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

Computational Building Design

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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
Metropolis Algorithm

- **Objective Function**
  \[ f(x) = \exp(-\beta C(x)) \]
  - \( x \) Building Layout
  - \( \beta \) Constant
  - \( C(x) \) Cost Function

- Each iteration, propose a new building layout \( x^* \)
- Accept with probability
  \[ \alpha(x^*|x) = \min\left(1, \frac{f(x^*)}{f(x)}\right) \]
Proposal Moves

• Slide a wall

\[ d \sim \mathcal{N}(0, \sigma^2) \]
The Cost Function

- Evaluates the quality of the layout

\[ C(x) = k_a C_a(x) + k_d C_d(x) + k_f C_f(x) + k_s C_s(x) \]

- 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
Results
Results
Procedural Extrusions

• Interactive Architectural Modeling with Procedural Extrusions
  Kelly and Wonka
  ACM TOG
Example

a

green

b

purple
Example

red

blue

g

h

i
Example
Results
Results
Deforming Architecture

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

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 preserved
  - Angles $\Leftrightarrow$ Edge directions
  - Contacts

- Flexible
  - Edge lengths
  - Relative positions of contacts

**Strict constraints:** Enforce

**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

(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

- Analyze material stress
  - Wrong physical model for masonry
  - Not deformable

- 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

Procedural Model

Analysis

feasible?

Update Parameters

model from output parameters
Typical Parameters

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

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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 \rightarrow \text{Subdiv(“Y”,3.5,0.3,1r)\{ firstfloor | ledge | floors\}}

• Floors \rightarrow \text{Repeat(“Y”,3)\{floor\}}
Modeling of Facades

- floor $\rightarrow$ Repeat(“X”,tile_width){ Tile }

![Diagram of facades and tiles]
Modeling of Facades

- Tile $\rightarrow$ 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
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