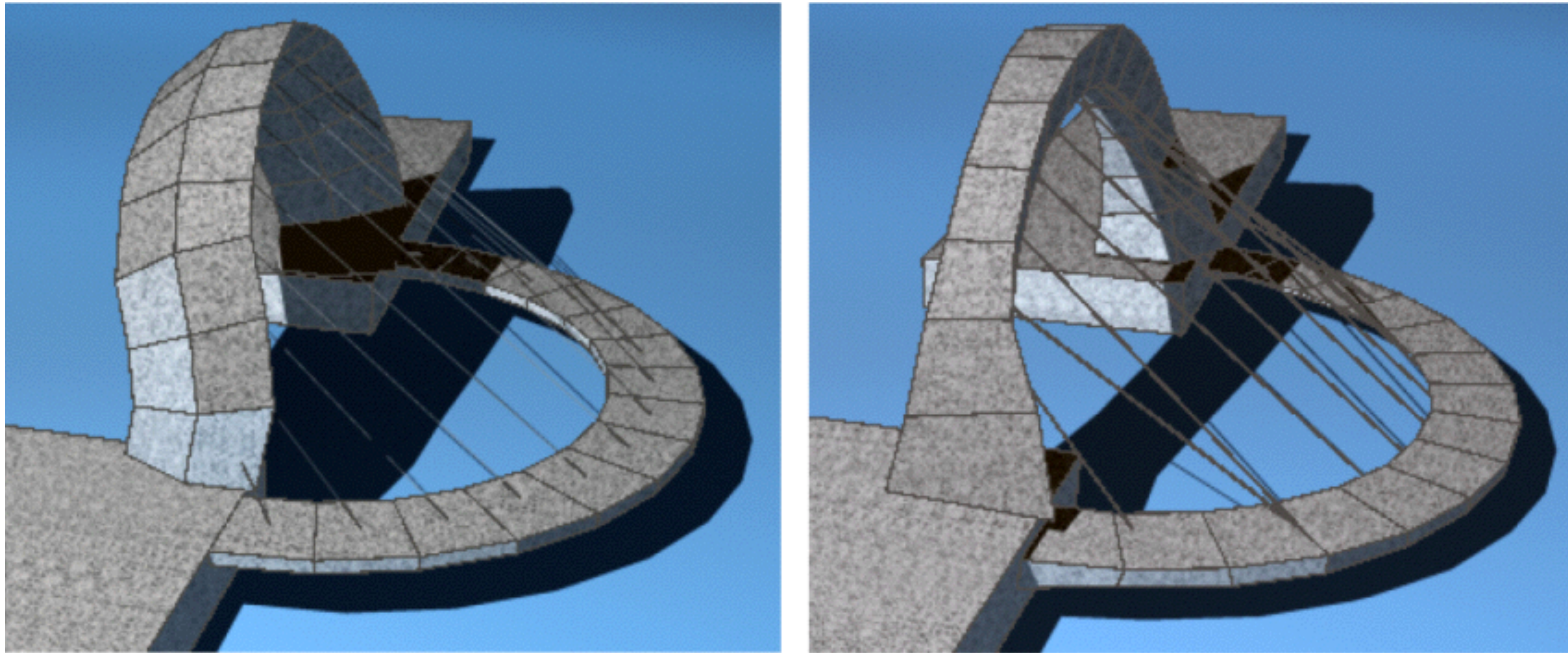
Walking on the Tangent Space



Flat Circular Mesh Exploration

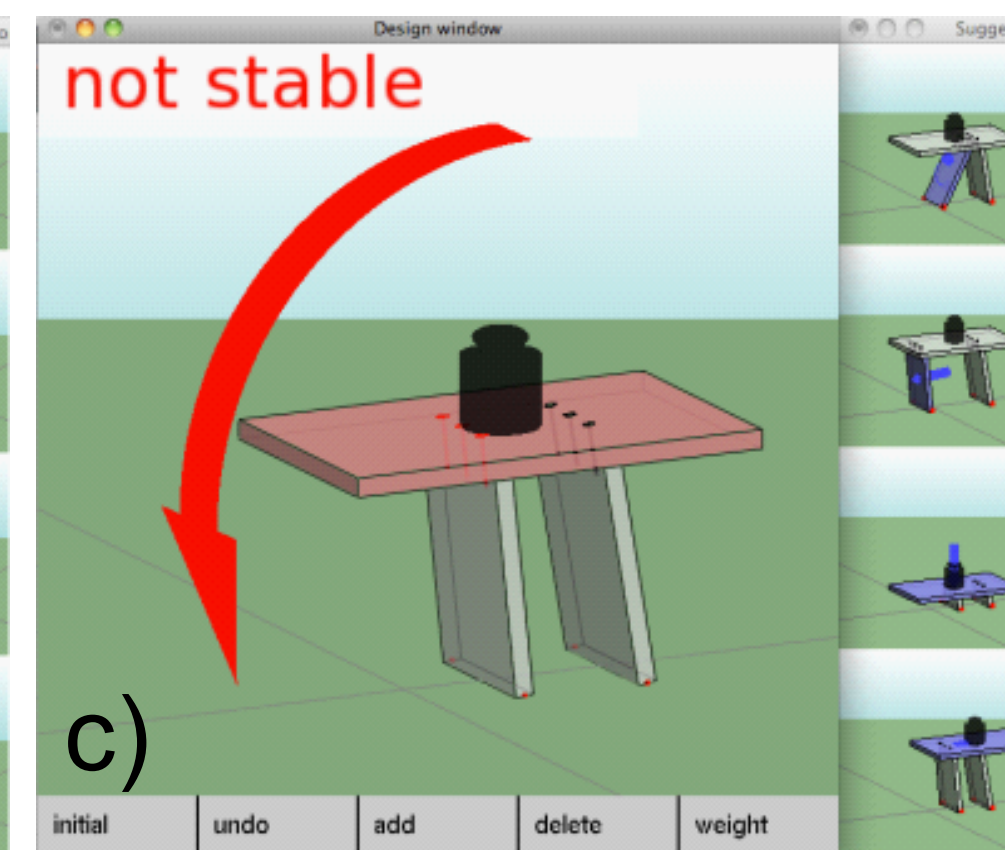
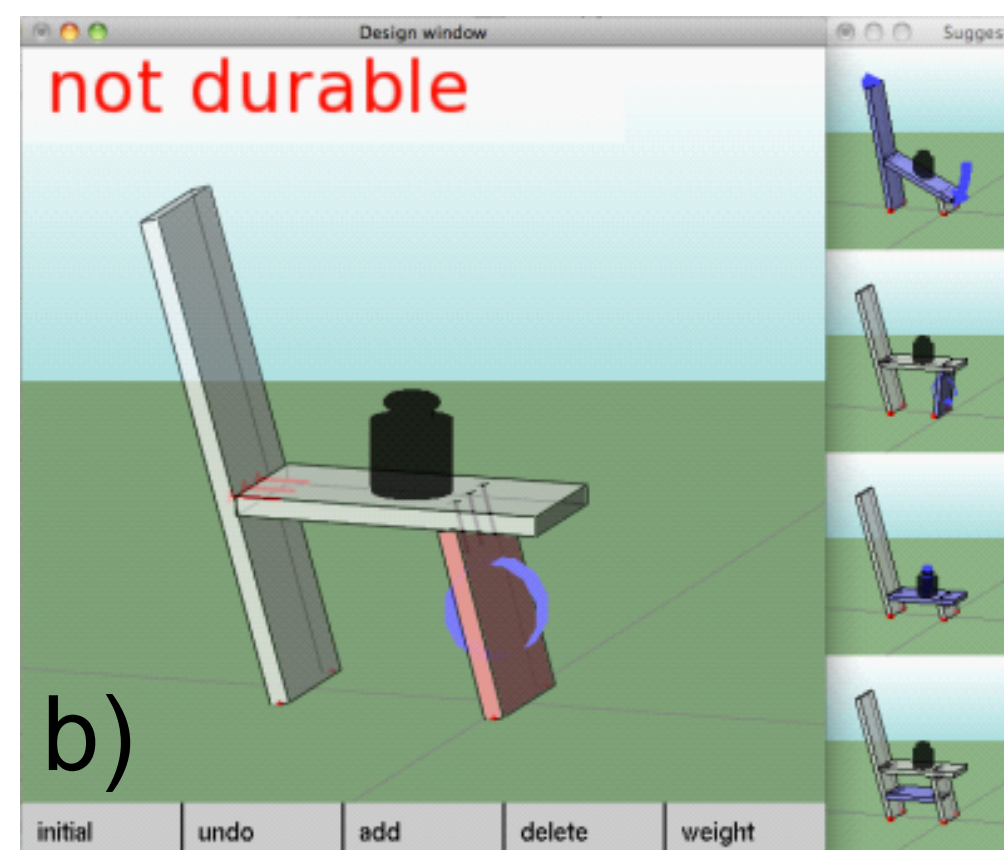
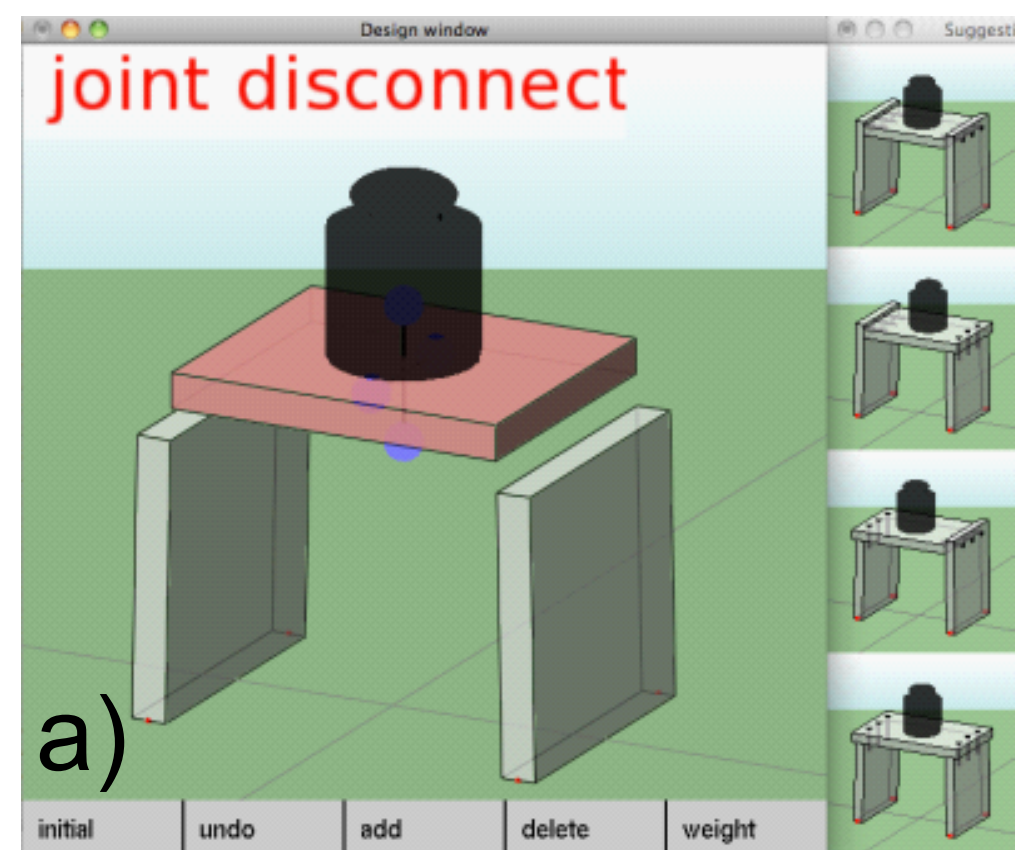
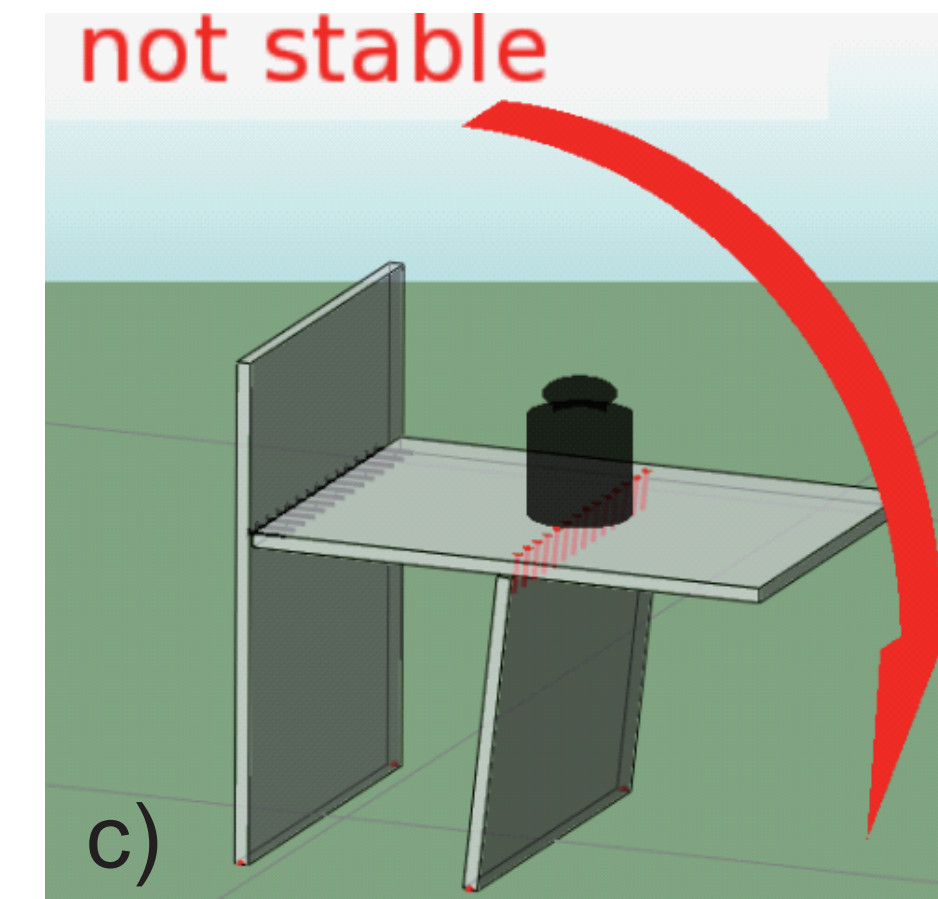
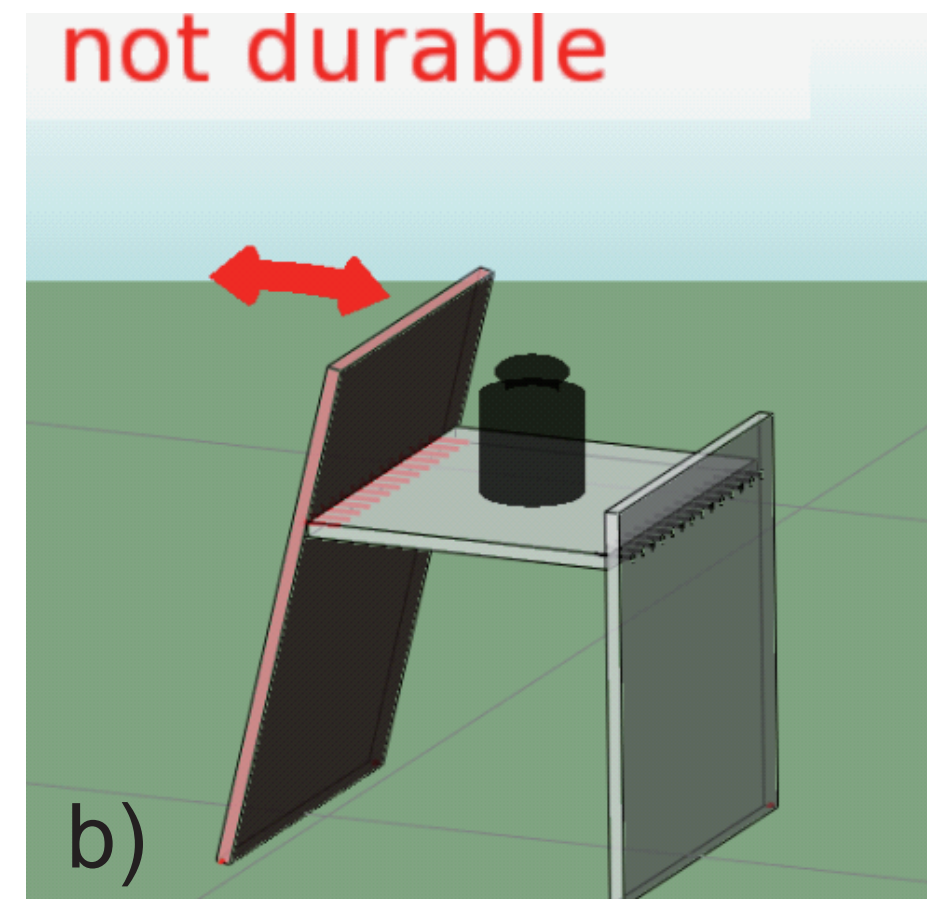
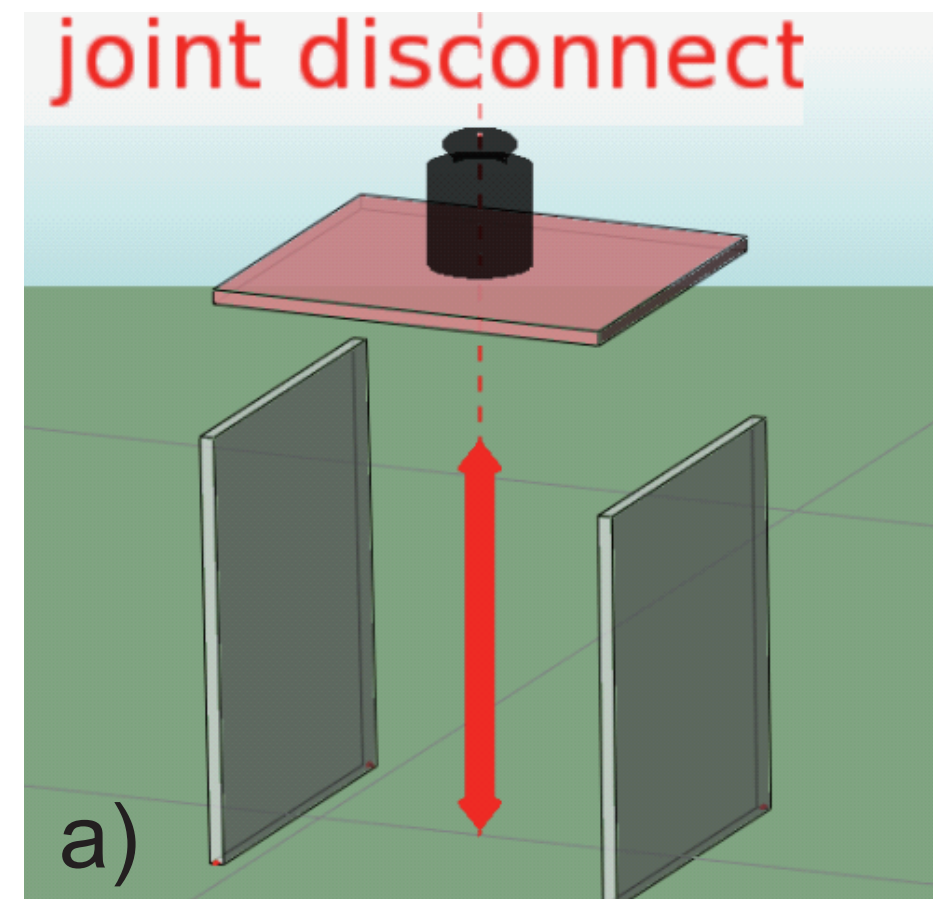
Structural Optimization

- Improve structural stability of 3D masonry buildings
 - Apply local changes to stabilize



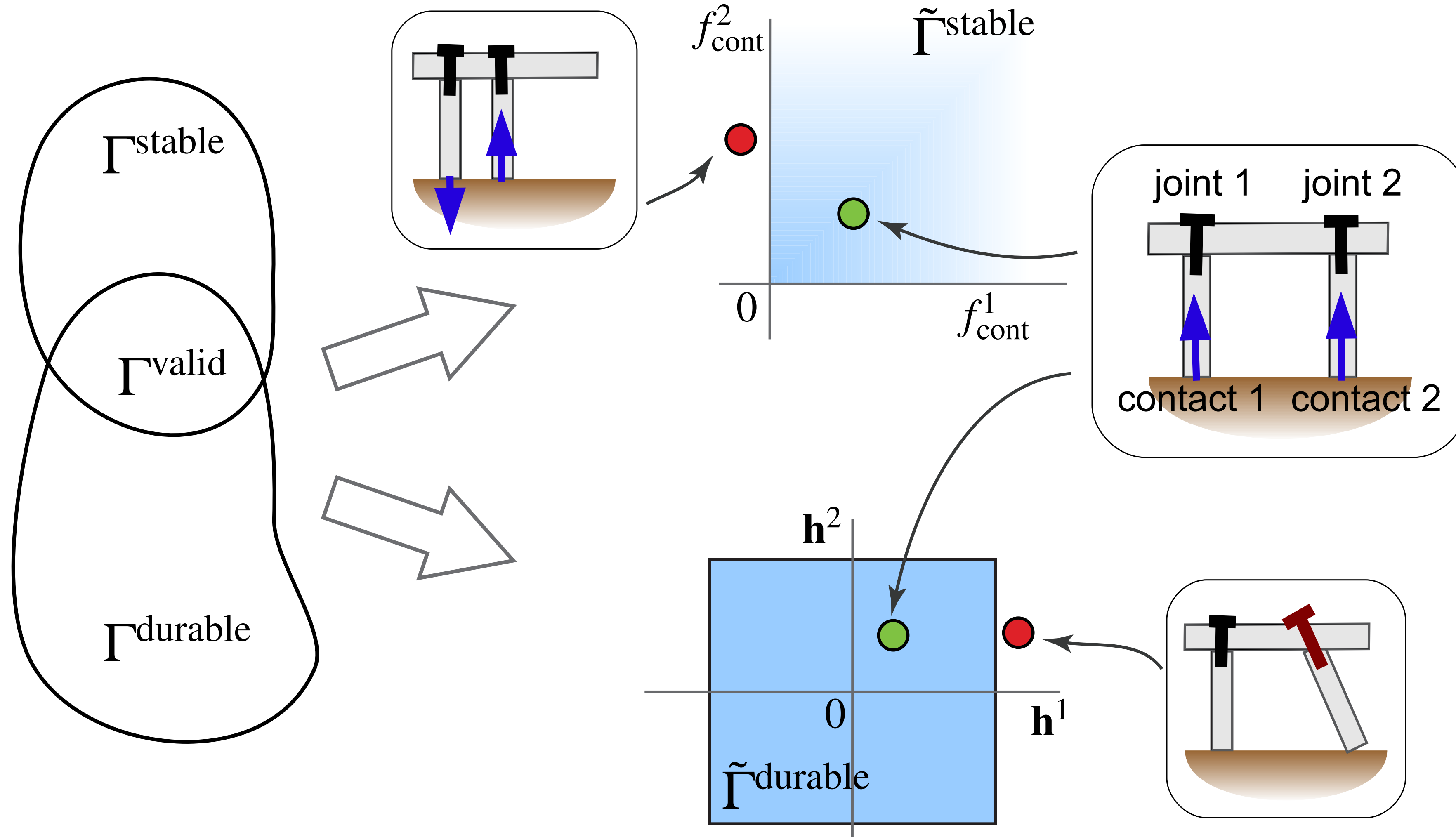
[Structural Optimization of 3D Masonry Buildings, Whiting et al. 2012]

When Forces Drive Geometry

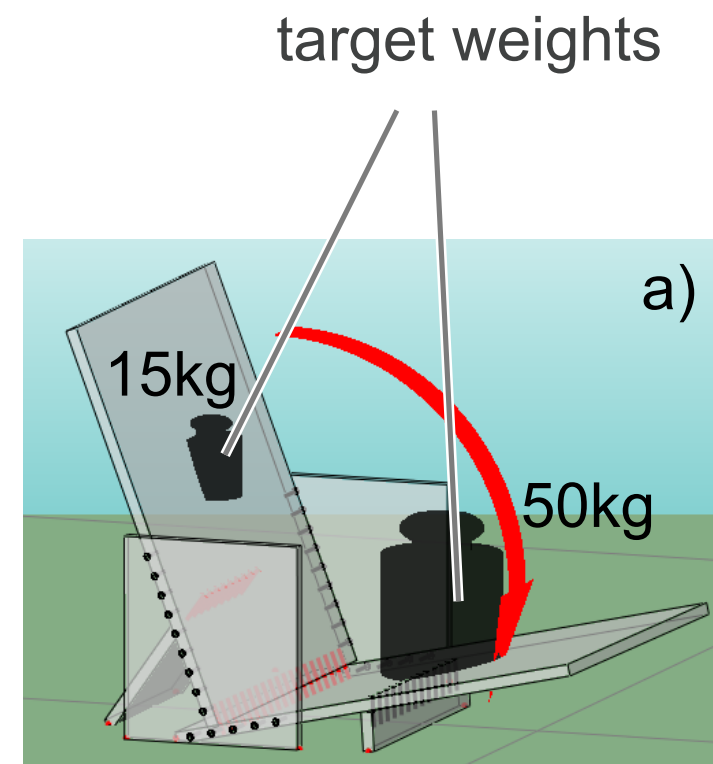


[Guided Exploration of Physically Valid Shapes for Furniture Design, Umetani et al. 2012]

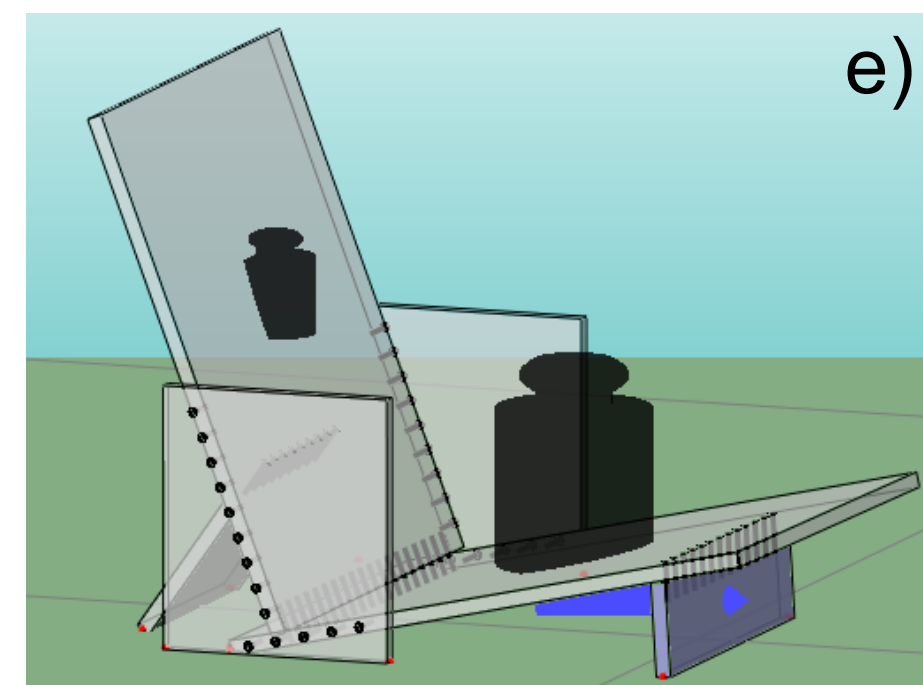
Guided Exploration



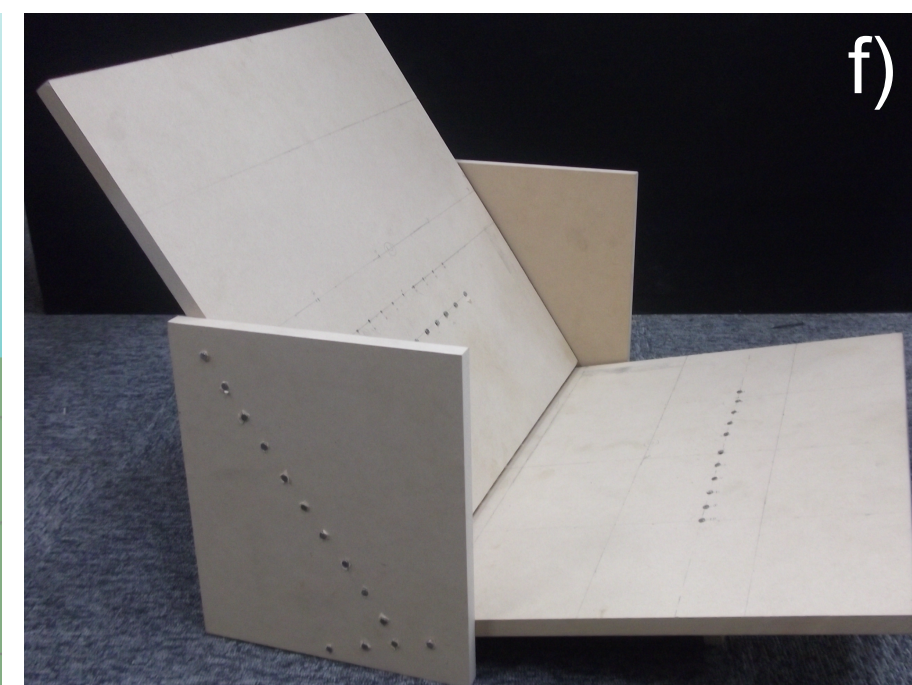
“Forms are Force Diagrams”



unstable shape

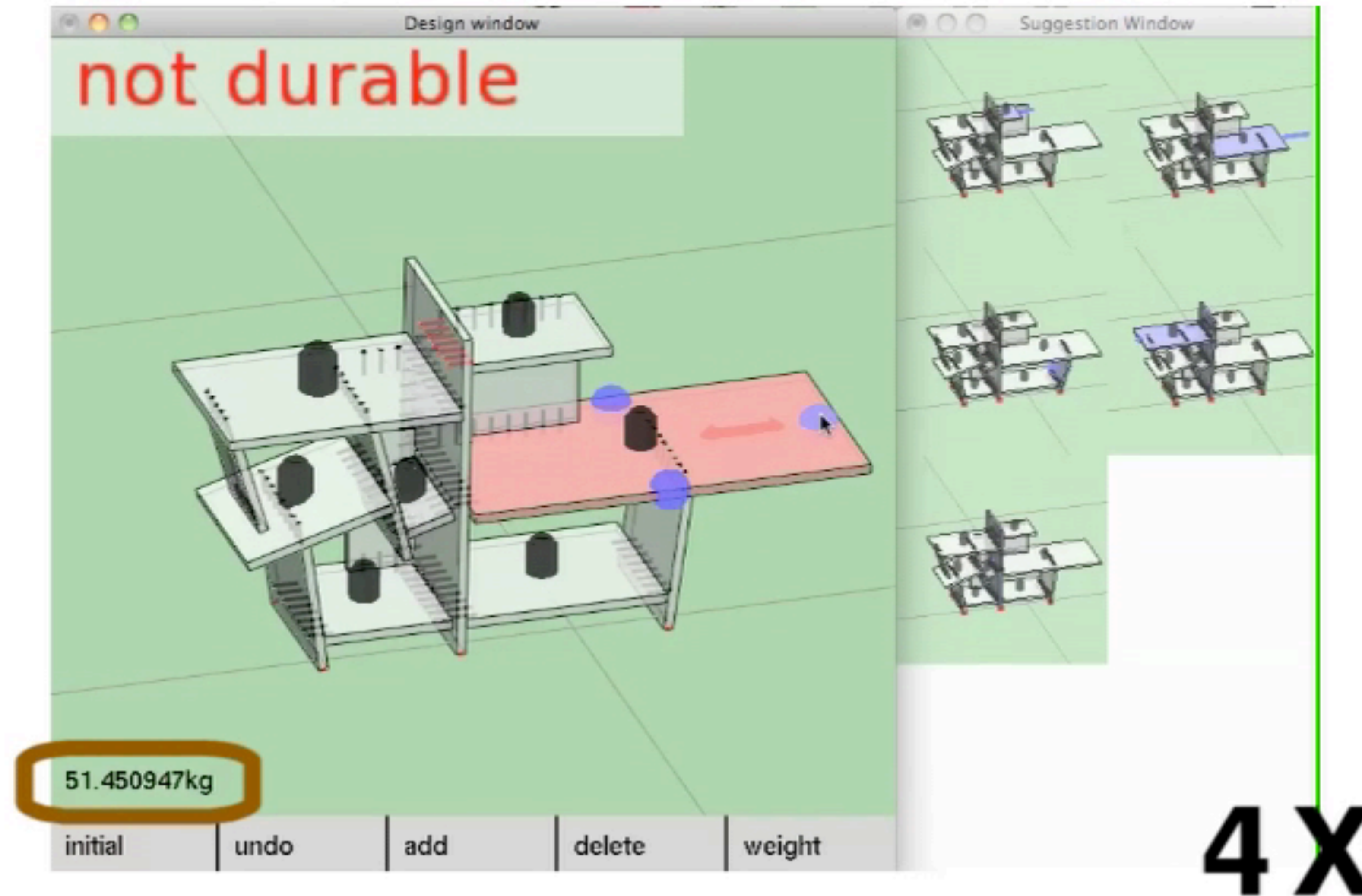


stable and durable shape

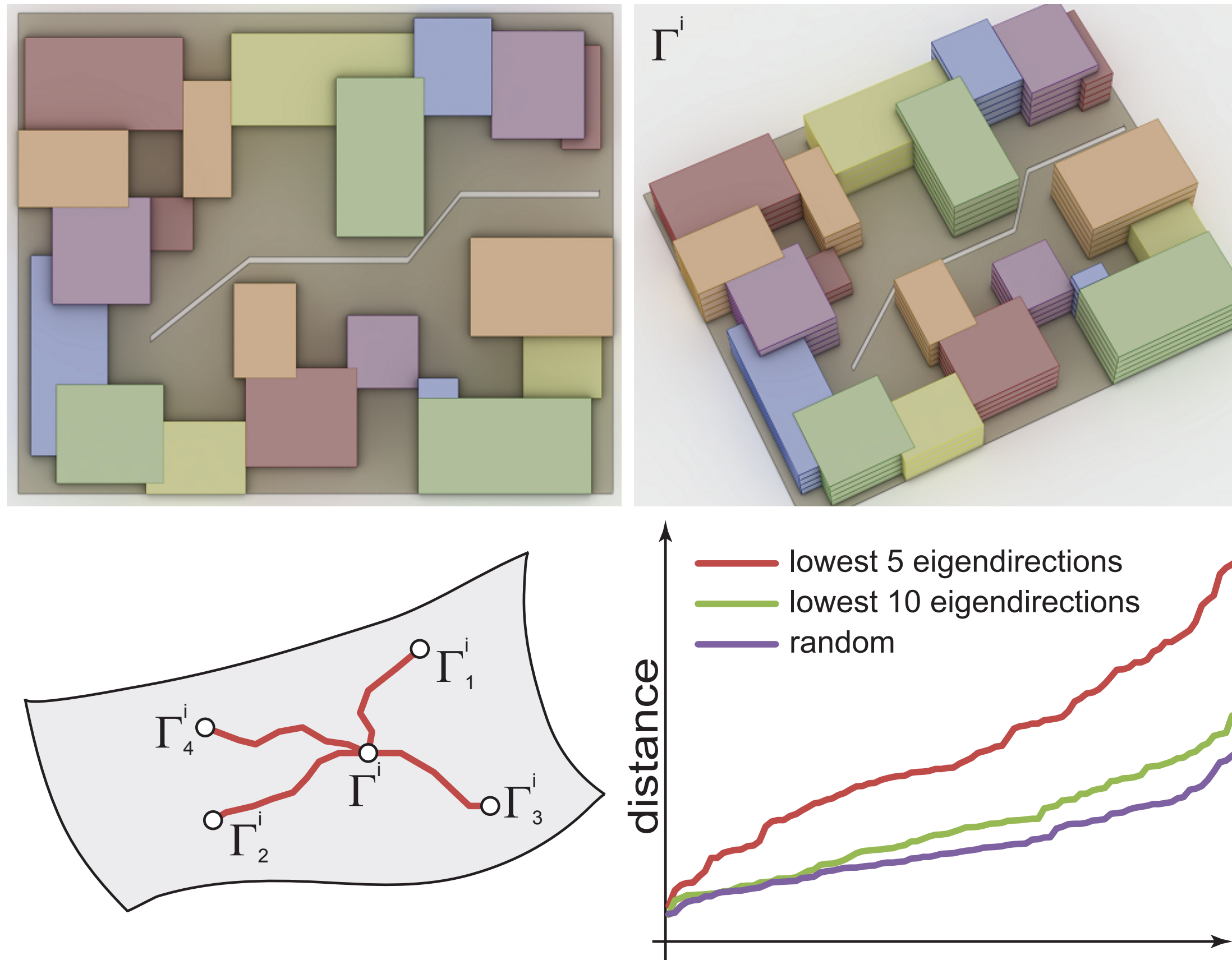


physical prototype

“Forms are Force Diagrams”



Geometry from Constraints



$$E(\Gamma_v) \sim E(\Gamma^i) + \sum_j \gamma_j^2 \lambda_j / 2$$

[Generating and Exploring Good Building Layouts, Bao et al. 2013]

Algorithm Steps

