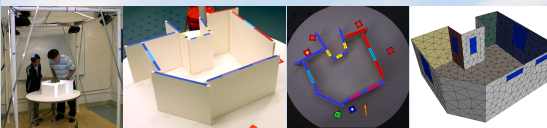
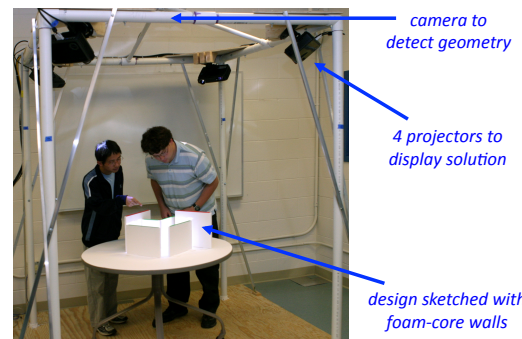


Interpreting Physical Sketches as Architectural Models



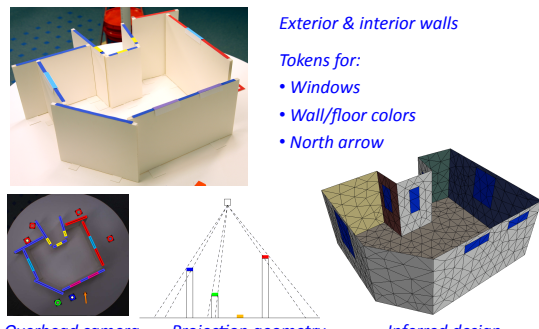
Barbara Cutler and Joshua Nasman
Department of Computer Science
Rensselaer Polytechnic Institute

“Virtual Heliodon” for Daylighting Analysis



camera to detect geometry
4 projectors to display solution
design sketched with foam-core walls

Tangible Interface for Architectural Design



Exterior & interior walls

Tokens for:

- Windows
- Wall/floor colors
- North arrow

Overhead camera Projection geometry Inferred design

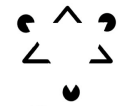


Our Contributions

- Algorithm for automatic interpretation of interior space vs. exterior space
- Construction of a watertight 3D mesh
- User study collected >300 example designs
- Validation of algorithm
 - Compare to annotations by the original designer
- Quantify design ambiguity
 - Compare annotations of a design by other users

Related Work

- Tangible User Interfaces [e.g., Ben-Joseph et al. 2001]
- Sketch-based Modeling User Interfaces [Zelevnik et al. 1996; Igarashi et al. 1999; Dorsey et al. 2007]
- Pen-based Sketch Recognition [e.g., Wacom 2010]
- Automated Recognition of CAD Drawings [Aoki et al. 1996; Lladós et al. 1997; Ah-Soon and Tombre 2001; Kulikov 2004; Lu et al. 2005]
- Human Vision, Perception, & Gestalt Psychology
 - Seek the simplest explanation for an incomplete diagram
 - Closure, proximity, symmetry, continuity, collinearity, & parallelism



Gestalt Psychology: Reification

- Constructive or generative aspect of perception

<http://en.wikipedia.org/wiki/File:Reification.jpg>

Pragnanz: Gestalt Laws of Grouping

- Proximity
- Similarity
- Closure
- Symmetry
- Common fate
- Continuity
- “Good” gestalt (regular, simple & orderly, eliminate complexity & unfamiliarity)
- Past experience

http://en.wikipedia.org/wiki/Gestalt_psychology

Overview of Algorithm

- Image Processing (our earlier publications)
- Lack of precision in sketch: Should elements be parallel? *collinear*? perpendicular? tangent?
- Link tangent walls to form continuous chains that divide space into zones
- Determine interior vs. exterior
- Generate floor plan diagram & watertight mesh geometry (more details in our paper)

Tolerance Example: Collinearity

Detected Geometry *Designer's Intention* *Favor Collinearity* *Favor Skew Lines*

Other Users' Interpretations

Linking Elements to Form Chains

- If $A \rightarrow B$ and $B \rightarrow A$ are best matches for tangent, then the walls are joined into a chain

Detected Geometry

Wall Chains, Extended to Infinity

Halfspace Zones & Enclosure

- Further subdivided using GraphCuts (if needed)

Halfspace Zones

Densely Sampled Enclosure (Visibility Test)

Interior/Exterior Enclosure Threshold

- Unfortunately, there is no universal threshold
- Varies design-to-design, and *within-a-design*

Automatic Interior/Exterior Determination & Final Floorplan

Compare to Designer's Intention

Interior/Exterior Optimization

- Analyze histogram of point-sampled enclosure values
- Maximize usage of lengths of real wall elements
- Minimize length of inferred (added) walls
- Minimize area assigned in opposition of simple threshold metric

Complex Boundaries & Varying Gaps

Interior/Exterior Optimization

- Analyze histogram of point-sampled enclosure values
- Maximize usage of lengths of real wall elements
- Minimize length of inferred (added) walls
- Minimize area assigned in opposition of simple threshold metric
- (Courtyard option) Minimize total enclosed area

Open Courtyards & Multiple Buildings

Our Goals in Conducting User Studies

- Understand **range of designs** possible
- Improve physical sketching user interface
- Improve algorithm for sketch recognition of interior/exterior space
 - Learn common human interpretation "rules"
 - Quantify design ambiguity
- Measure effectiveness of *Virtual Heliodon* as an architectural daylighting design tool

User Study 1: Open-Ended Design

- 30 participants (15 architects)
- 20 mins of sketching
- 329 unique designs (154 by architects)
- After design session:
 - Designer annotates each design
 - Then, we reveal our automatic interpretation

Identify/Quantify Ambiguous Designs

Designer's Annotation

Re-Interpretation by Other Users

Automatic Interpretation

User Study 2: Re-Interpretation

- 114 designs from Study 1
 - All ambiguous designs included
 - Some clear designs (as controls)
- 15 participants
- Re-interpreted by another user
 - 3-6 new annotations for each
 - 346 total (124 by architects)
- Then compare to original designer's annotation
- And finally, to our automatic interpretation

Re-Interpretation Results

	<i>matches the original designer's intention</i>				
	correct	mostly correct	incorrect		total
clear	155 78%	17 9%	26 13%		198
ambiguous	74 56%	35 27%	22 17%		131
total	229 70%	52 15%	48 15%		329

multiple interpretations possible

- No correlation found between background (architecture/arts/none) & interpretation accuracy
- We will continue to improve the robustness of our software

Domain-Specific Knowledge Required

- Standard vocabulary of architectural forms (e.g., cruciform, portico, etc.)

Designer's Annotation *Re-Interpretation by Other Participants* *Automatic Interpretation*

Future Work

- Improve/robustify interpretation algorithm
 - Detect symmetry & repetition
 - Multi-zone interiors & circulation paths
- Incorporate domain-specific knowledge
- Enhance user interface
 - Additional tokens, more complex element shapes
 - Alternative to sketching in plan: sketch (double height, multi-floor) vertical sections
- Apply to pen-based sketch interpretation

Thanks!

- Yu Sheng, Ted Yapo, & Andrew Dolce
- Our user study volunteer participants
- Funding from NSF & IBM

Designer's Annotation *Re-Interpretation by Other Participants* *Automatic Interpretation*