SIGGRAPH2011

Modeling 3D Urban Spaces Using Procedural and Simulation-Based Techniques

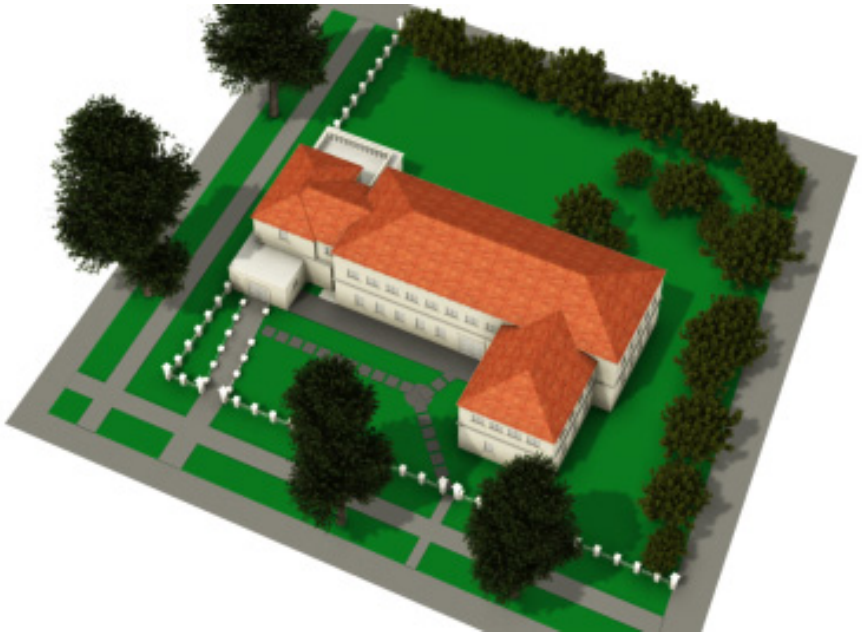
Computational Building Design

Peter Wonka

Arizona State University

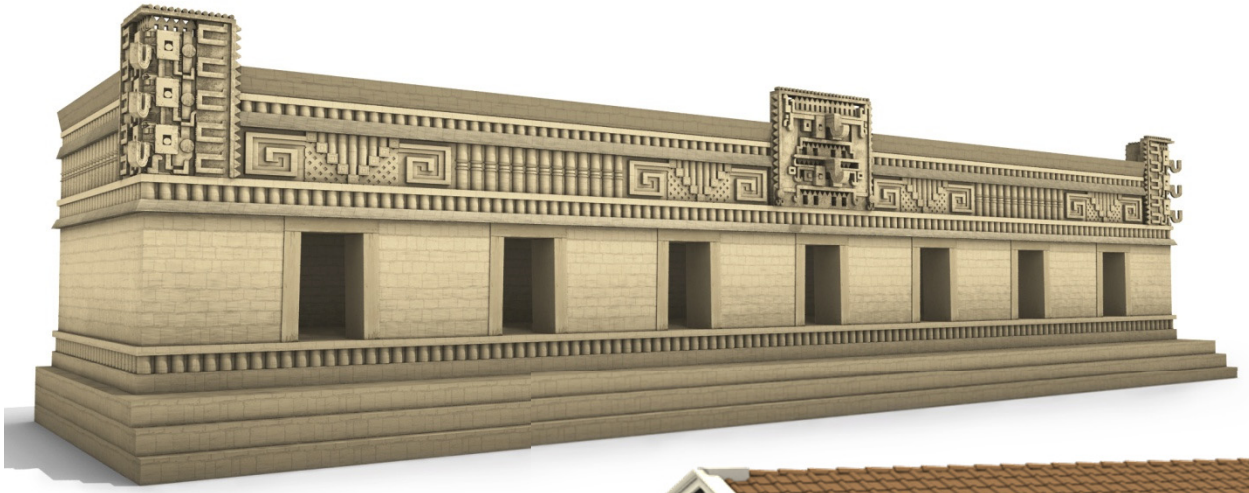
CGA-Shape

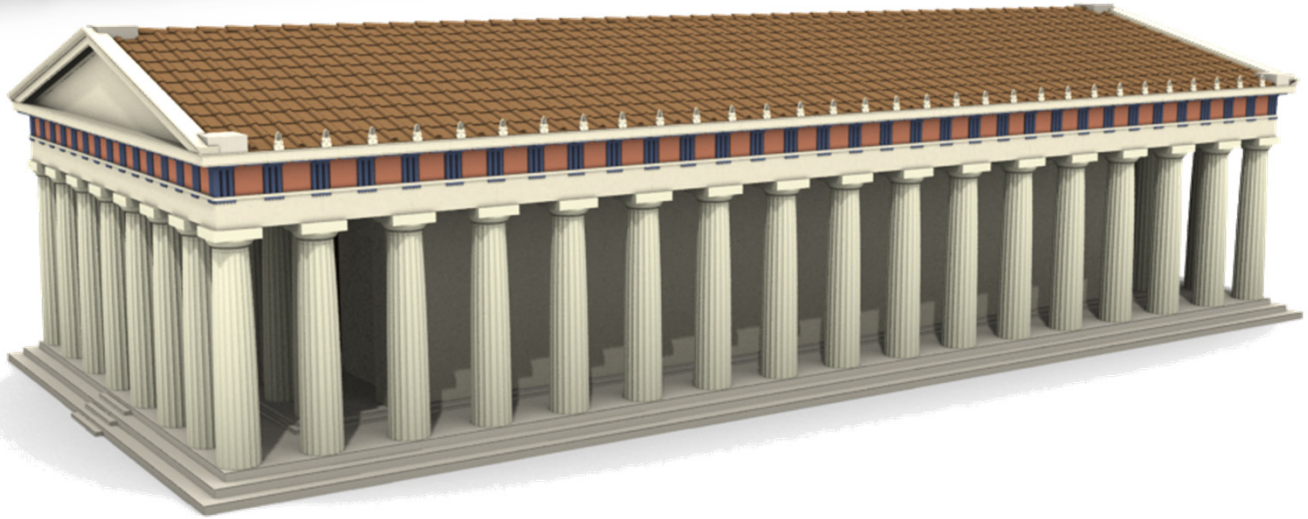
- **Procedural Modeling of Buildings**
  Pascal Mueller, Peter Wonka, Simon Haegler, Andreas Ulmer, Luc Van Gool.
  Siggraph 2006



Results: Shape Interaction

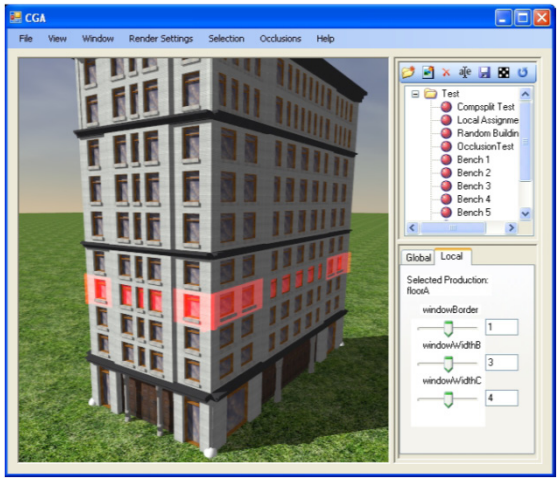
Mayan Architecture and Temples





Editing of CGA-Shape Grammars

- **Interactive Visual Editing of Grammars for Procedural Architecture**
  Markus Lipp, Peter Wonka, Michael Wimmer
  Siggraph 2008

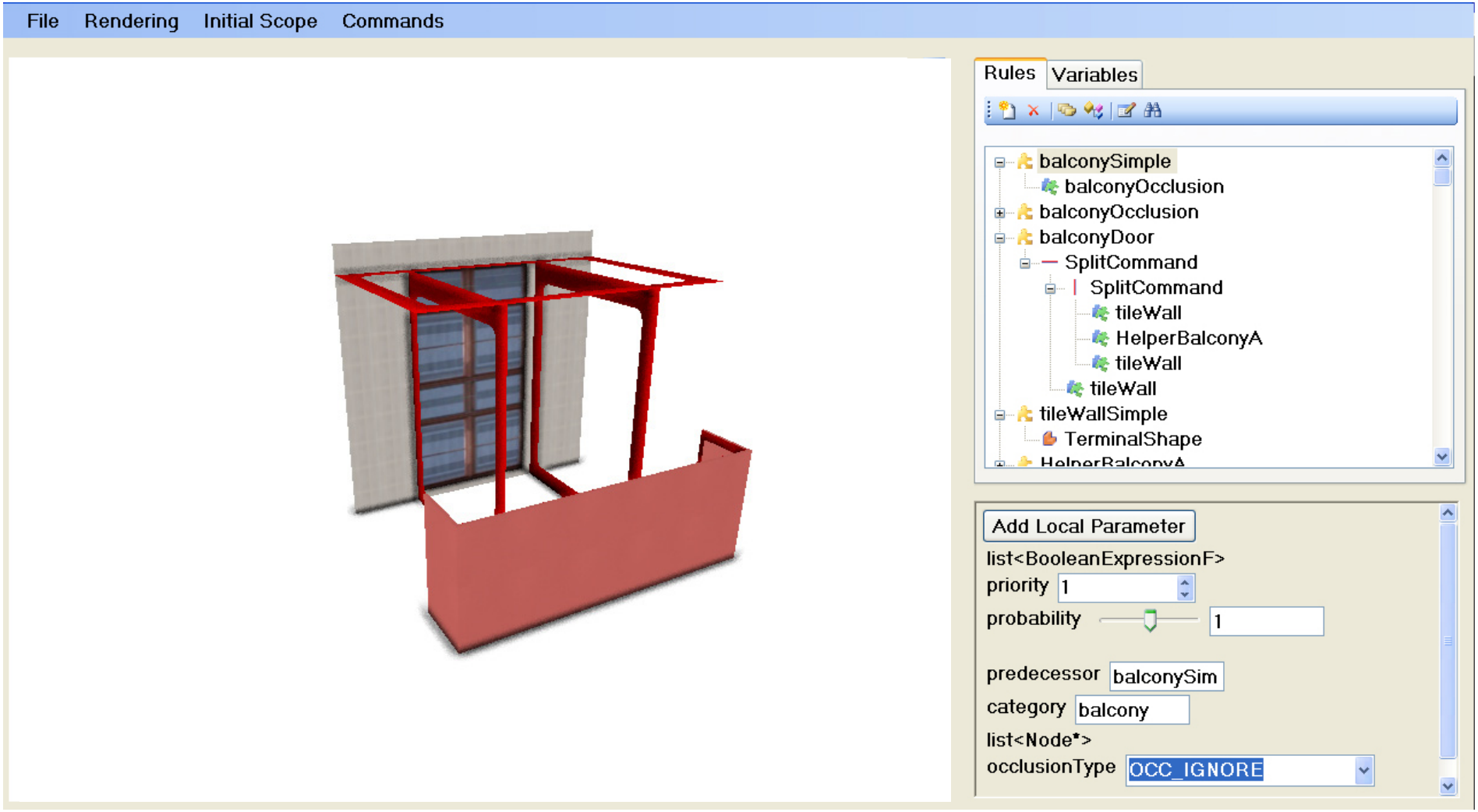


Overview

- Problem #1: no direct artistic control
  - Solution: instance locators
- Problem #2: text-based grammars
  - Solution: visual grammar editing

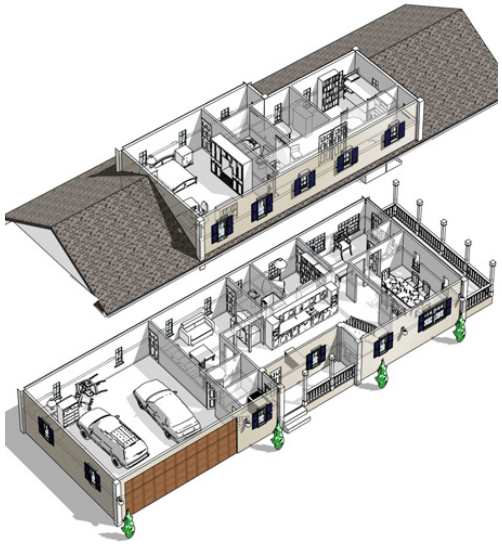
Direct Artistic Control!

Visual Rule Editing



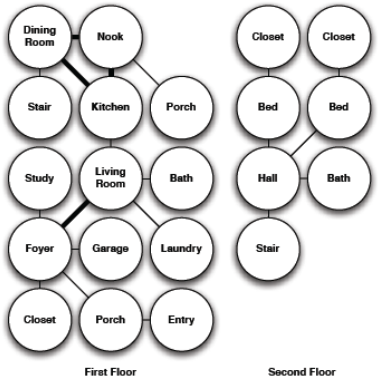
Modeling Buildings from Floorplans

- **Computer-Generated Residential Building Layouts**
  Merrell, Schkufza, Koltun
  Siggraph Aisa 2010



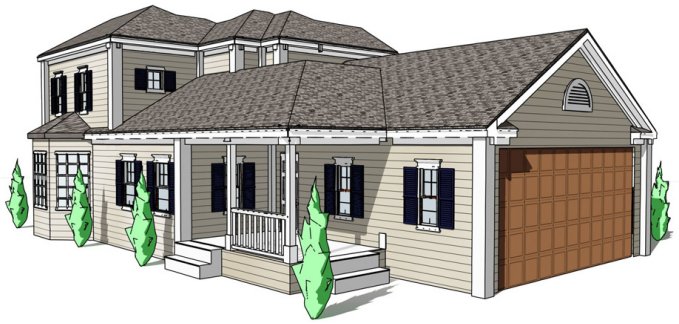
Design Overview

Client's
High-level
Specifications



Architectural Program
Rooms & Adjacencies

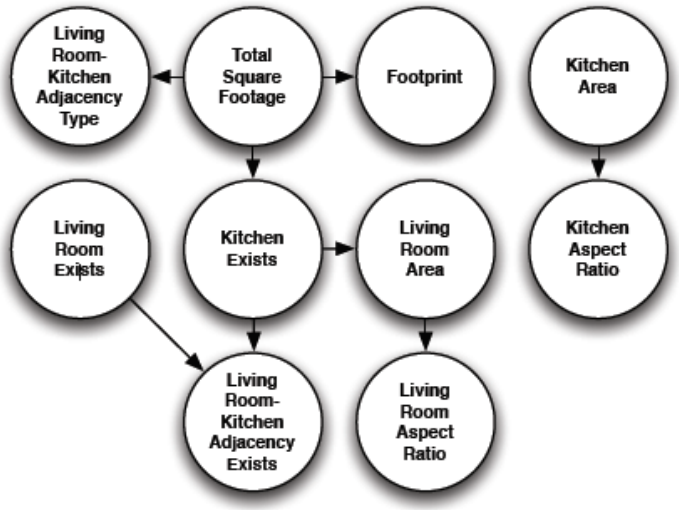
Set of Floor Plans



3D Model

Learning Structural Relationships

- Train a probabilistic graphical model.
  - Compactly represents the structure of the data.
  - Bayesian Network
- Nodes – probabilities
- Edges – conditional dependencies
- Sample from conditional distributions
  - Use high level specifications



Bayesian Network

Metropolis Algorithm

- Objective Function

$$f(\mathbf{x}) = \exp(-\beta C(\mathbf{x}))$$

$\mathbf{x}$ Building Layout

β Constant

$C(\mathbf{x})$ Cost Function

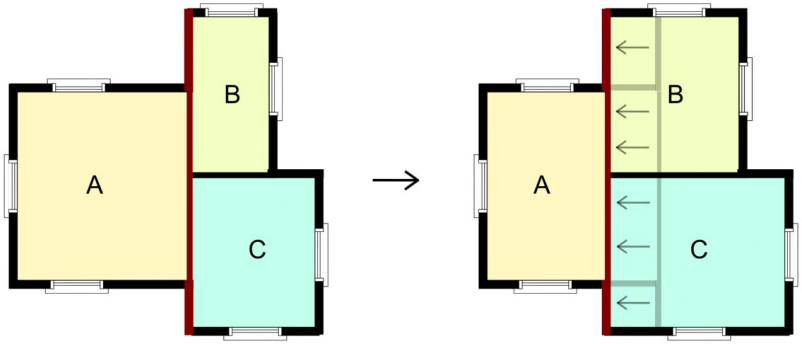
- Each iteration, propose a new building layout $\mathbf{x}^\star$
- Accept with probability

$$\alpha(\mathbf{x}^\star|\mathbf{x}) = \min\left(1, \frac{f(\mathbf{x}^\star)}{f(\mathbf{x})}\right)$$

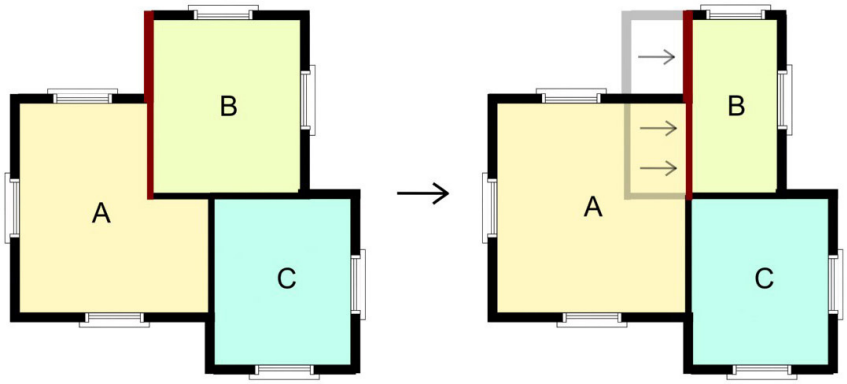
Proposal Moves

- Slide a wall

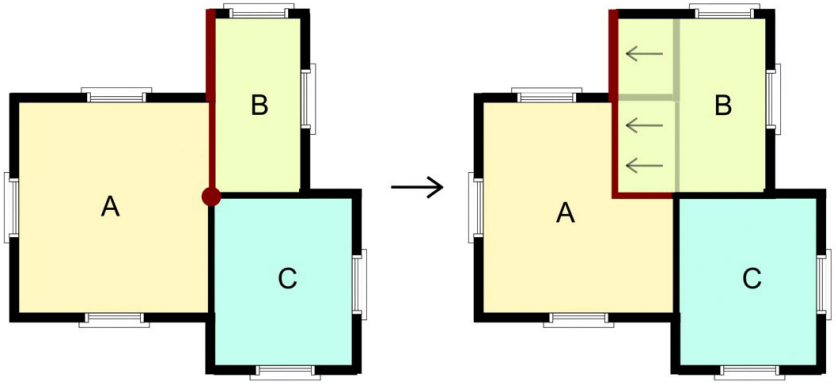
$$d \sim \mathcal{N}(0, \sigma^2)$$



Slide the entire wall



Snap walls together



Split into two collinear walls

The Cost Function

- Evaluates the quality of the layout

$$C(\mathbf{x}) = k_a C_a(\mathbf{x}) + k_d C_d(\mathbf{x}) + k_f C_f(\mathbf{x}) + k_s C_s(\mathbf{x})$$

Accessibility Term

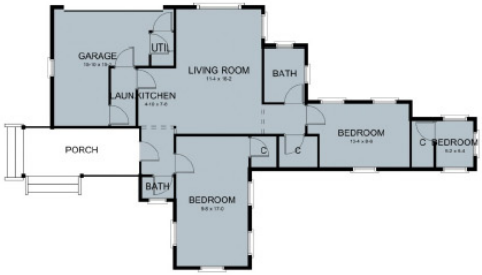
Dimension Term

Floor Compatibility Term

Shape Term

Floor Plan Optimization

200 Iterations

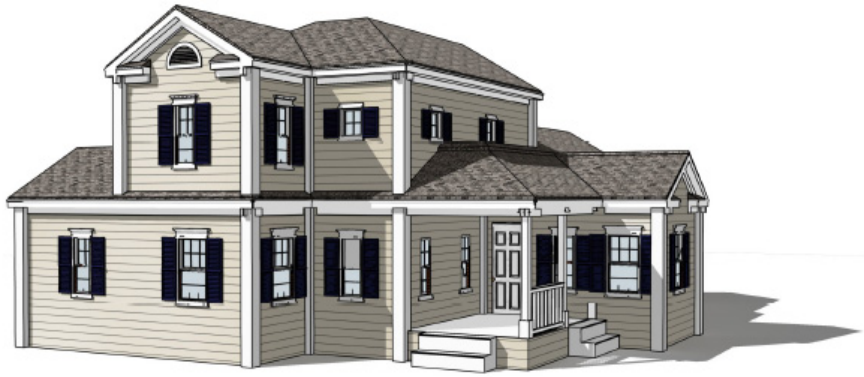


2,000 Iterations

20,000 Iterations

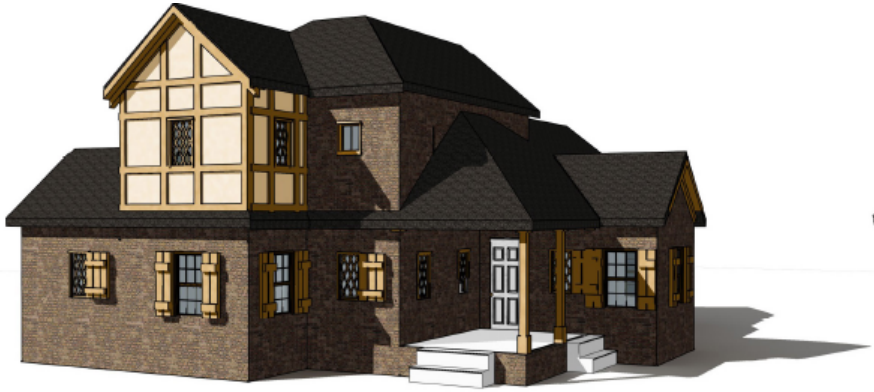
100,000 Iterations

Different Styles of Architecture

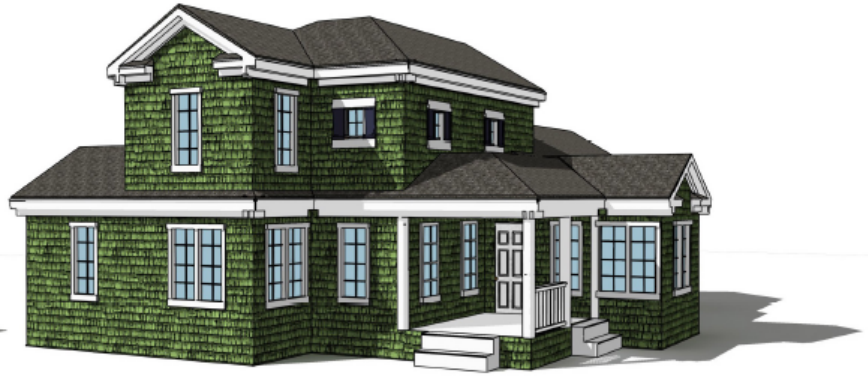


Cottage

Italinate

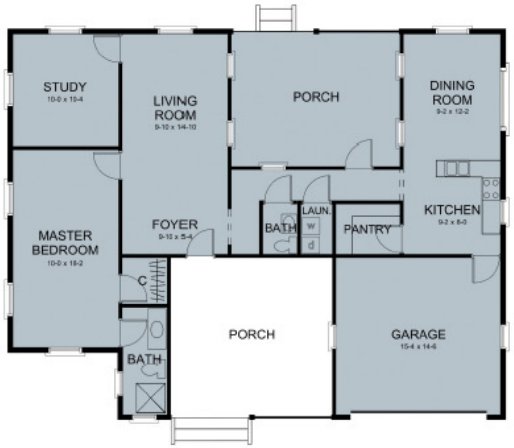


Tudor



Craftsman

Results



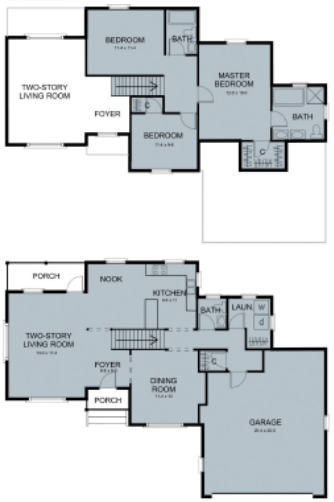
(a)

(b)

(c)

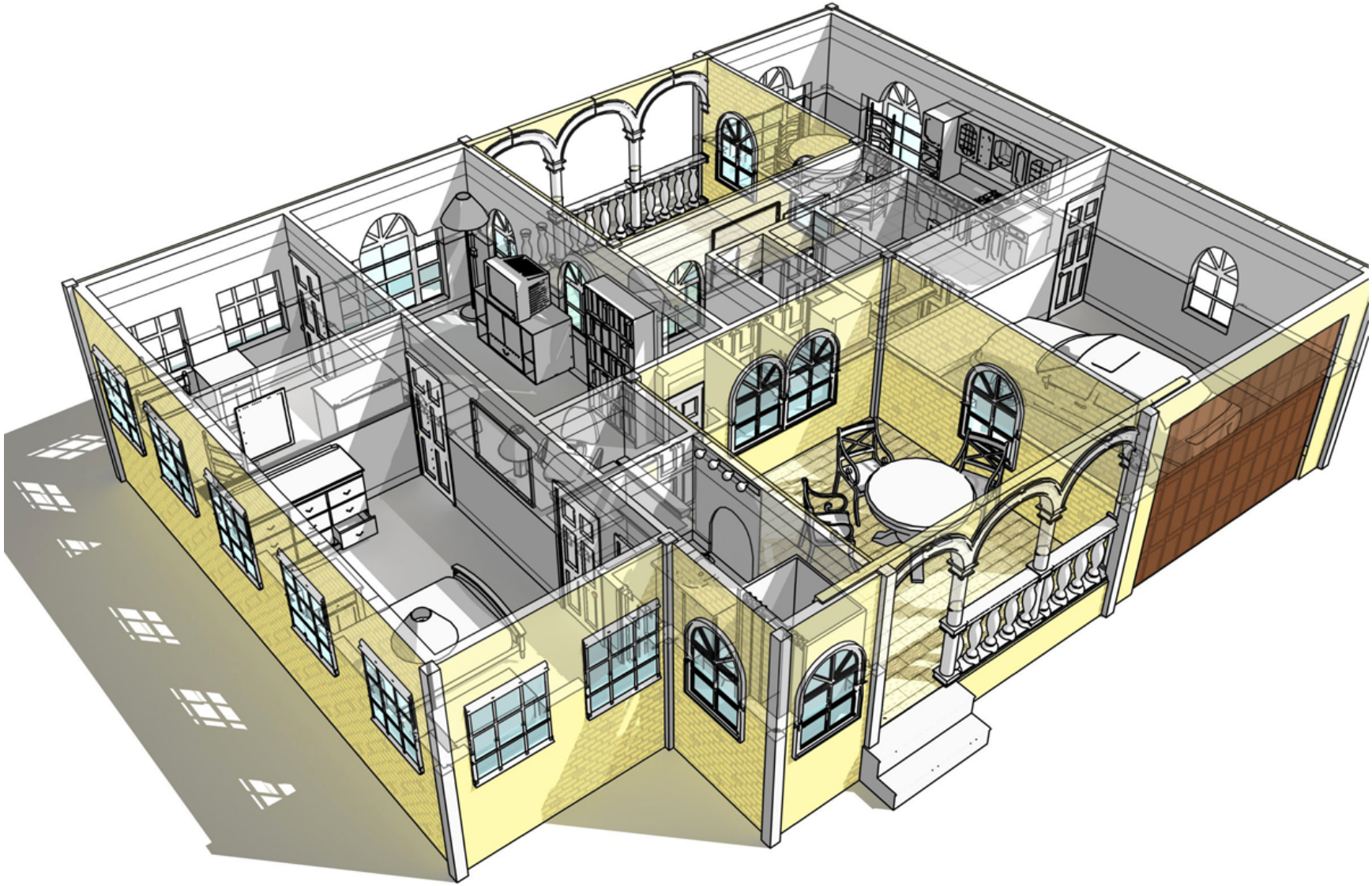
(d)

(e)



(f)

Results

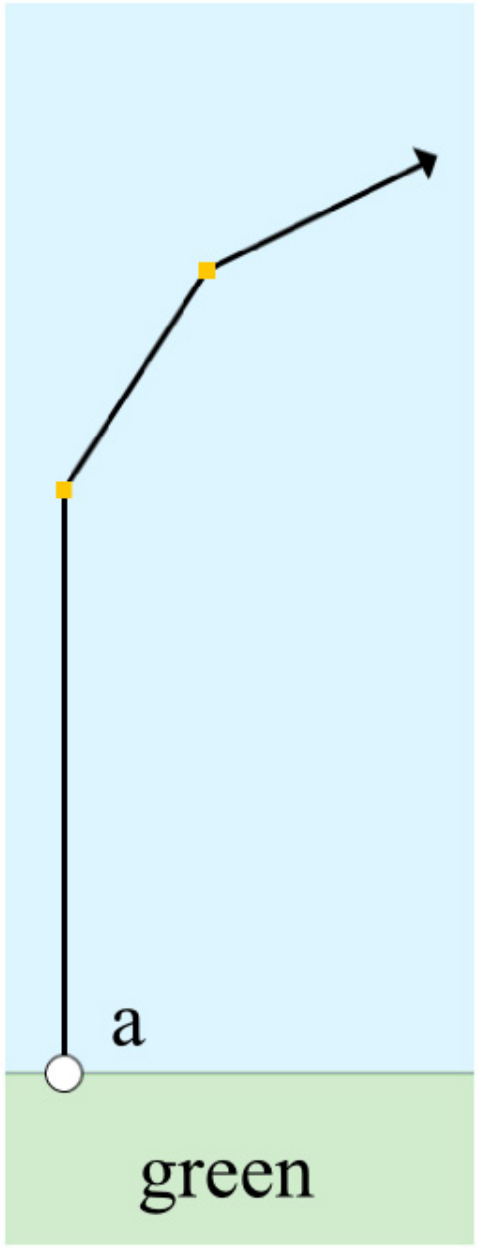


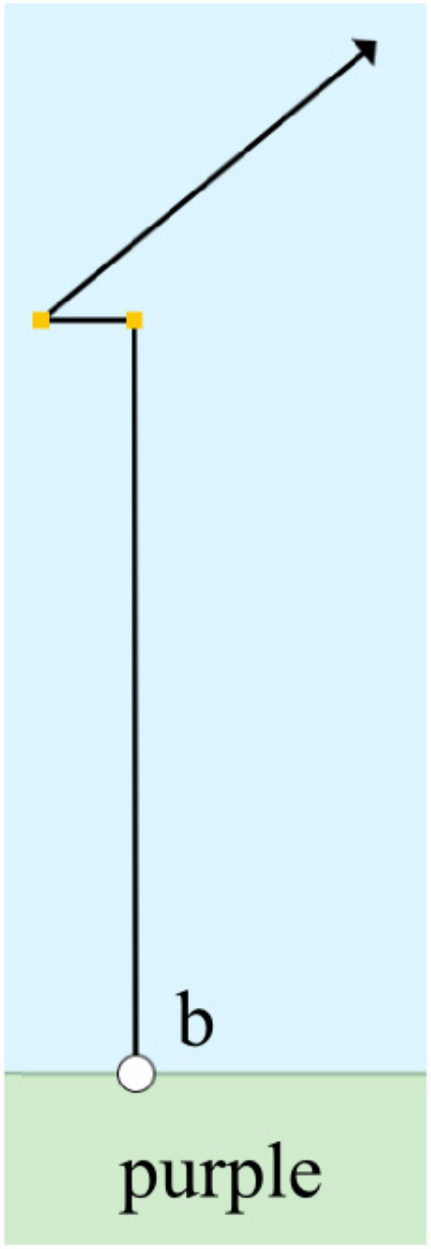
Results

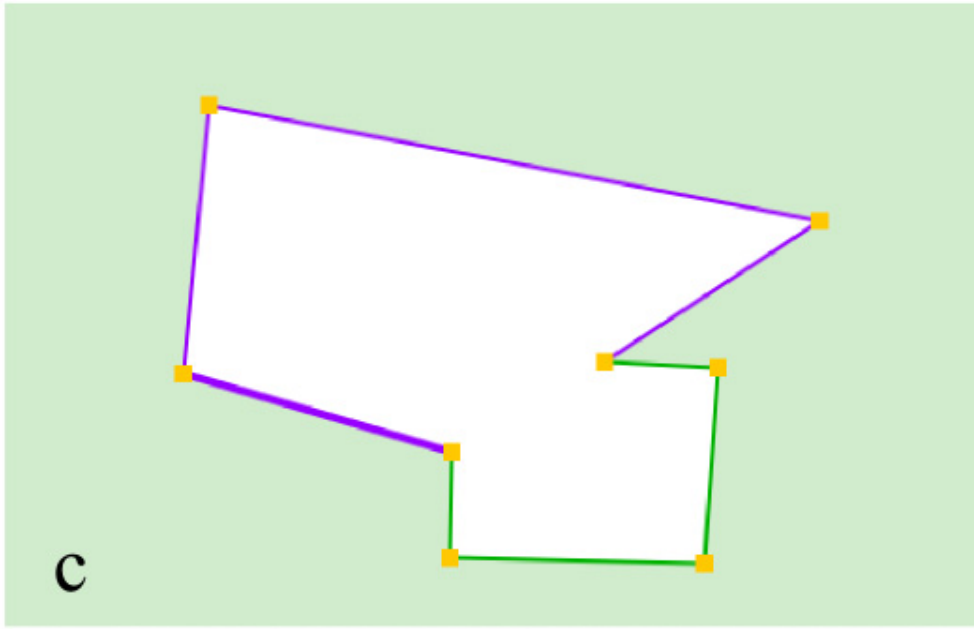
Procedural Extrustions

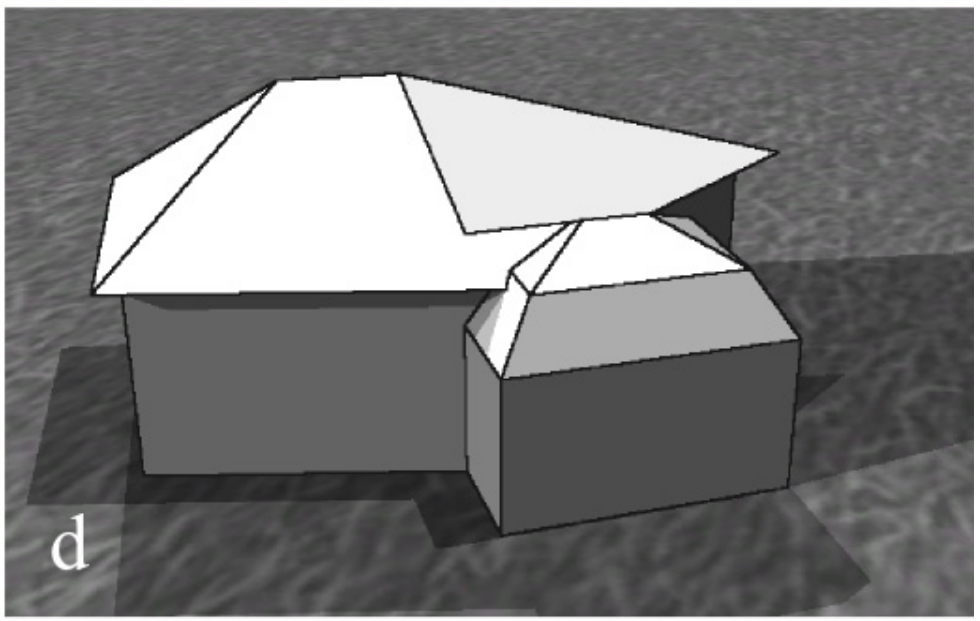
- **Interactive Architectural Modeling with Procedural Extrusions**
  Kelly and Wonka
  ACM TOG

Example

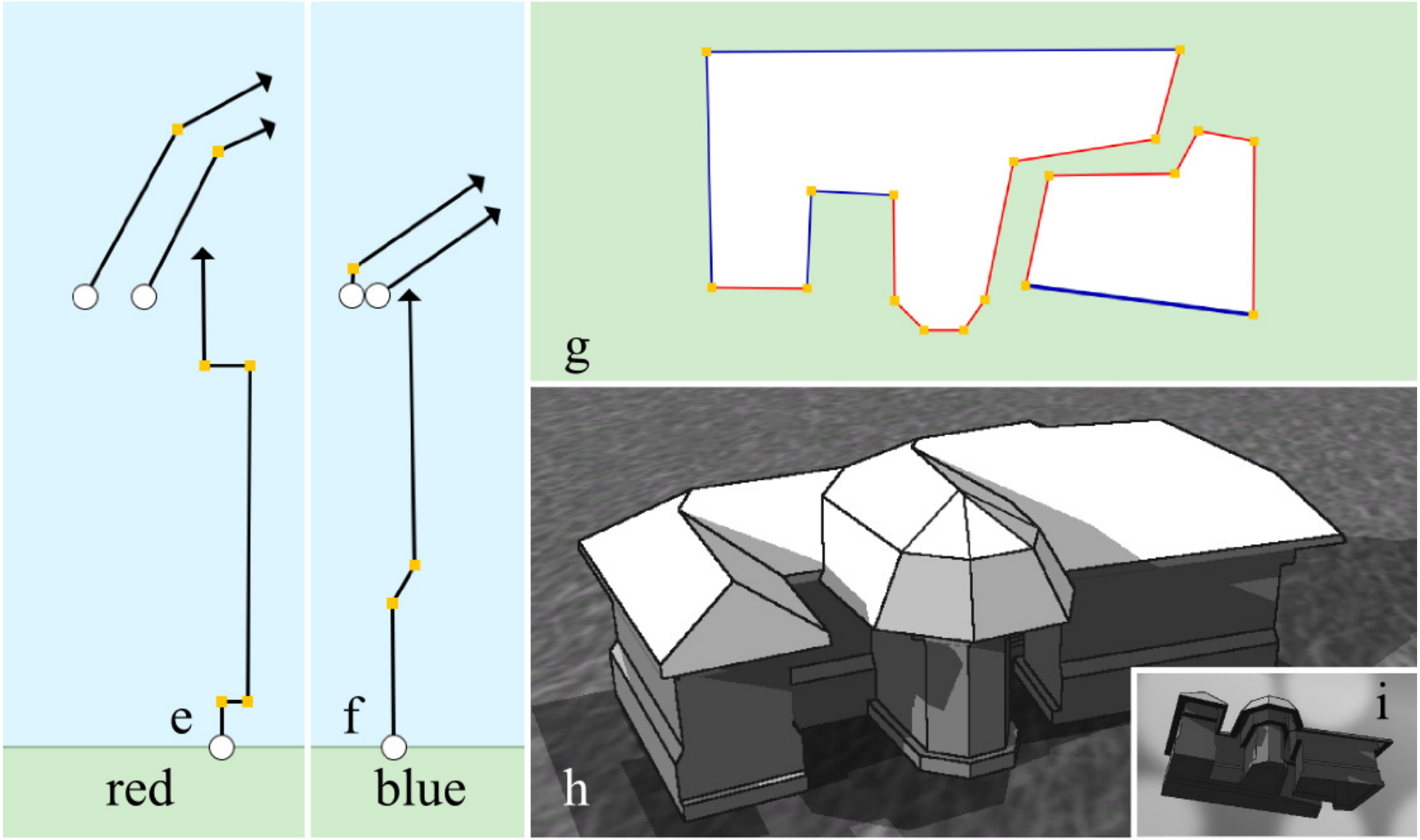




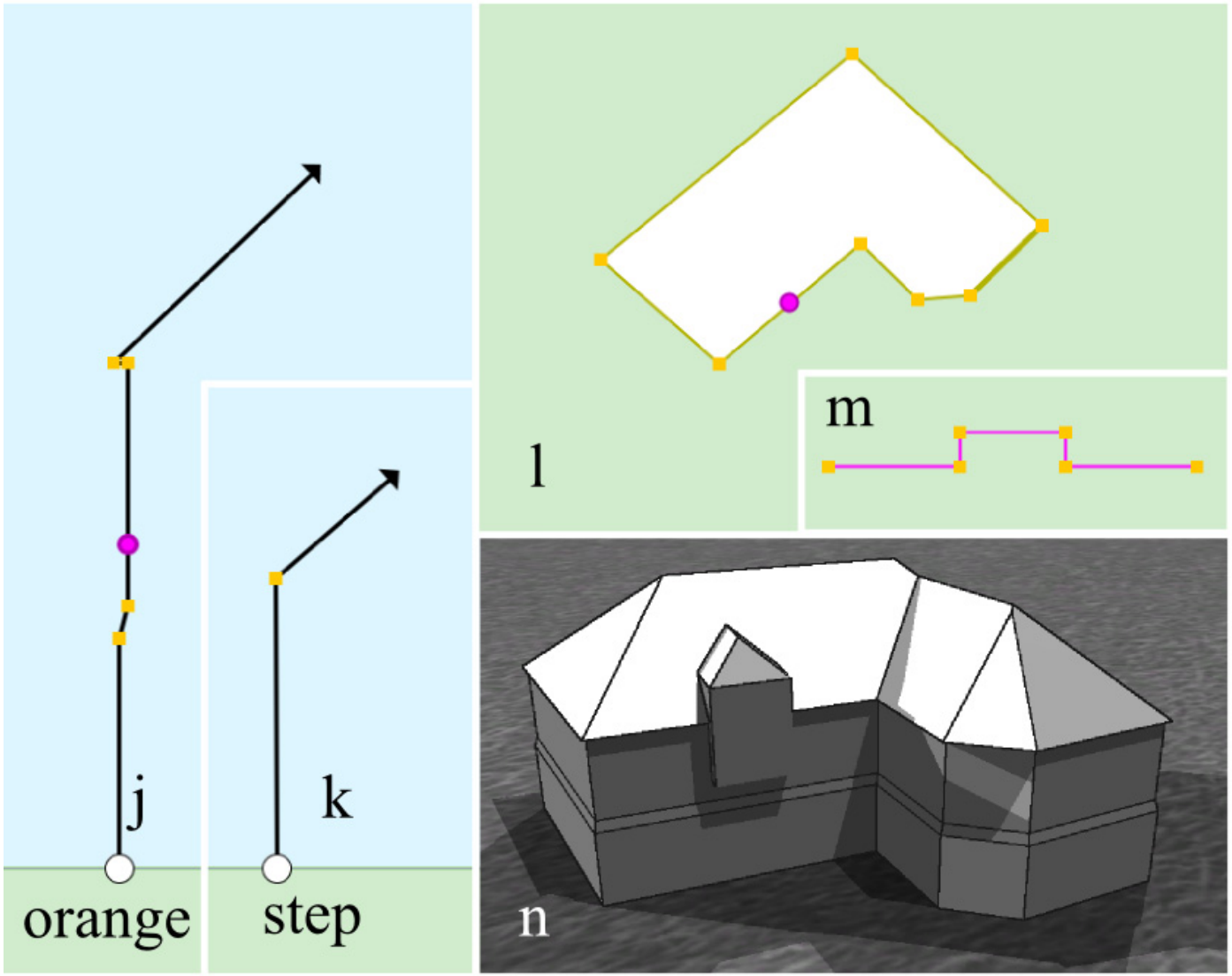




Example



Example



Results

1.	
v	18(0)
l	2(1)
p	11
s	1(1)
o	0

2.	
v	41(2)
l	2(1)
p	13
s	1(1)
o	0

3.	
v	26(0)
l	3(3)
p	8
s	2(2)
o	0

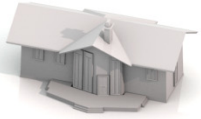
4.	
v	13(0)
l	2(1)
p	12
s	3(5)
o	0

5.	
v	26(0)
l	1(1)
p	10
s	2(3)
o	1

6.	
v	43(7)
l	2(1)
p	10
s	2(2)
o	0

7.	
v	24(3)
l	2(1)
p	14
s	4(6)
o	0

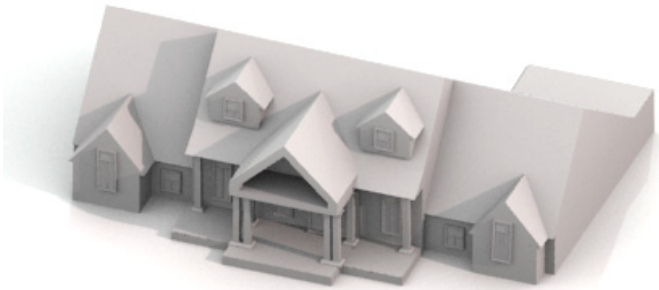
8.	
v	41(1)
l	2(1)
p	21
s	4(4)
o	0

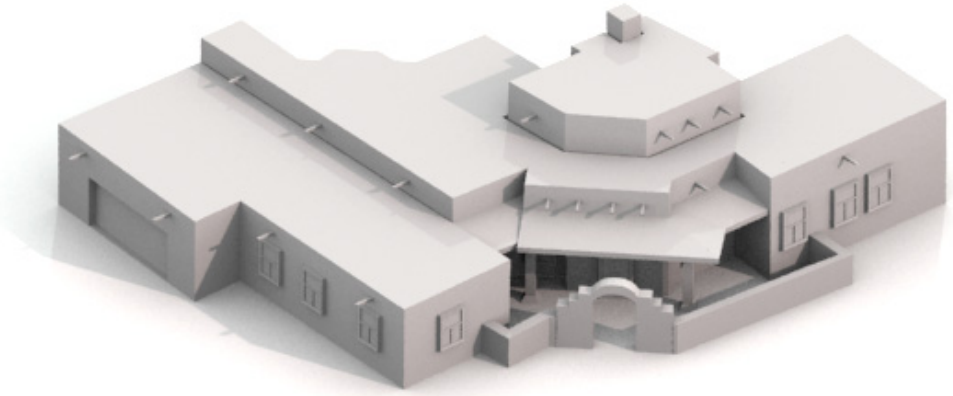


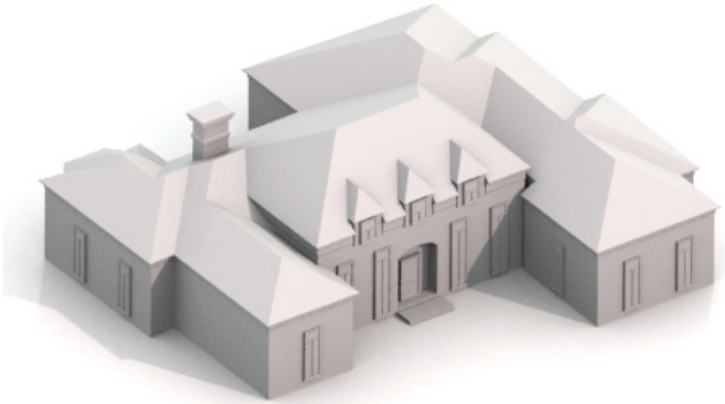
9.	
v	31(0)
l	2(1)
p	6
s	1(1)
o	1

10.	
v	24(0)
l	2(1)
p	12
s	2(2)
o	0

Results

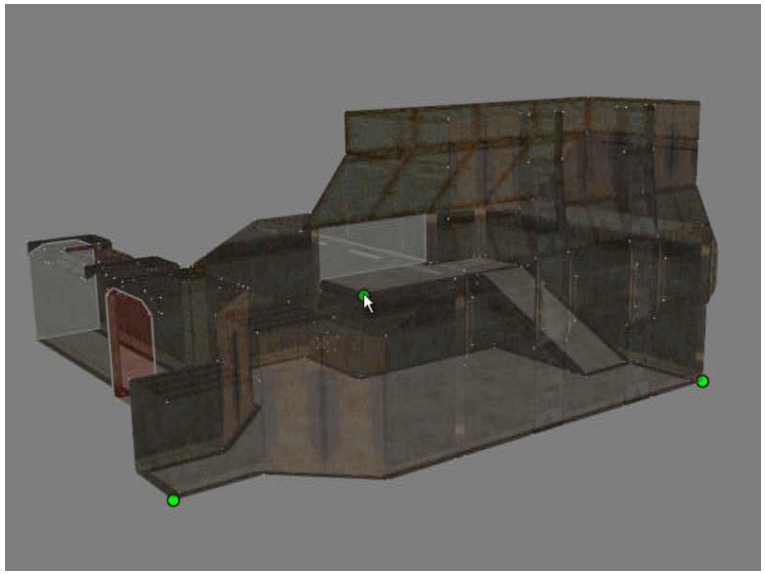




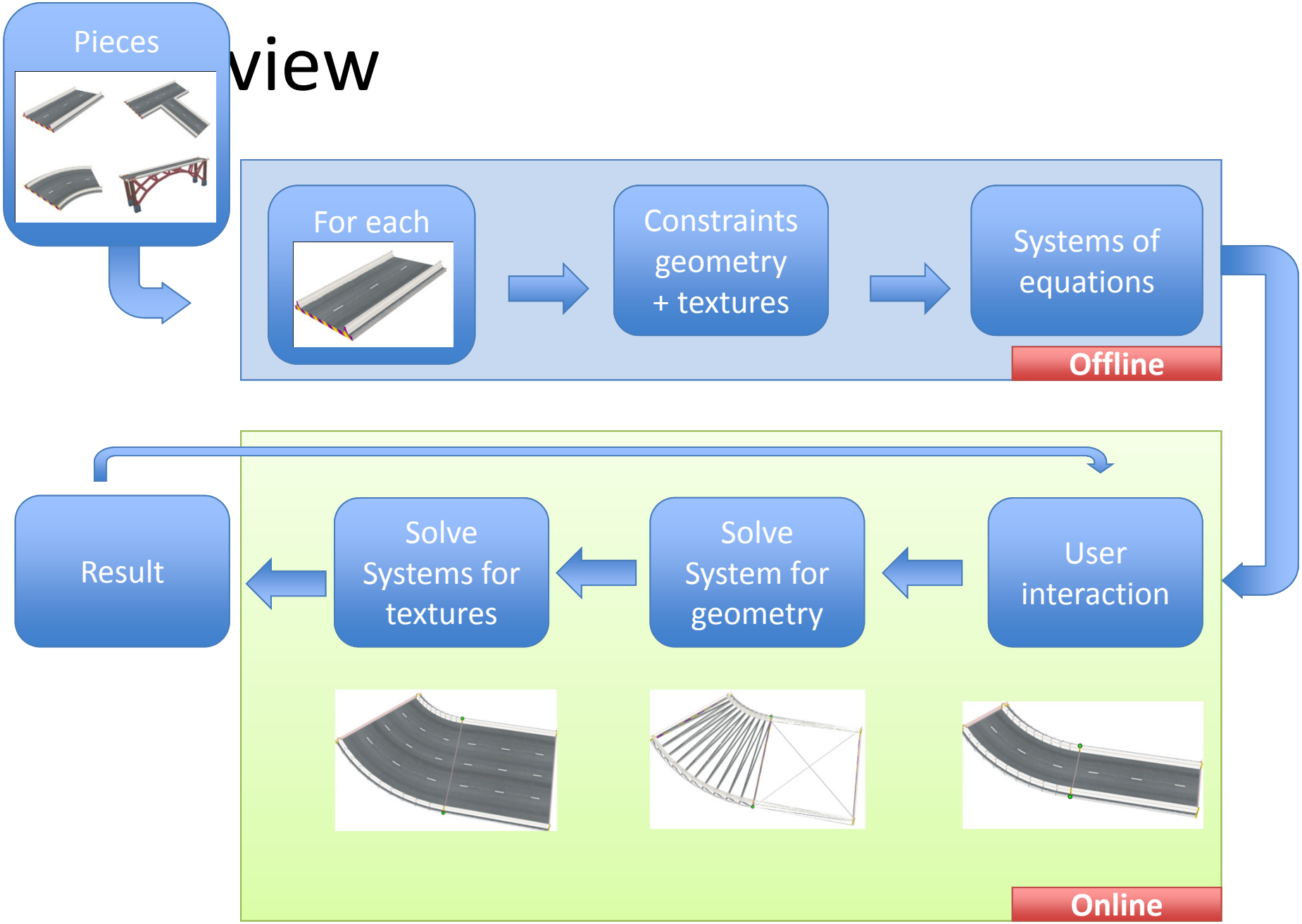


Deforming Architecture

- **Structure-Preserving Reshape for Textured Architectural Scenes**
  Marcio Cabral, Sylvain Lefebvre, Carsten Dachsbacher, George Drettakis

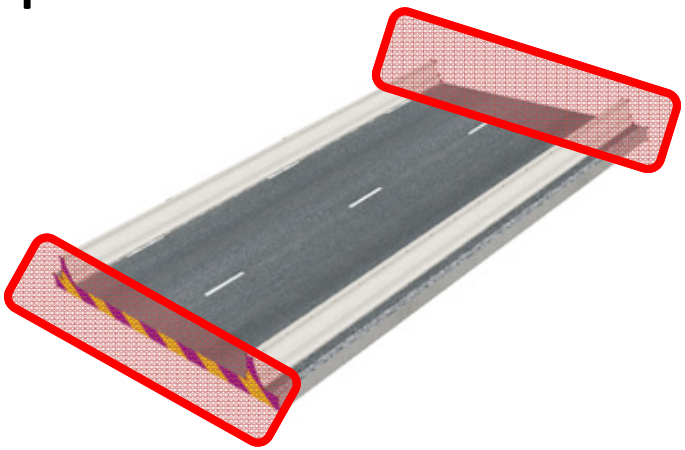


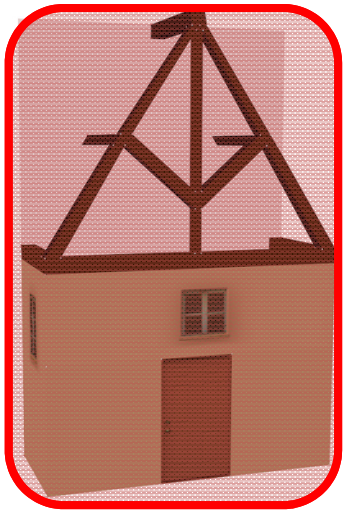
view


Pieces
For each
Constraints geometry + textures
Systems of equations
Offline
Result
Solve Systems for textures
Solve System for geometry
User interaction
Online

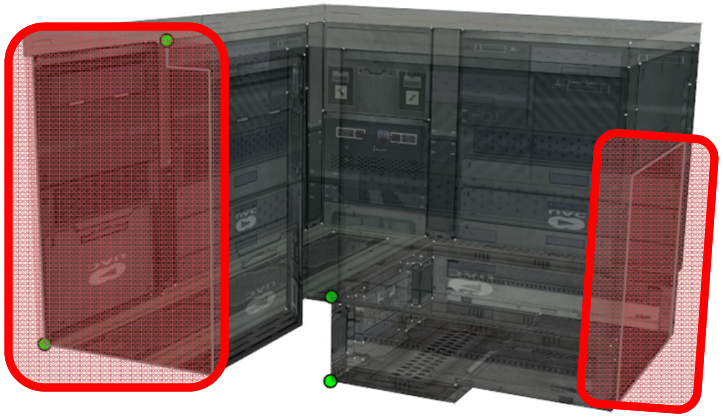
Geometry Reshape

- piece = set of textured faces



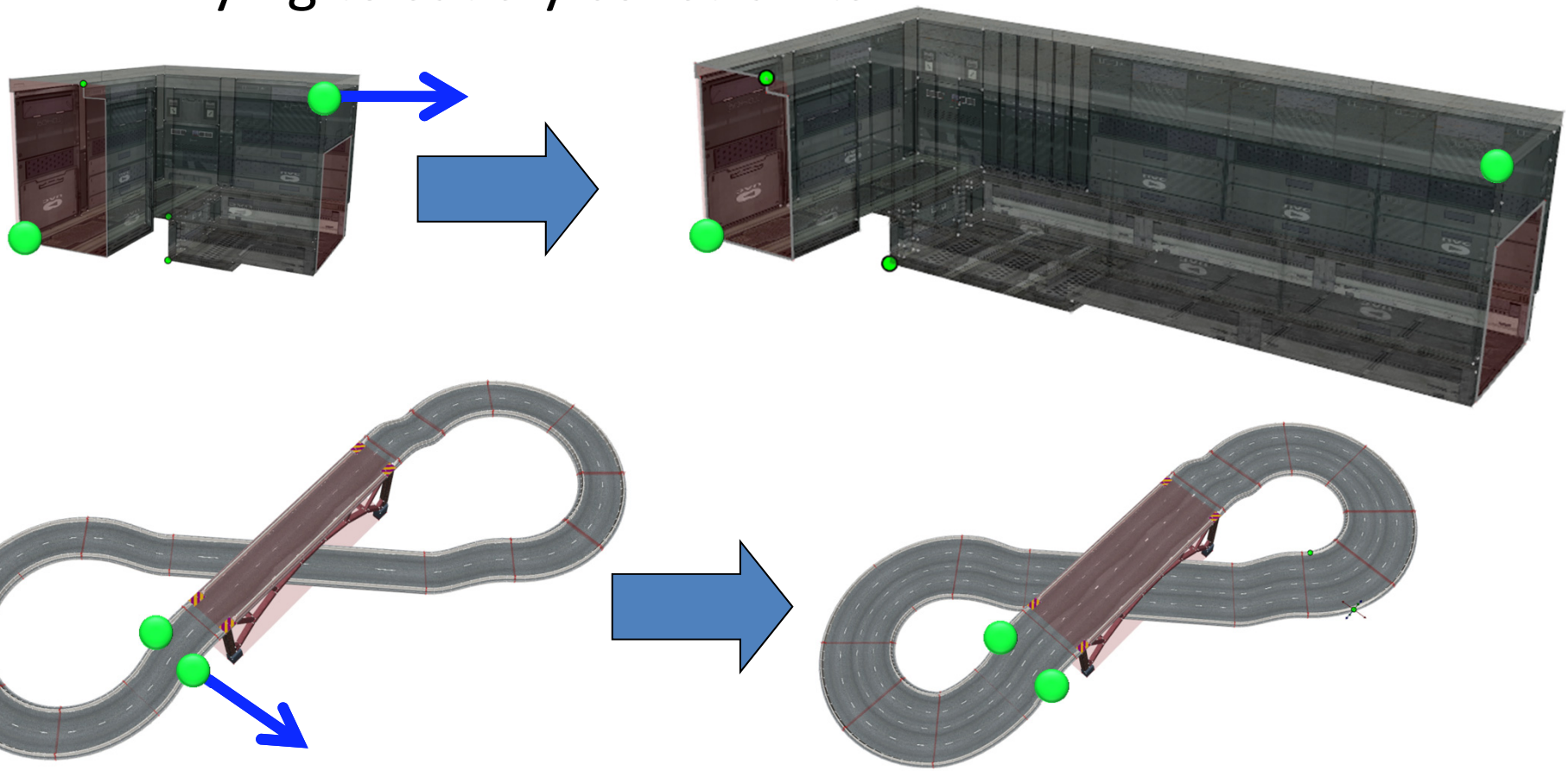


- one or several openings (portals)



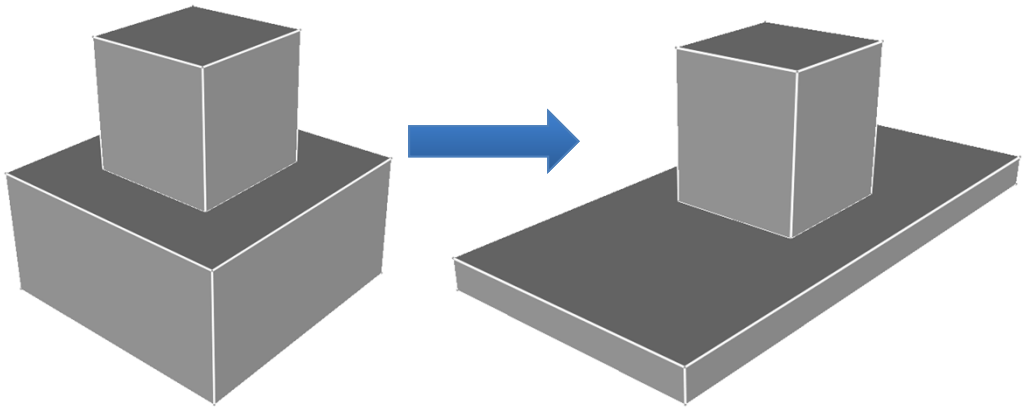
User control

- User controls **few** vertices.
- System computes other vertices positions.
  - Trying to satisfy constraints



Reasonable behavior

- Preserve wall angles



- Preserve contacts
  (e.g. pillars)

- Allow some flexibility in edge length
  - Long edges more flexible than short ones
  - As little change as possible

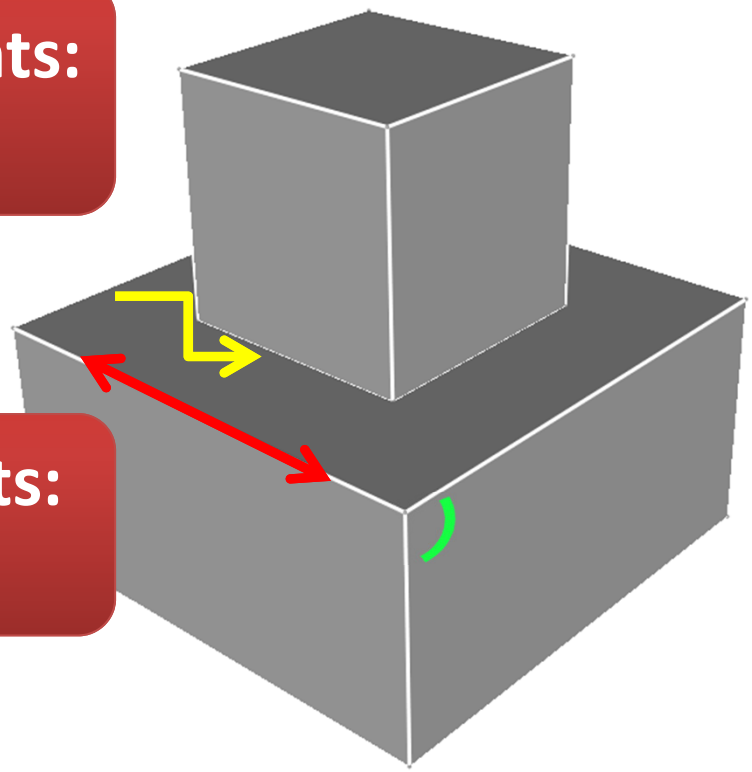
Geometry Reshape

- To be preserv
  - Angles ⇔ Ed
  - Contacts

Strict constraints: Enforce

- Flexible
  - Edge lengths
  - Relative positions of contacts

Soft constraints: Minimize

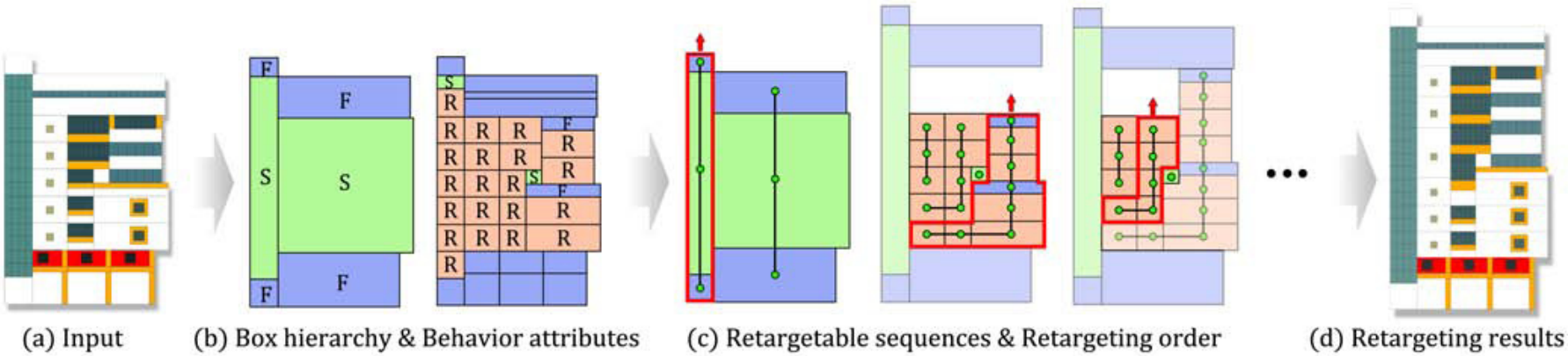


Limitations and Future Work

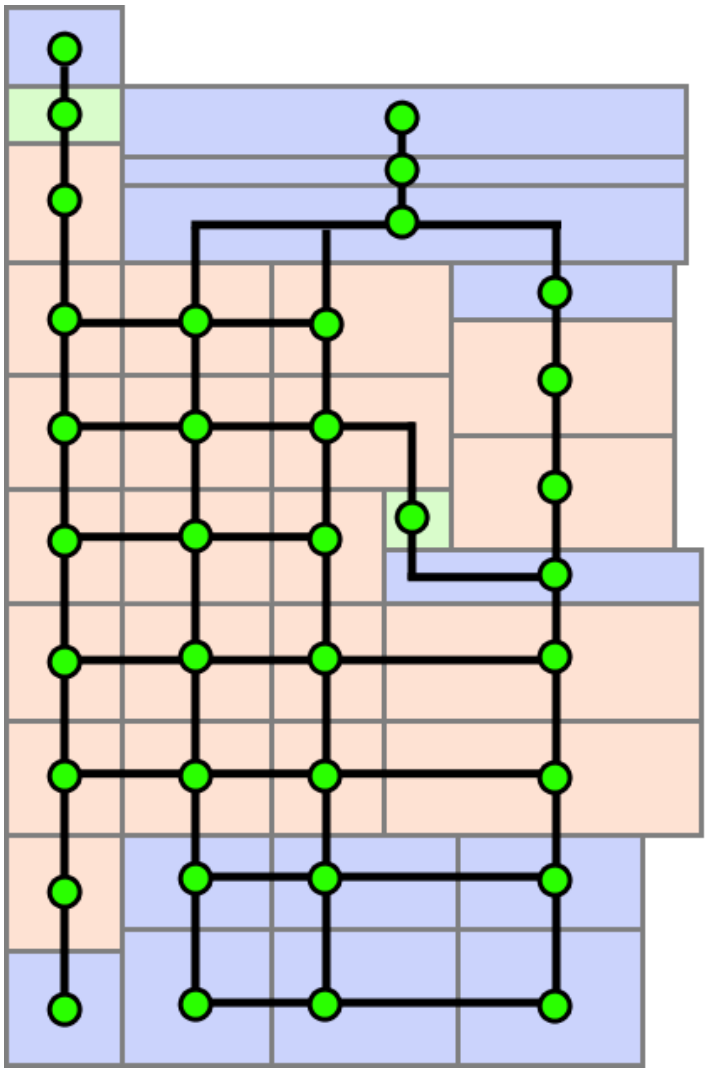
- Portals must be compatible
- Detail tiles have strong limitations
- 3D models must have indexed textured faces
  - It is the case with most game models
- Self collision / Intersection
- Add feedback from texture rigidity constraints to geometry

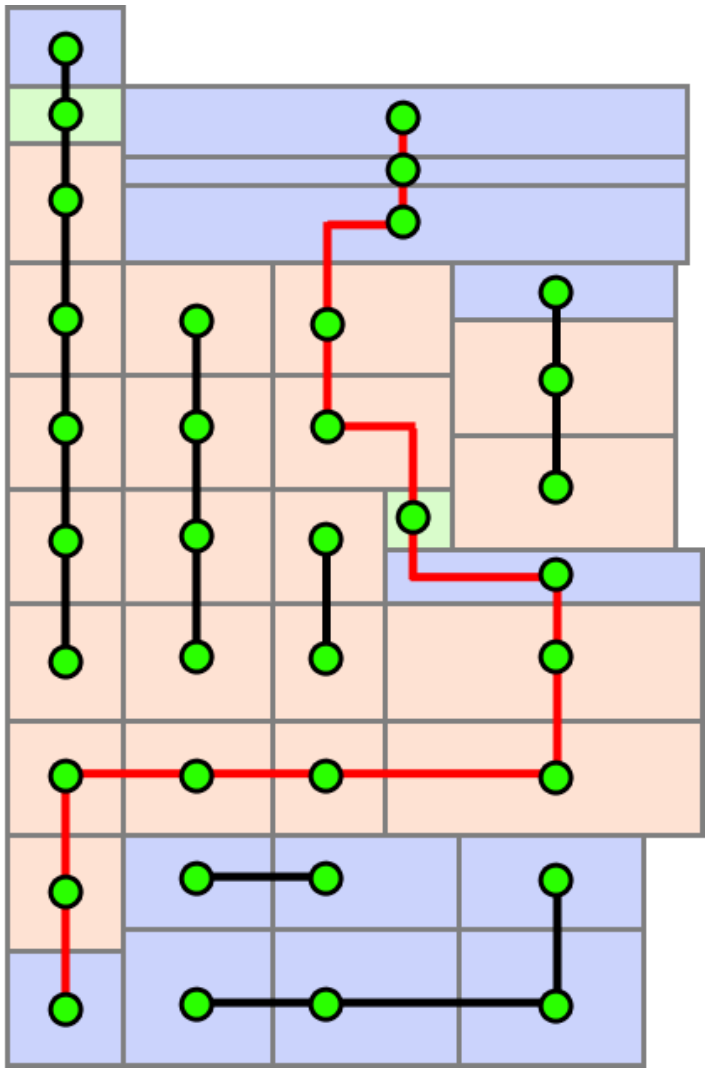
Reshaping 3D Architecture

Pipeline


F
S
S
F
F
S
R
R R R
R R R
R R R S
R R R
R
F
R
R
R
R
(a) Input
(b) Box hierarchy & Behavior attributes
(c) Retargetable sequences & Retargeting order
(d) Retargeting results

Finding the longest path

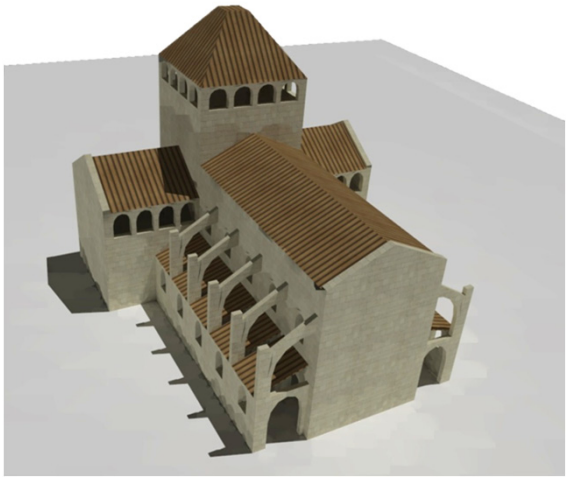




More Results

Masonry Building Design

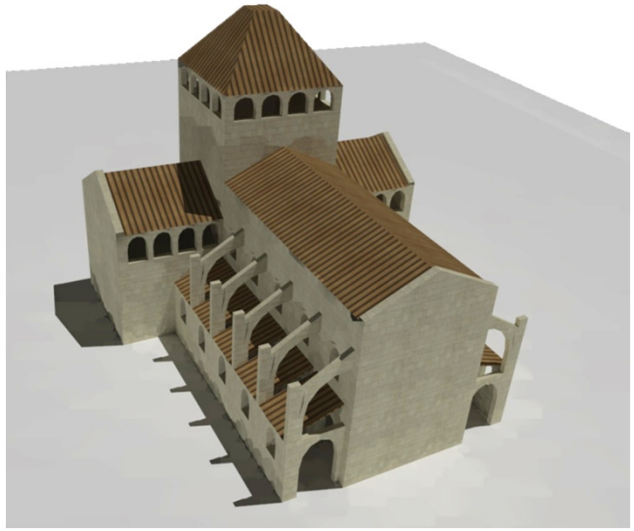
- **Procedural Modeling of Structurally-Sound Masonry Buildings**
  Whiting, Ochsendorf, Durand
  Siggraph Asia 2009

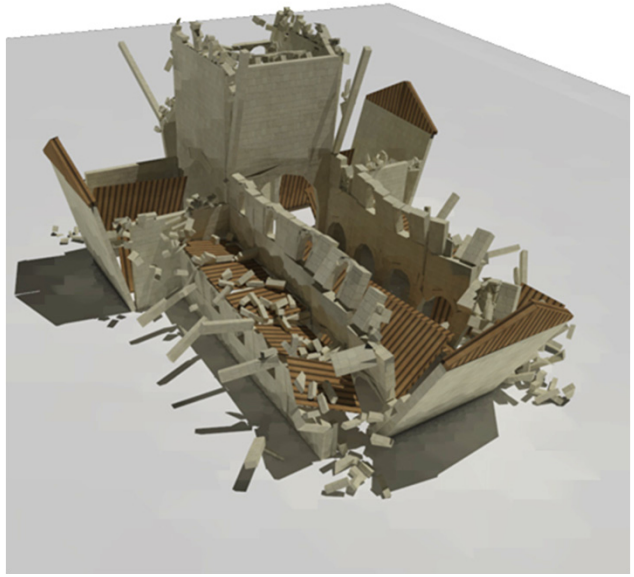


Procedural Buildings for Simulation

structurally stable

- will look more realistic
- suitable for physical simulations
- react to external forces

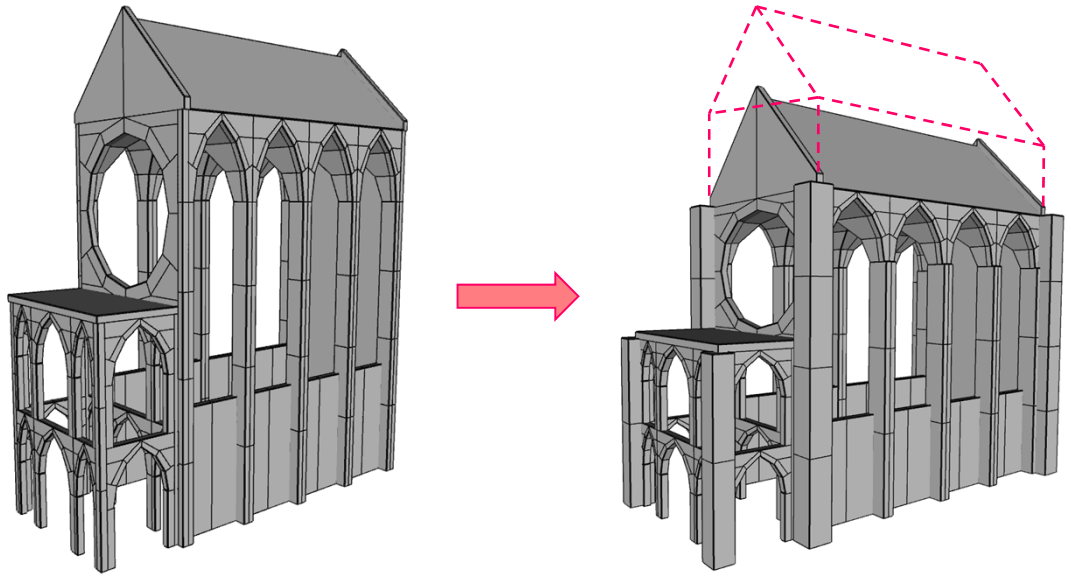




Goals

Generate models that are structurally sound

- Inverse Statics
- Special case of brick structures
- Parametric Models as input

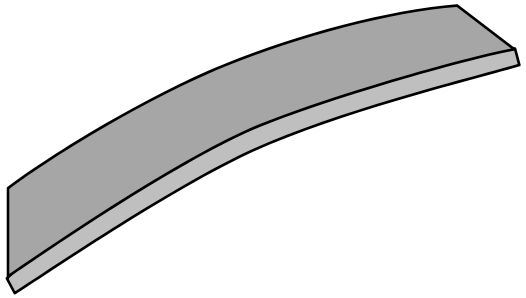


unstable input

stable output

Related work structural analysis

elastic material

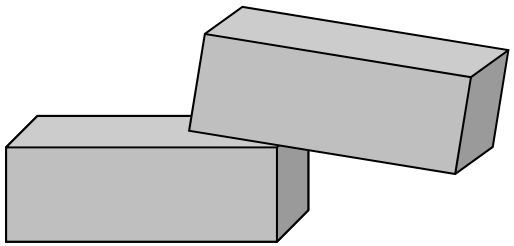


analyze material stress

wrong physical model for masonry
not deformable

vs.

masonry

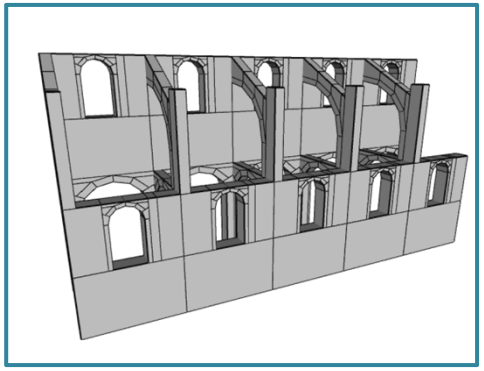


geometric configuration

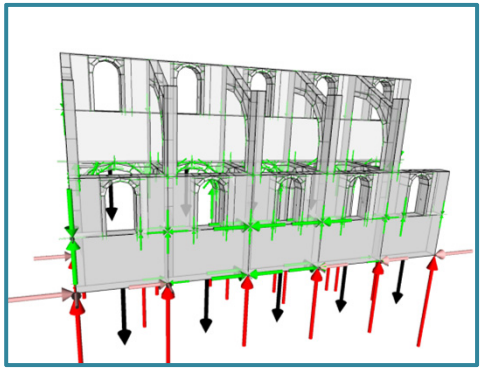
rigid block assemblage [Heyman 1995]

linear constraint formulation
[Livesley 1978, 1992; RING software]

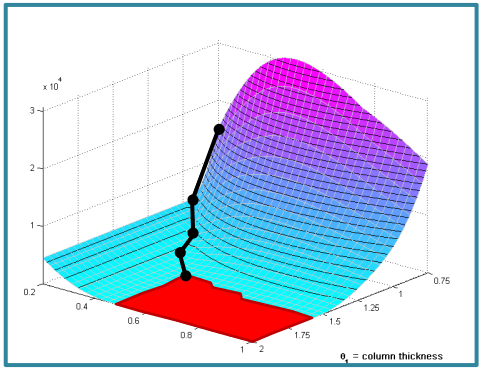
Overview



procedural building generation

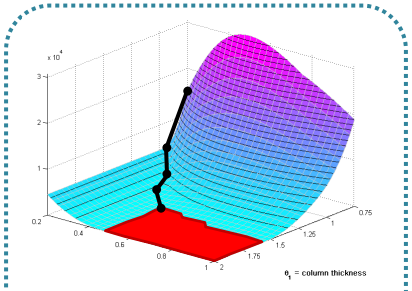


analysis method for masonry



inverse problem

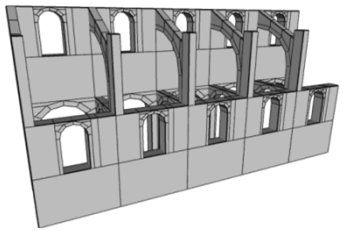
Optimization loop



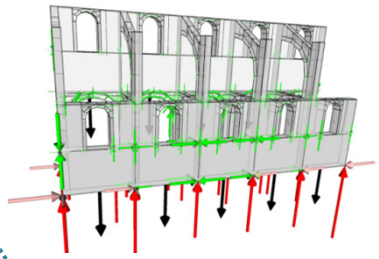
parameters

Update Parameters

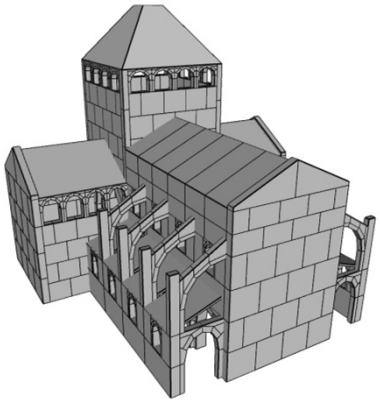
Procedural Model



Analysis

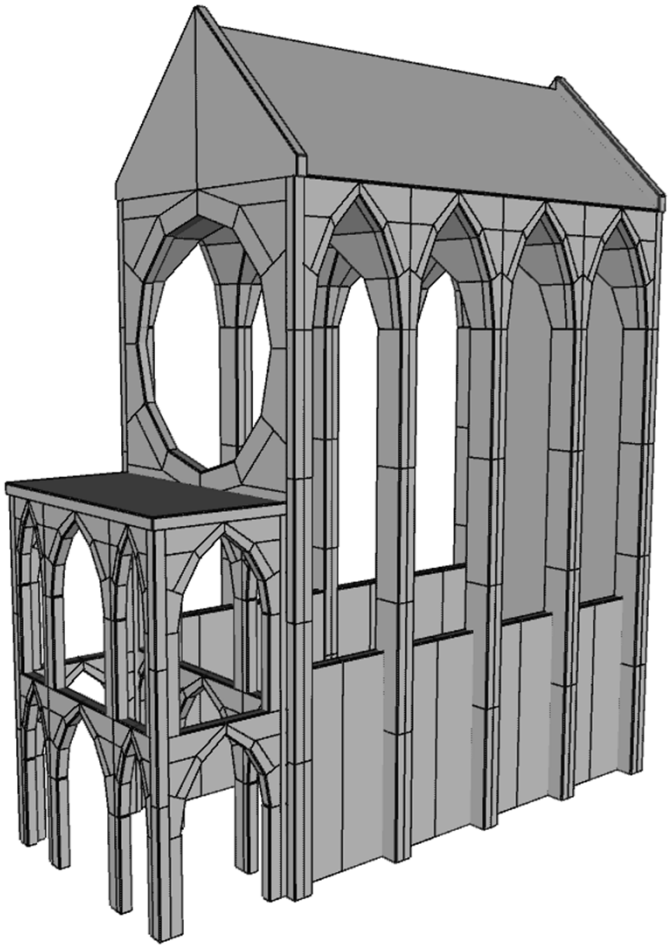


feasible?



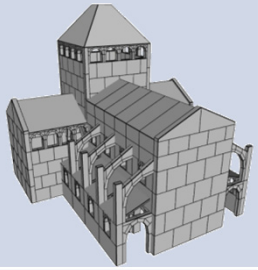
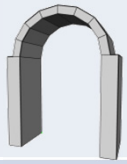
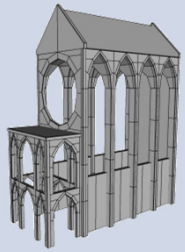
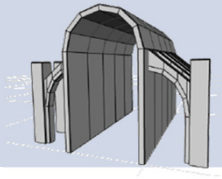
model from output parameters

Typical Parameters



- building height
- thickness of columns, walls, arches
- window size
- angle of flying buttresses

performance

model	#blocks	#params	#iters	time/iter
Cluny 	986	4 5 7 9	10 5 4 9	45.7 s 57.3 s 70.0 s 106.6 s
arch 	10	2	6	0.1 s
Sainte Chapelle 	486	3 5 7 10	4 9 6 8	12.5 s 26.5 s 29.3 s 40.1 s
tower 	96	32	6	12.5 s
barrel vault 	140	1	8	0.6 s

Modeling of Facades

- **Instant Architecture**
  Wonka, Wimmer, Sillion, Ribarsky
  SIGGRAPH 2003

Modeling of Facades

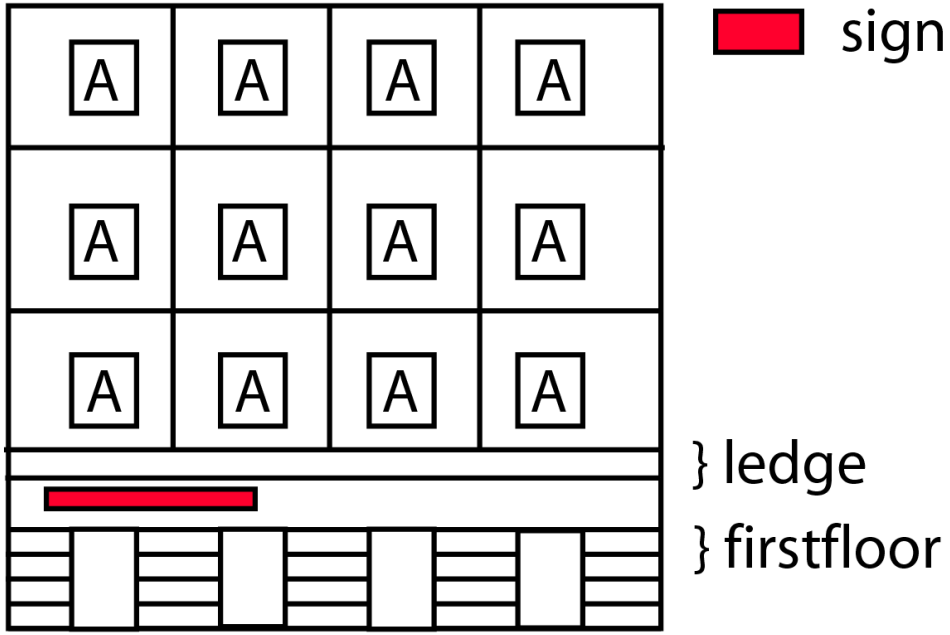
- Input: Target building design
- Output: Textured 3D models of building facades

Modeling of Facades

- Approach: **Split grammars**
  - Used instead of L-systems
  - L-systems simulate growth in open spaces (better for plants and road networks)
  - Buildings have stricter spatial constraints and their structure does not reflect a growth process

Modeling of Facades

- Take Photograph
- Create abstraction

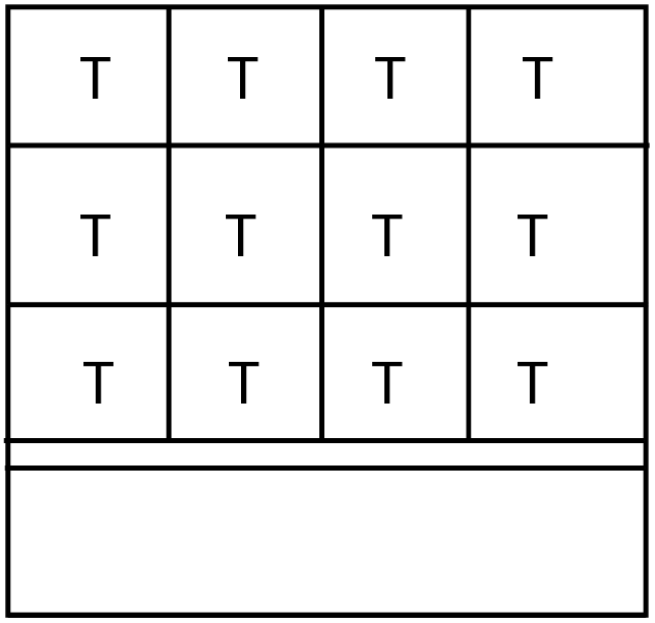


Modeling of Facades

- Facade → Subdiv(“Y”,3.5,0.3,1r){ firstfloor | ledge | floors}
- Floors → Repeat(“Y”,3){floor}

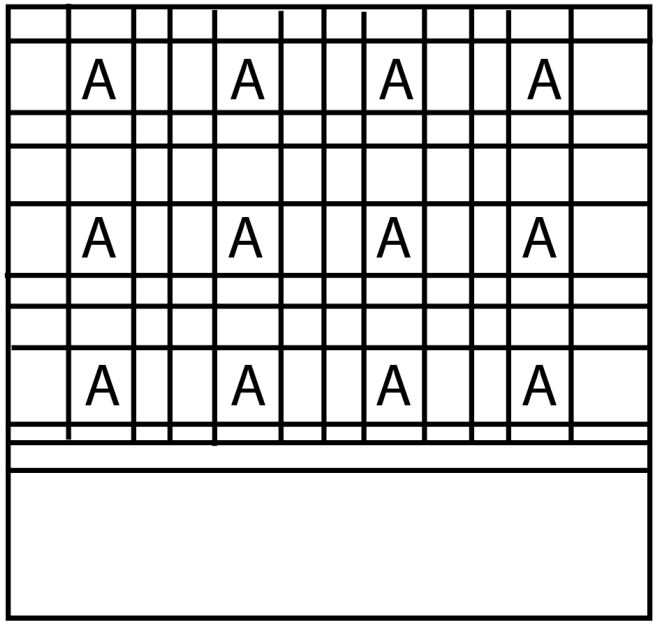
Modeling of Facades

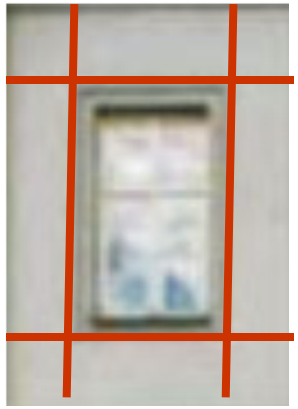
- floor → Repeat("X",tile_width){ Tile }



Modeling of Facades

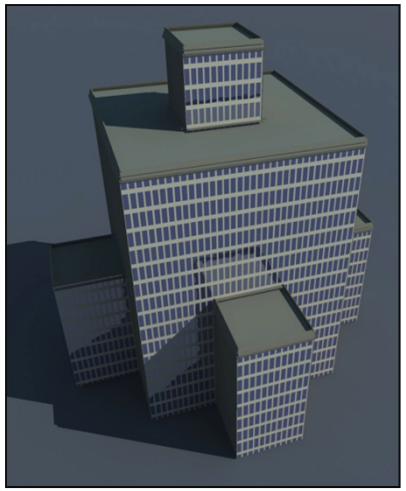
- Tile → Subdiv("XY", …){ Wall | Wall |…| A | Wall | … }

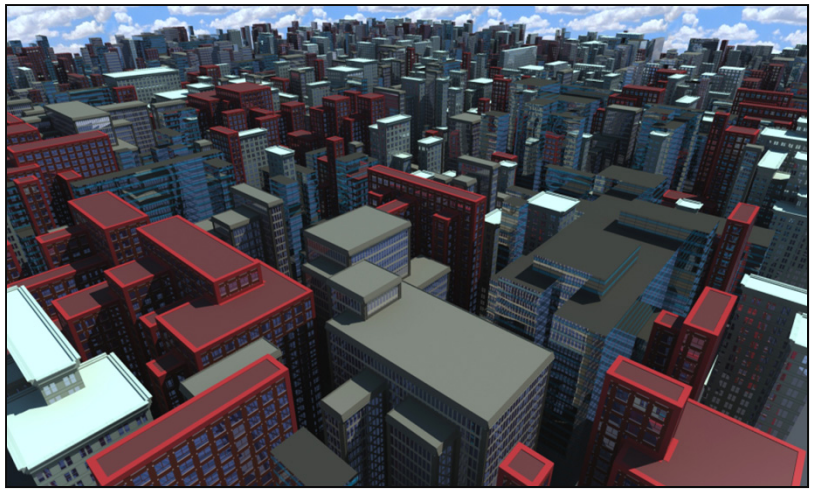




Synthesis of Mass Models

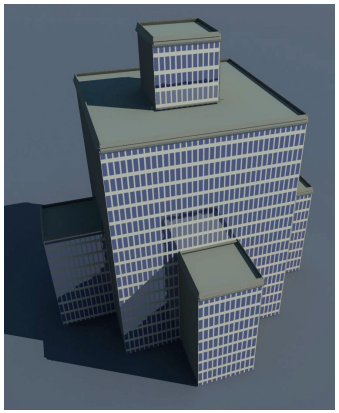
- **Continuous Model Synthesis**
  Merrell, Manocha
  SIGGRAPH Asia 2008



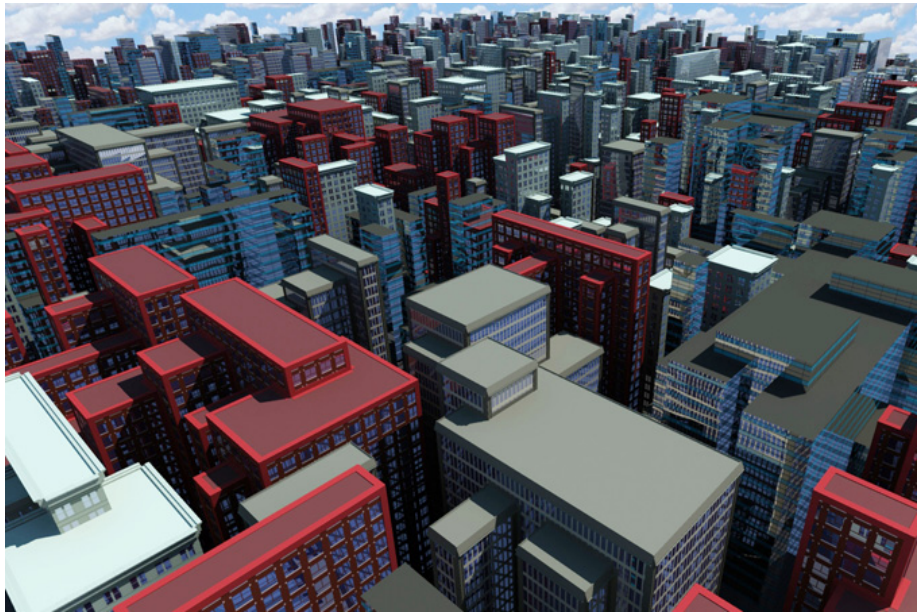


Modeling of Mass with Facades

- Inspired by texture synthesis



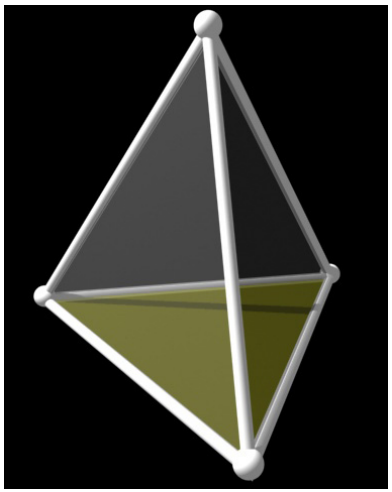
Example Model

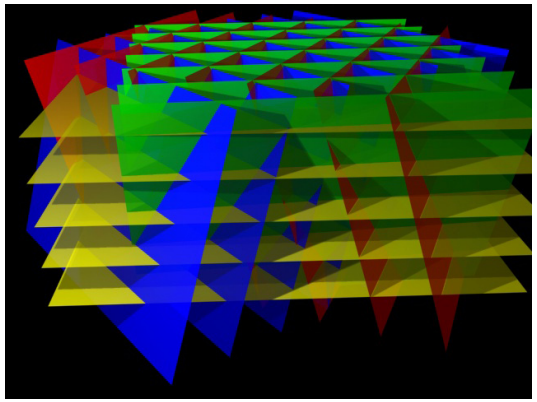


Output Model

Modeling of Mass with Facades

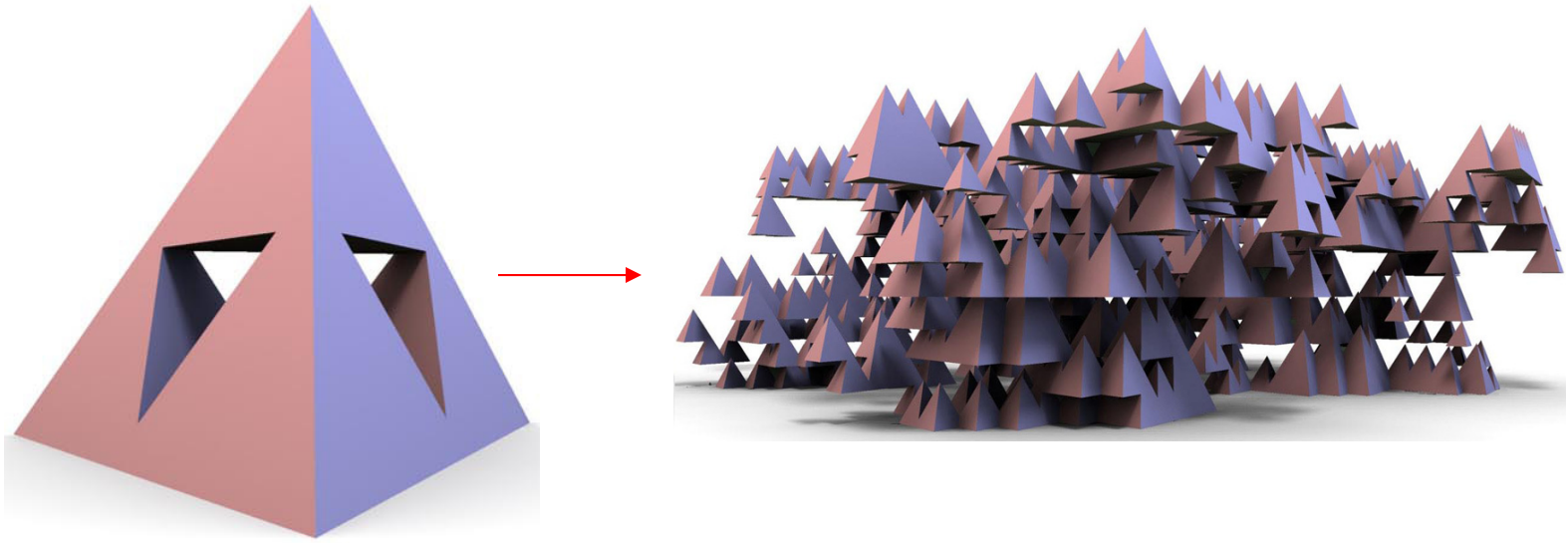
- Approach:
  - maintain adjacency constraints between boundary features (e.g. faces, edges, and vertices)
  - create planes parallel to the faces of the example model that subdivide the space into basic components to generate novel models





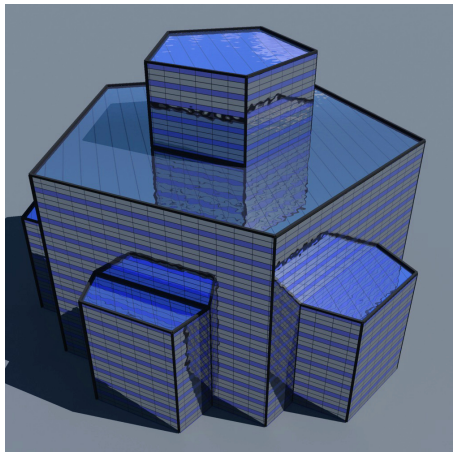
Modeling of Mass with Facades

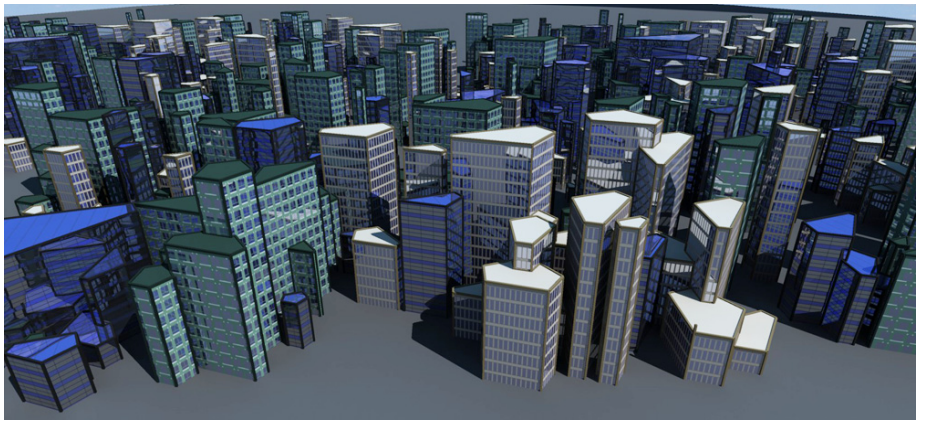
- Example



Modeling of Mass with Facades

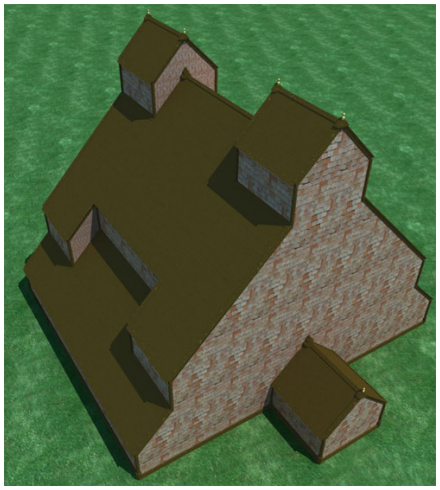
- Applied to buildings





Modeling of Mass with Facades

- Applied to buildings



Free-form Architecture

Procedural Mesh Labeling