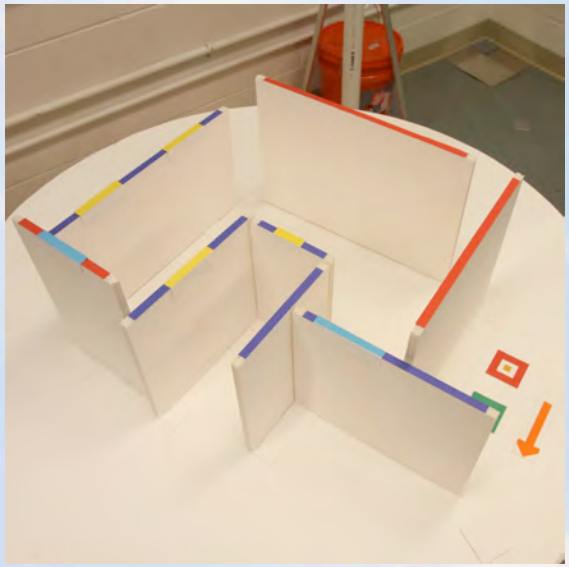
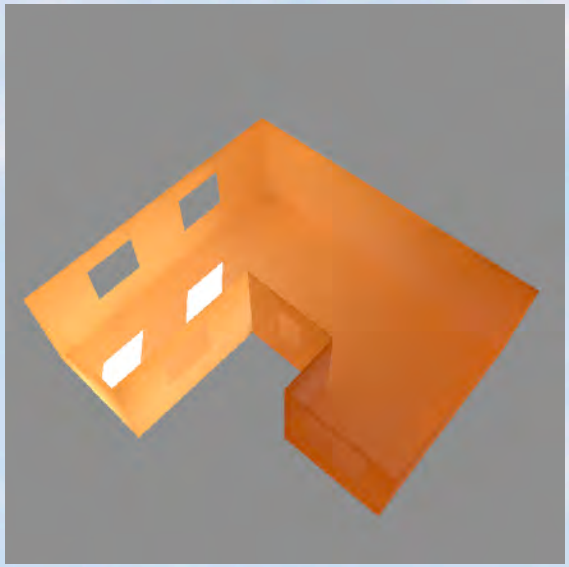
Virtual Heliodon: Spatially Augmented Reality for Architectural Daylighting Design





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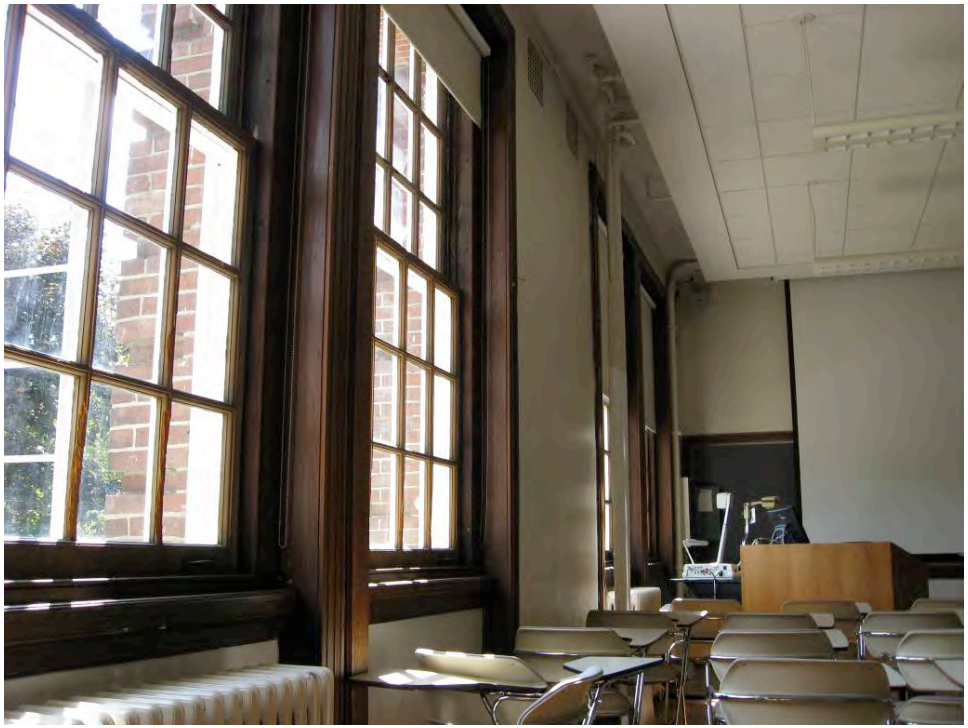
Natural Light vs. Electric Light

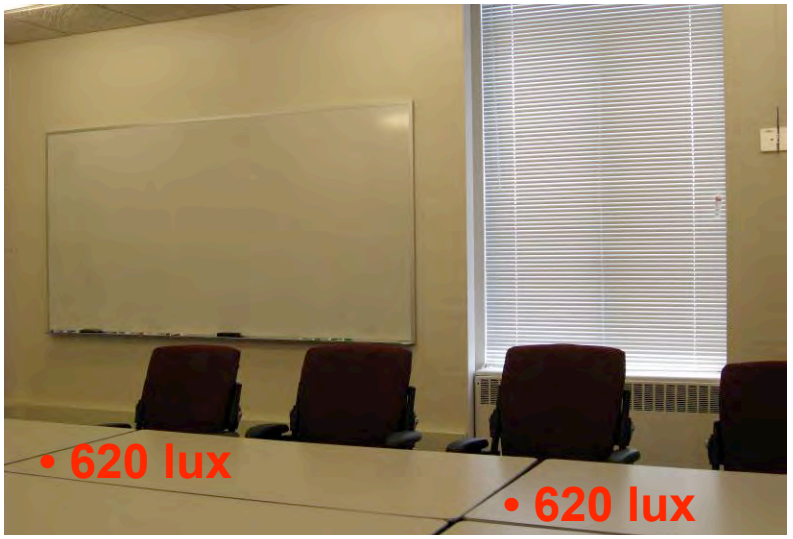


Lighting accounts for 22% of US electricity consumption

Lights off, no blinds

Lights off, blinds open

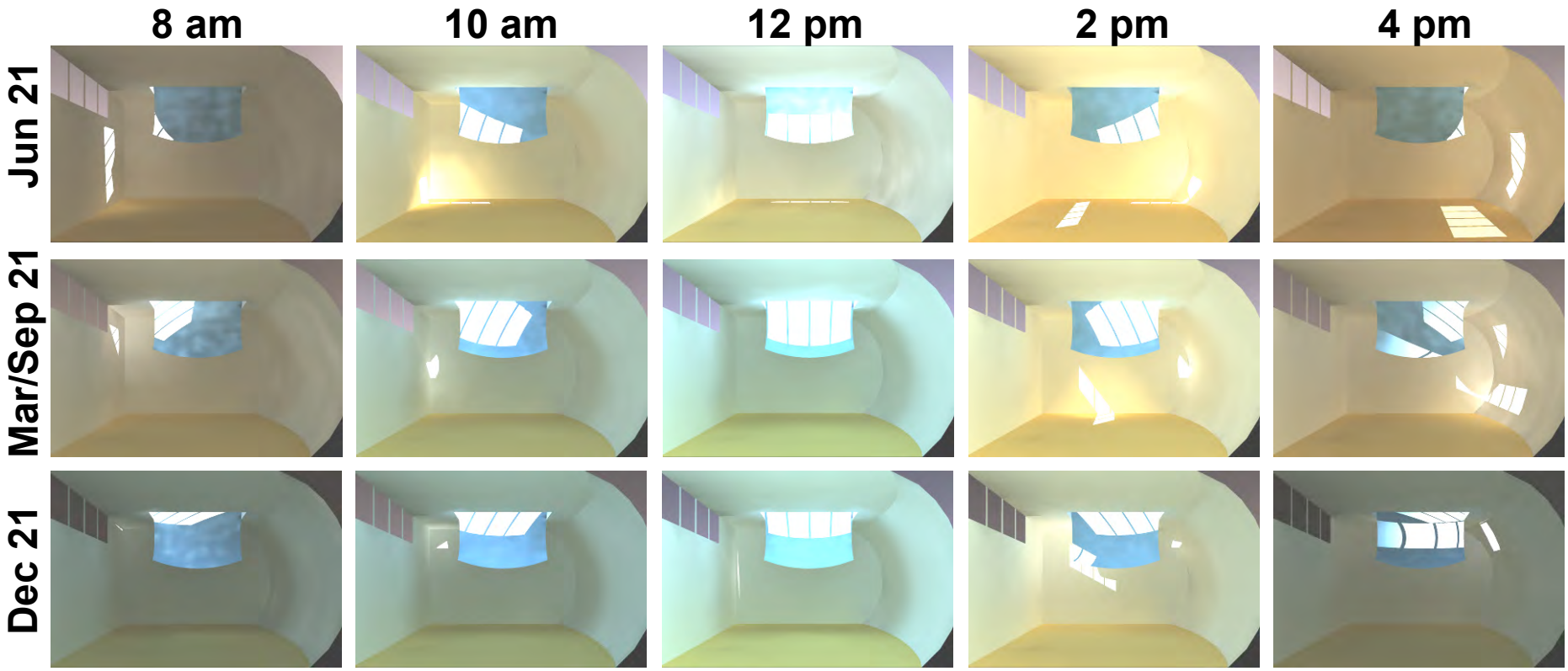
Lights off, blinds closed



Lights on, blinds closed

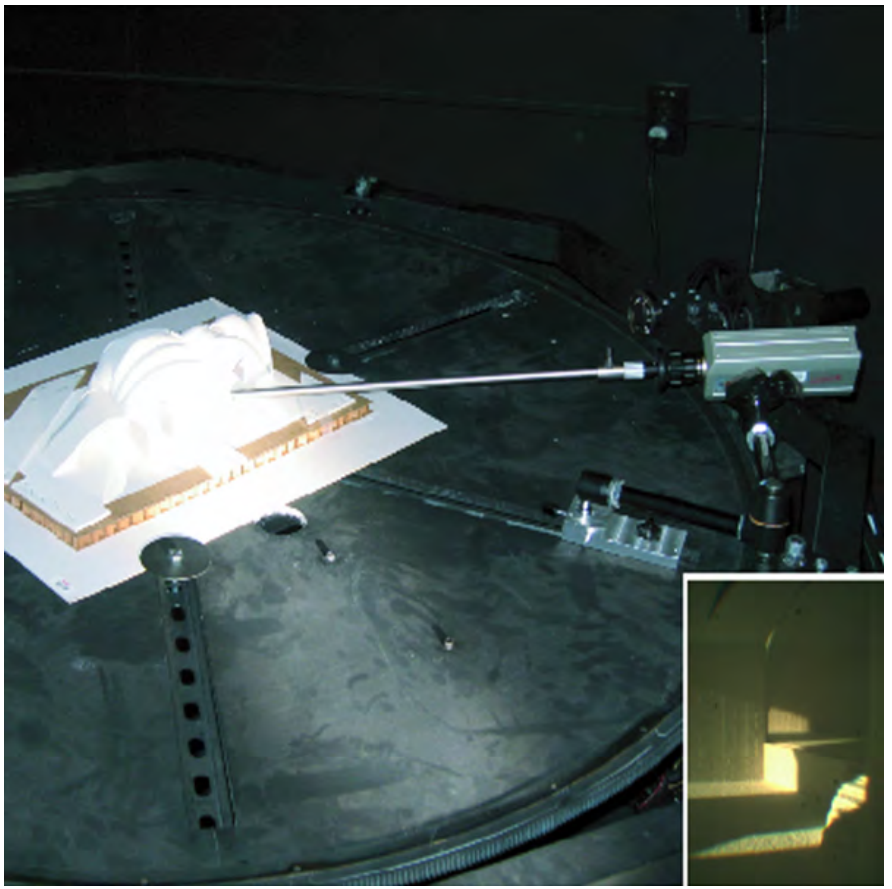
500-1000 lux recommended for reading
direct sunlight ≈ 100,000 lux

Architectural Daylighting Design: The use of windows and reflective surfaces to allow natural light from the sun and sky to provide effective and interesting internal illumination.



Residential design proposal by Mark Cabrinha

Analysis with Traditional Heliodon

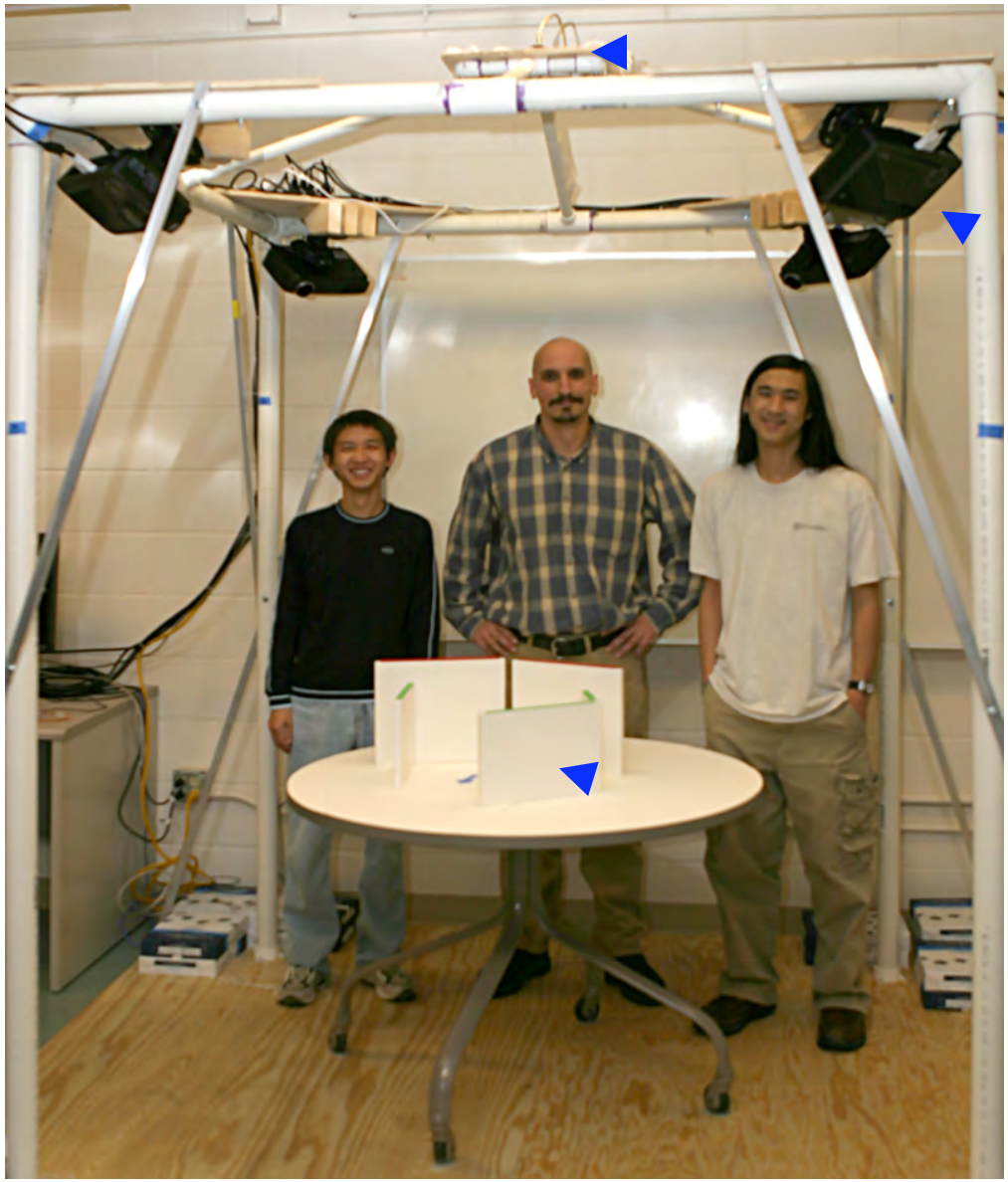


Shadows and light penetration can be observed on small scale physical model

Related Work:

- Daylighting Design
  - Radiance, Greg Ward Larson
- Virtual / Augmented Reality
  - CAVE (Cruz-Neira et al., 1992)
  - Interior Architectural design (Mackie et al., 2004, Dunston et.al, 2007)
- Spatially Augmented Reality
  - Office of the future (Raskar et al., 1998)
  - Everywhere Display (Underkoffler et al., 1999)
  - Shader Lamps (Raskar et al., 2001)
  - Automatically-calibrated cameras and projectors (Raskar et al., 2001)
  - Multi-planar display (Ashdown et al., 2004)
  - Shadows and occlusions (Audet & Cooperstock, 2007)

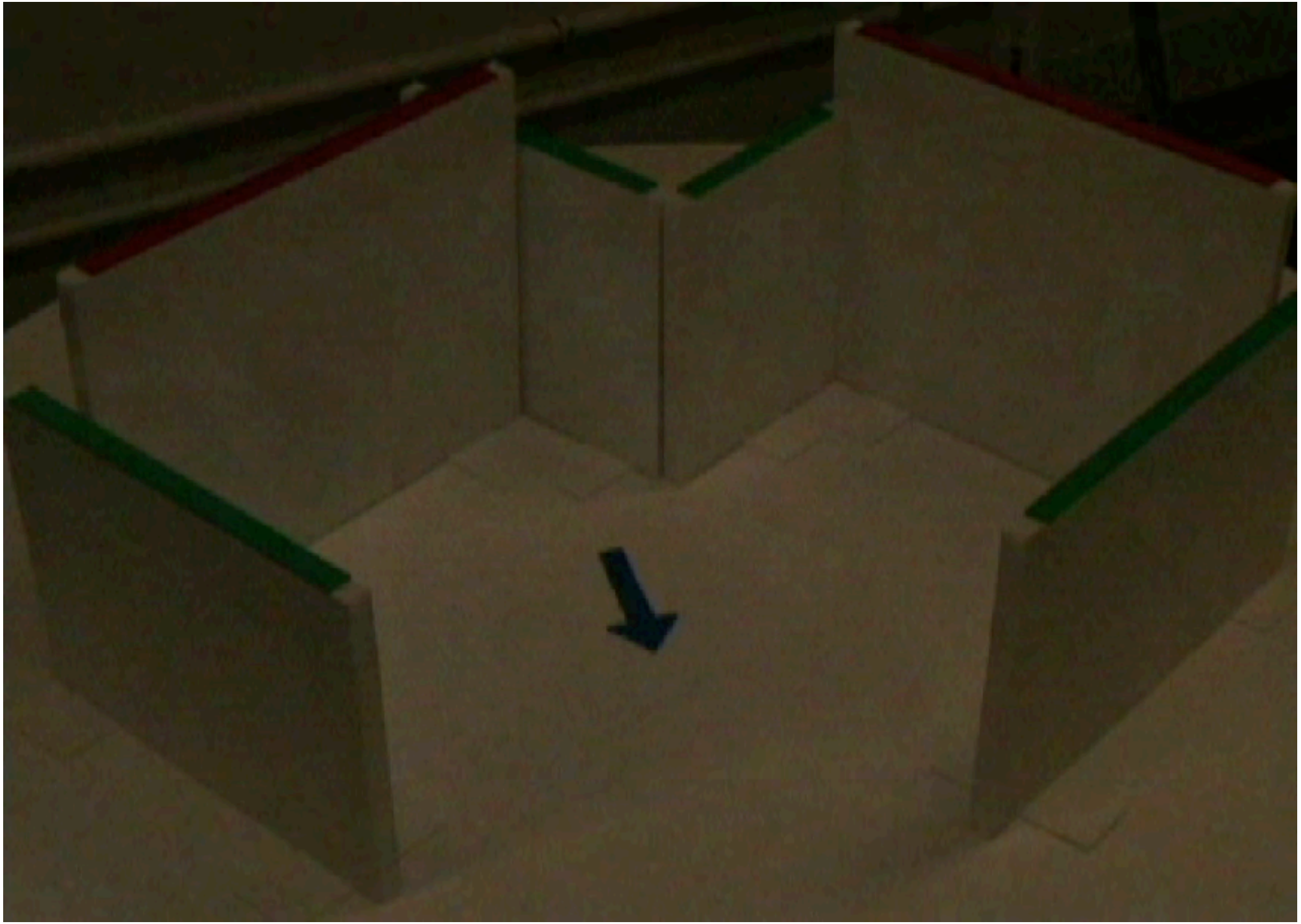
Table-top Daylighting Design



camera to detect geometry

4 projectors to display solution

design sketched with foam-core walls



Algorithms and Implementation

- Hybrid Rendering Algorithm
- Model Construction
- Camera & Projector Calibration
- Primitive Detection
- Multi-Projector Display

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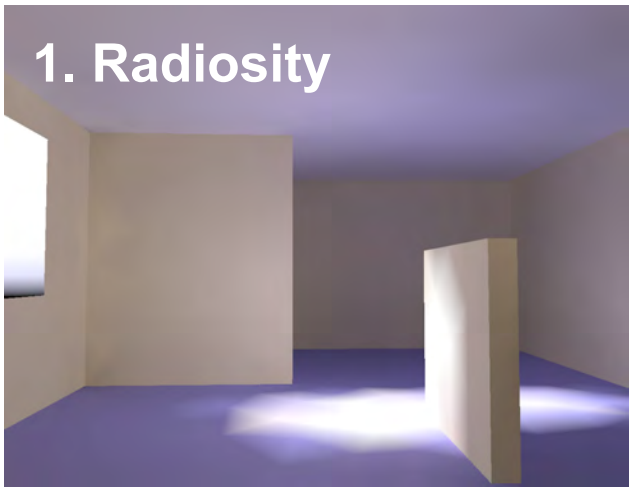
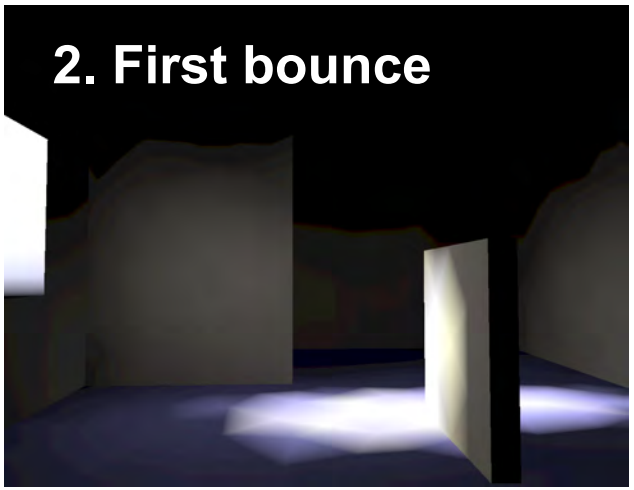
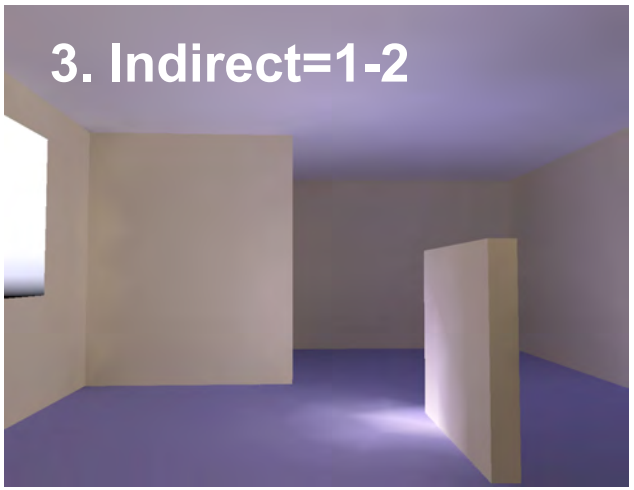
Radiosity

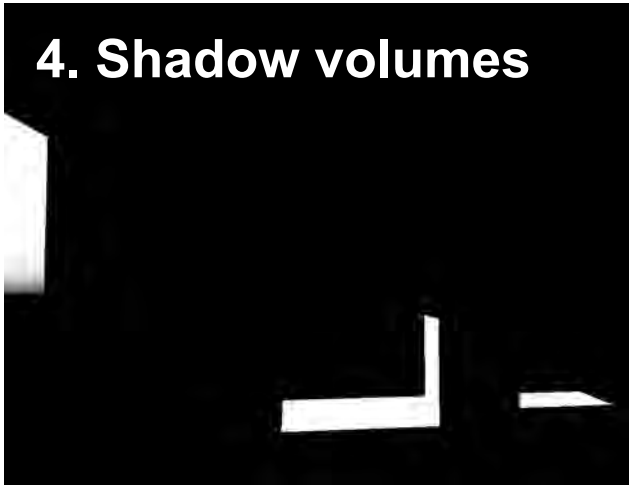
- Global illumination algorithm
  - Diffuse surfaces
- Why not radiosity alone?
  - Low resolution mesh → inaccurate shadows
- Why do we need “hard shadows”?
  - More realistic
  - More intuition about scene geometry & lighting

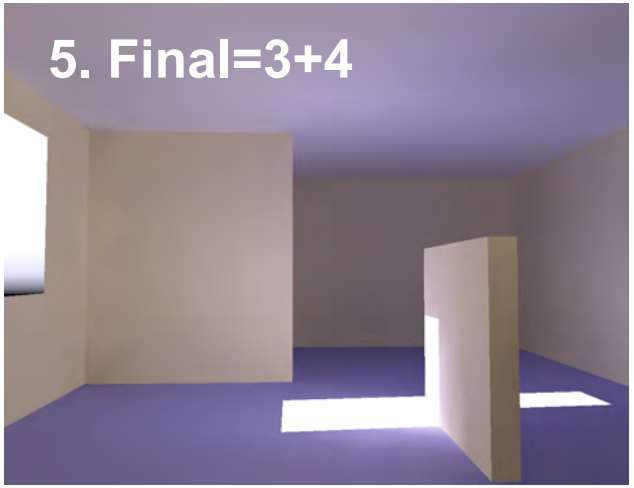
Interactive Global Illumination: Hybrid Radiosity/Shadow Volumes











Exploit smoothness in indirect illumination

Efficiently compute direct illumination

Algorithms and Implementation

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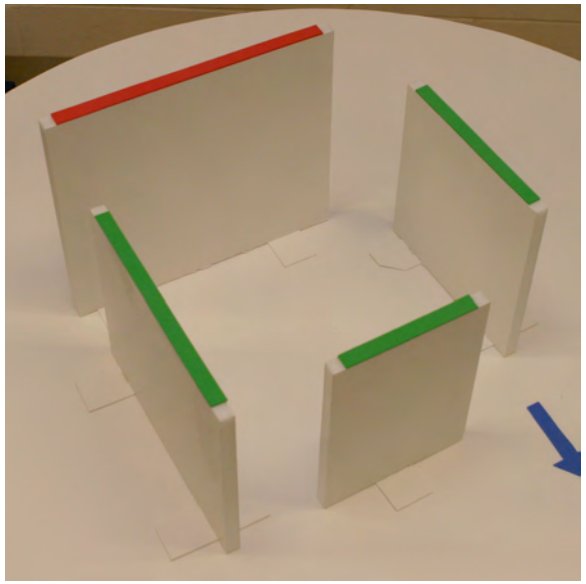
Sketch Interpretation

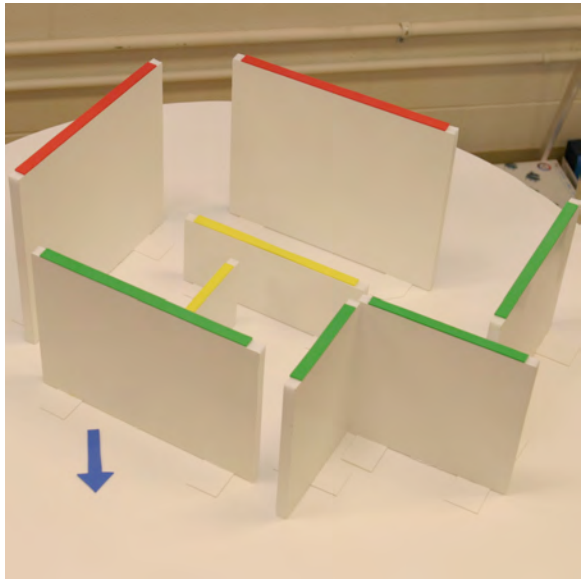
red: exterior wall w/ window

green: exterior wall

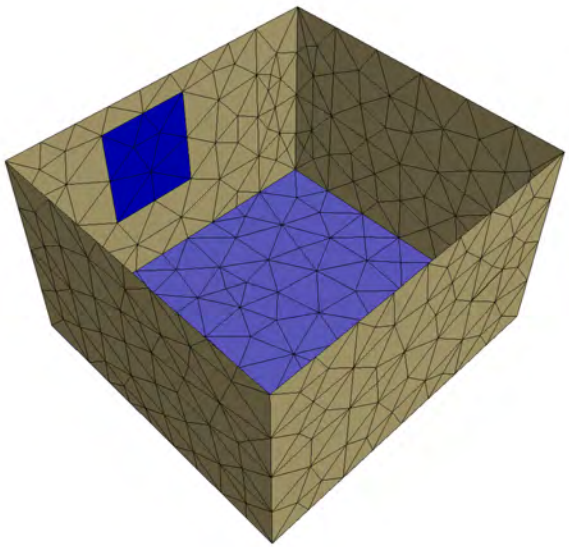
yellow: interior wall

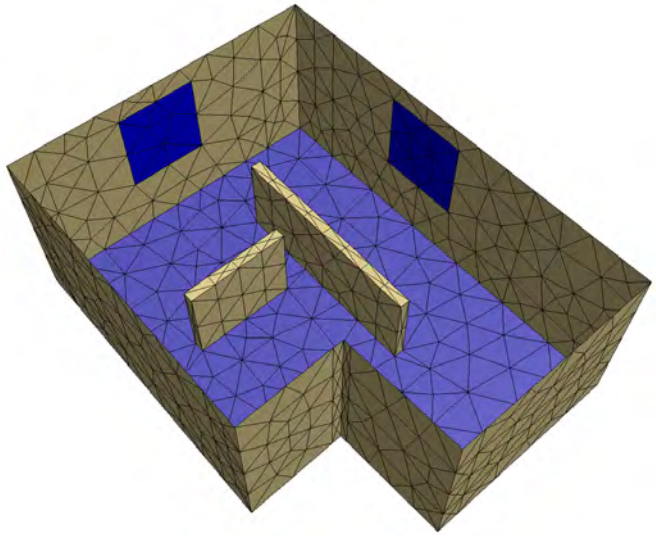
blue north arrow





software automatically constructs closed polygonal model for simulation





Algorithms and Implementation

- Hybrid Rendering Algorithm
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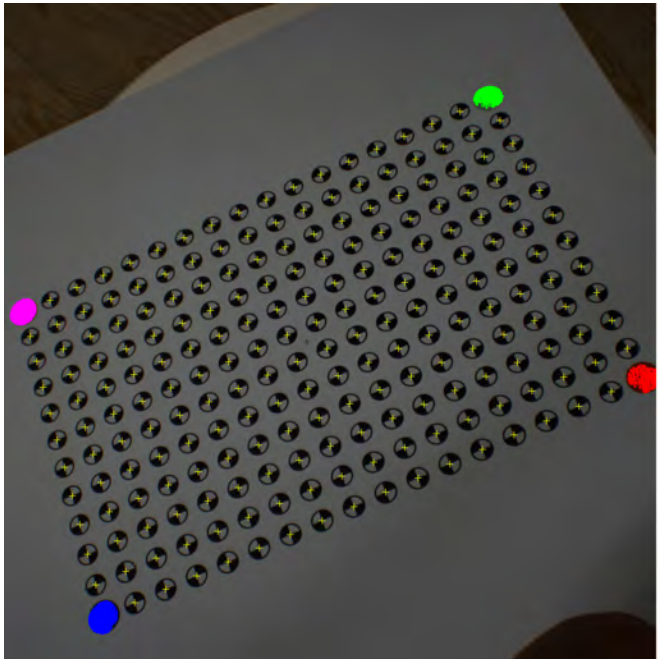
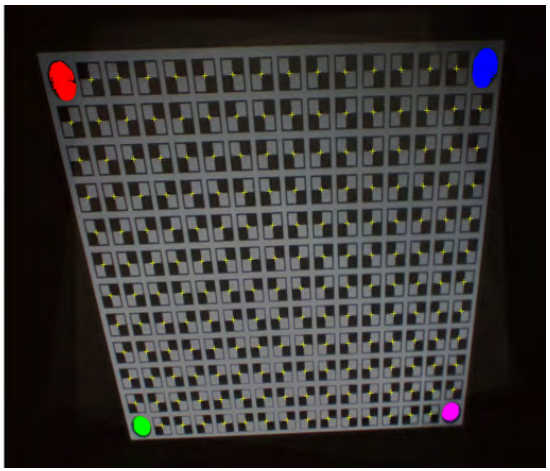
Camera Calibration

- Using Zhang's algorithm [Zhang 1999] to estimate the intrinsic parameters of camera
  - Calibration target consisting of 212 black and white corner marks on a white background
  - 40 pictures taken at different orientations

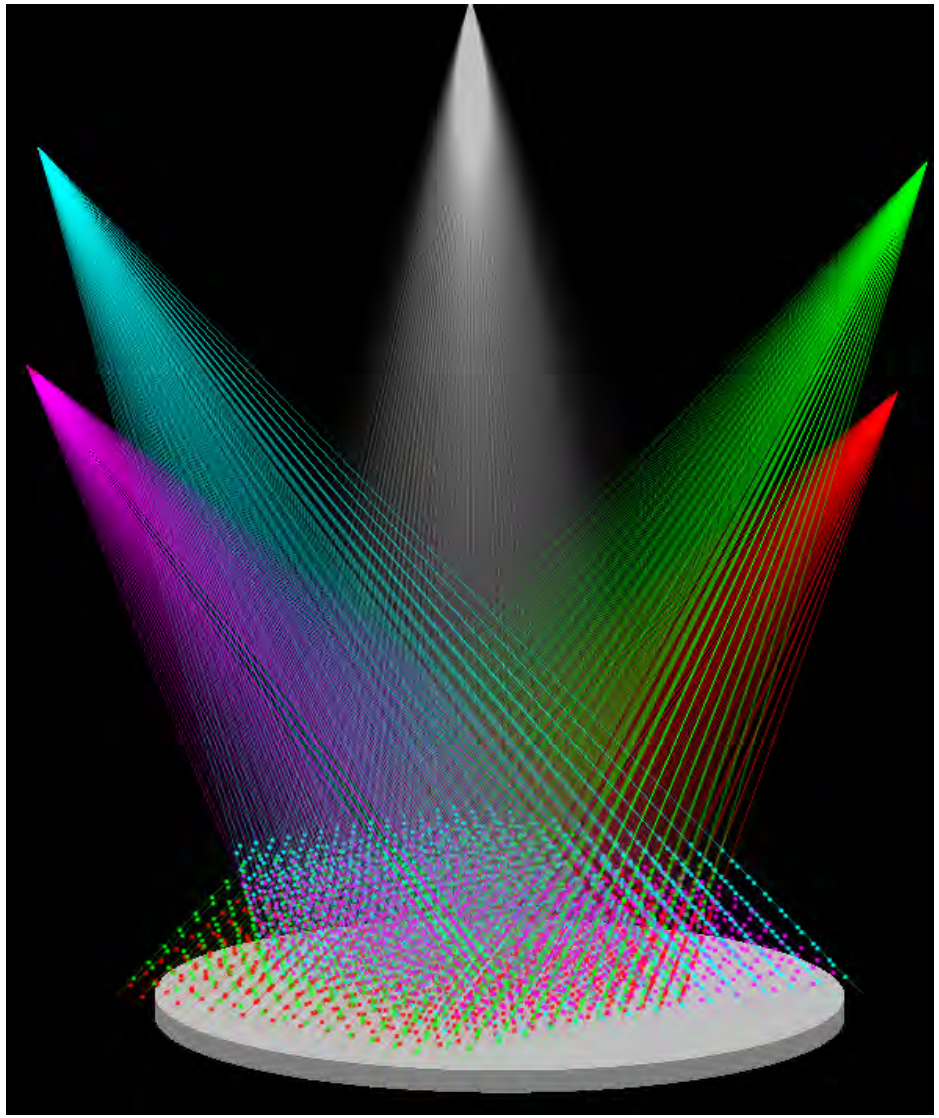


Projector Calibration

- Tsai's algorithm [Tsai 1987]
  - Uniformly spaced horizontal planes



Projector calibration



Common coordinate system

Algorithms and Implementation

- Hybrid Rendering Algorithm
- Model Construction
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- Primitive Detection
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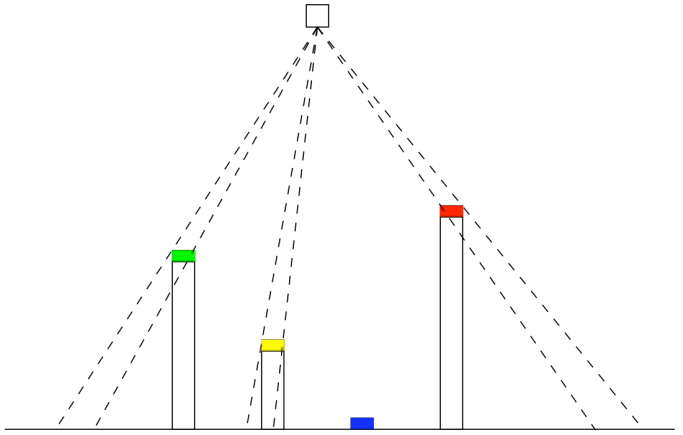
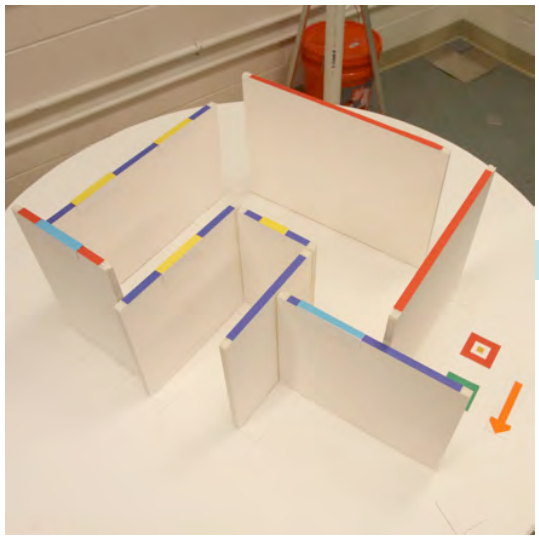
Primitive Detection

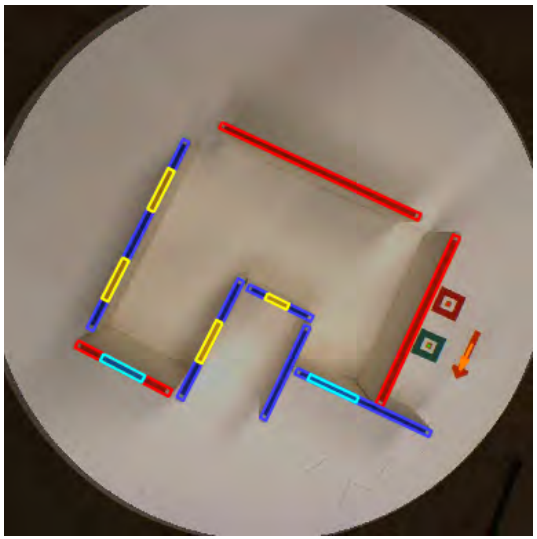
- Color classification
- RANSAC: fit line to edges
- 2D➔3D, projection matrix



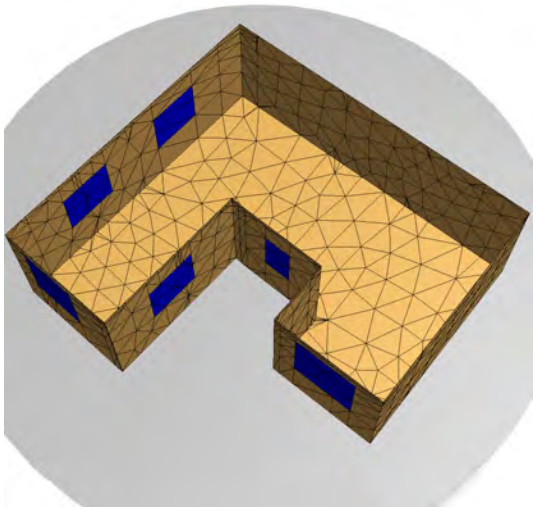
Projection Geometry



Physical Sketch

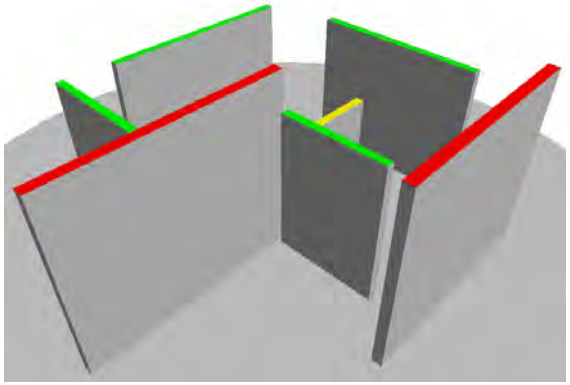


Edge Detection

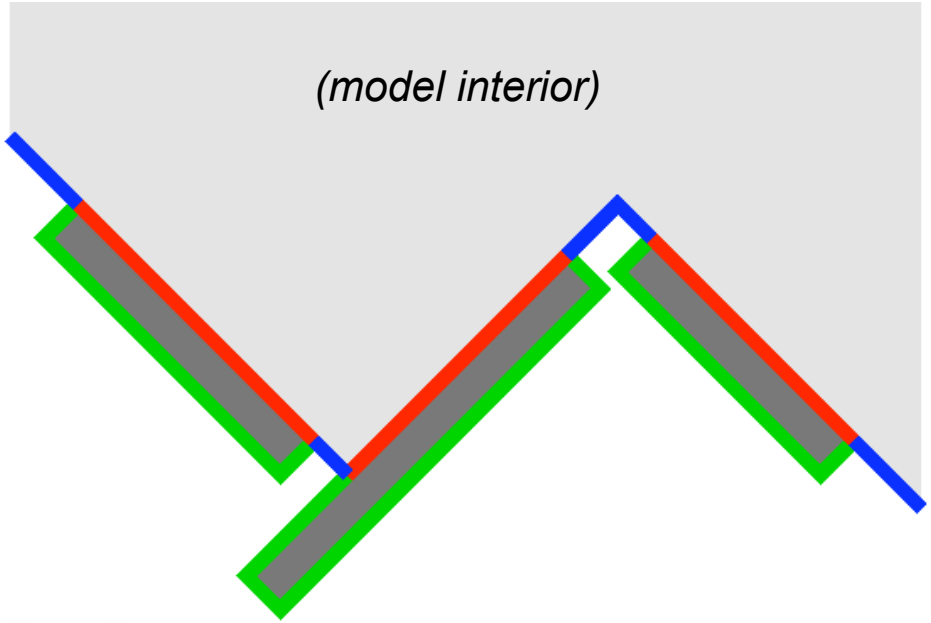


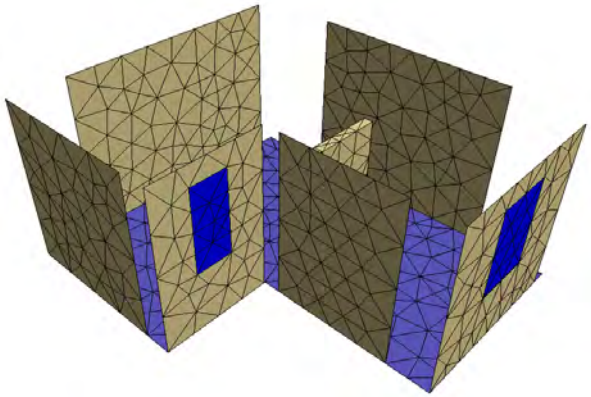
Reconstructed Scene

Watertight Mesh for Simulation

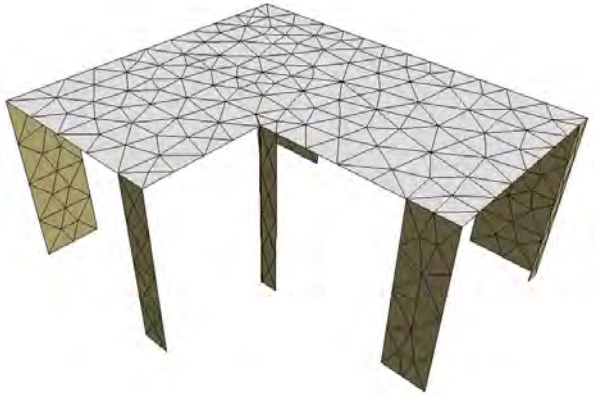


Detected geometry

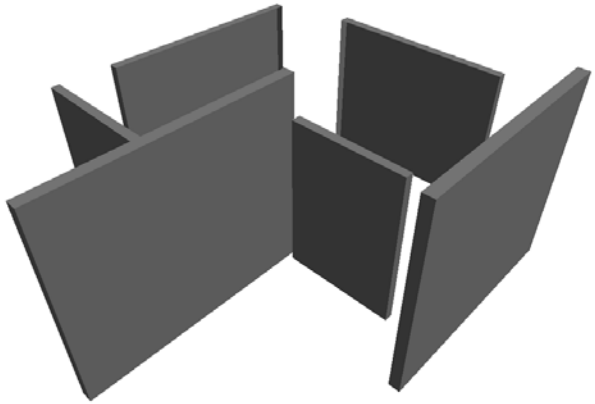




Projection surfaces



"Fill-in" geometry



"Extra" physical geometry

Algorithms and Implementation

- Hybrid Rendering Algorithm
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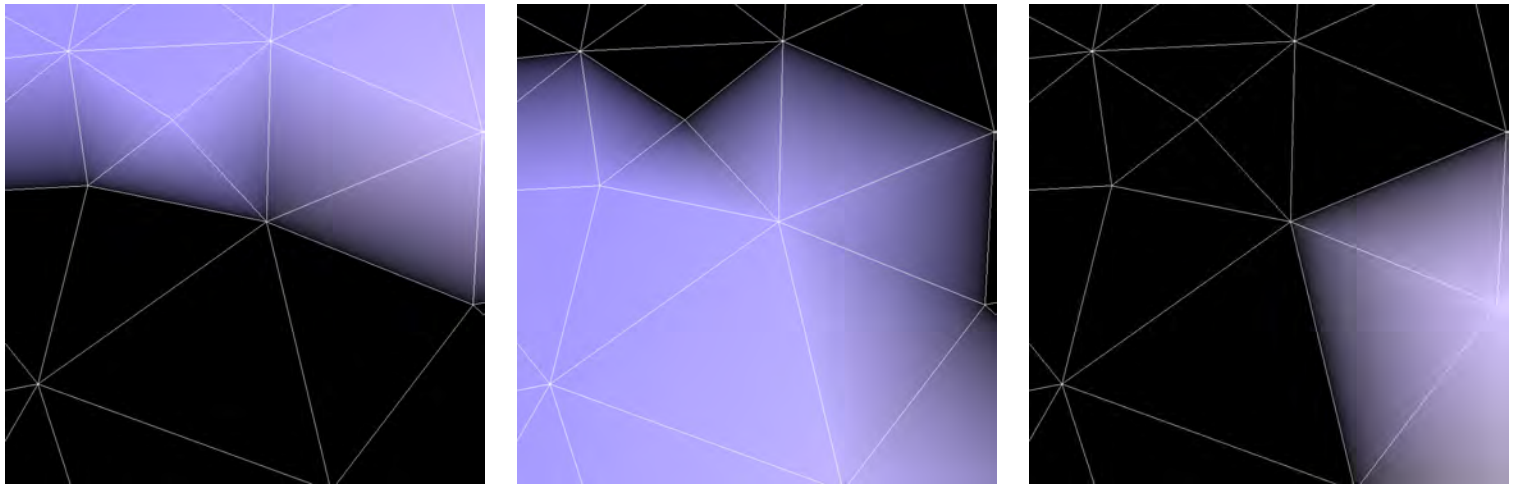
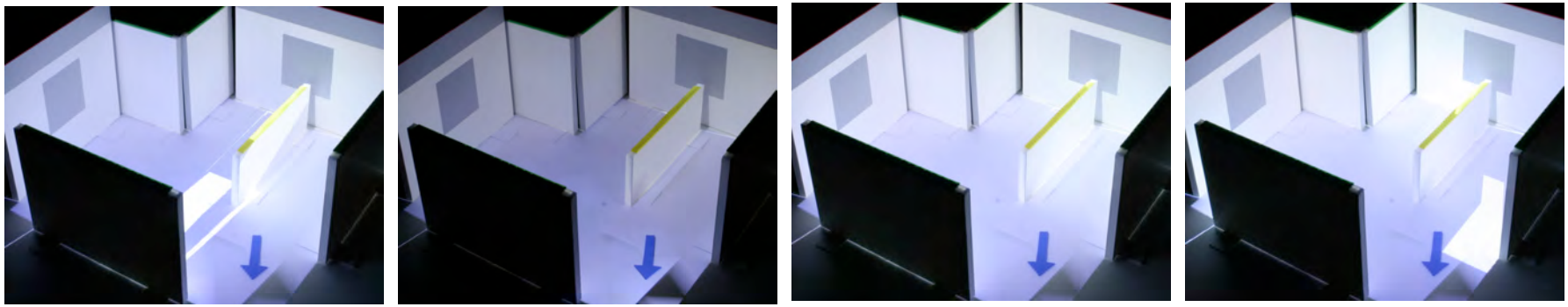
Multi-Projector Display

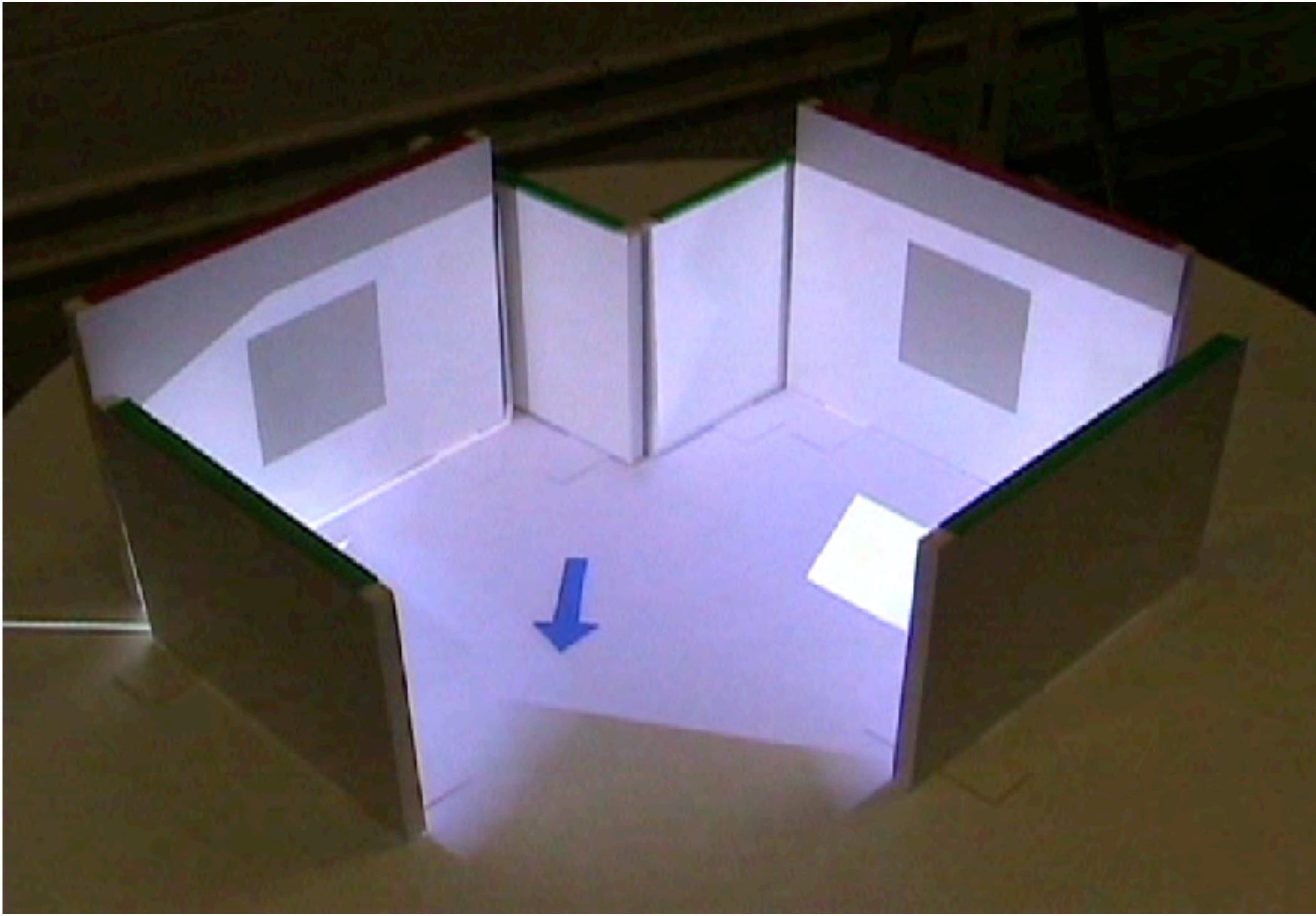
- Radiange adjustment $I = E\frac{r^2}{\rho \cos\theta}$
- Intensity blending
  - Smooths transitions between projectors
  - Each vertex in the mesh has a “best projector” for display



Results

- For a geometry with 1500 triangles
  - 0.6 seconds to relight for changing time / day, north orientation, etc.
  - 6-7 seconds to generate the projection images for a new geometry
    - Image processing: 0.05 seconds
    - Remeshing: 2.5 seconds
    - Form factor computation: 3 seconds





Traditional Heliodon

- Must peer in the windows, but avoid blocking the “sun”
- Close approximations of all materials must be used in model construction
- Model construction is tedious

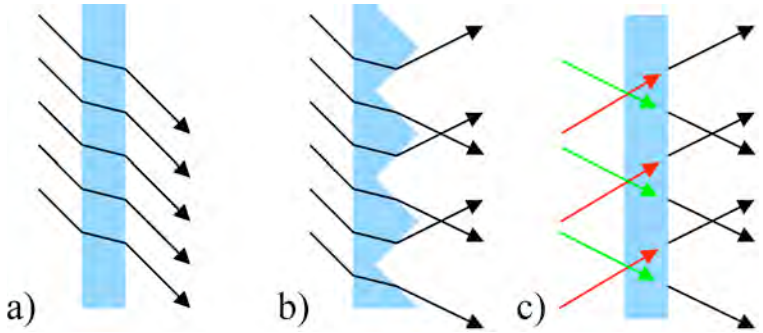
Virtual Heliodon

- Ceiling has been removed allowing easy viewing
- Less precision is needed in joining walls
- Materials are specified digitally and do not require a physical sample of the material
- Initial construction and edits are fast and easy

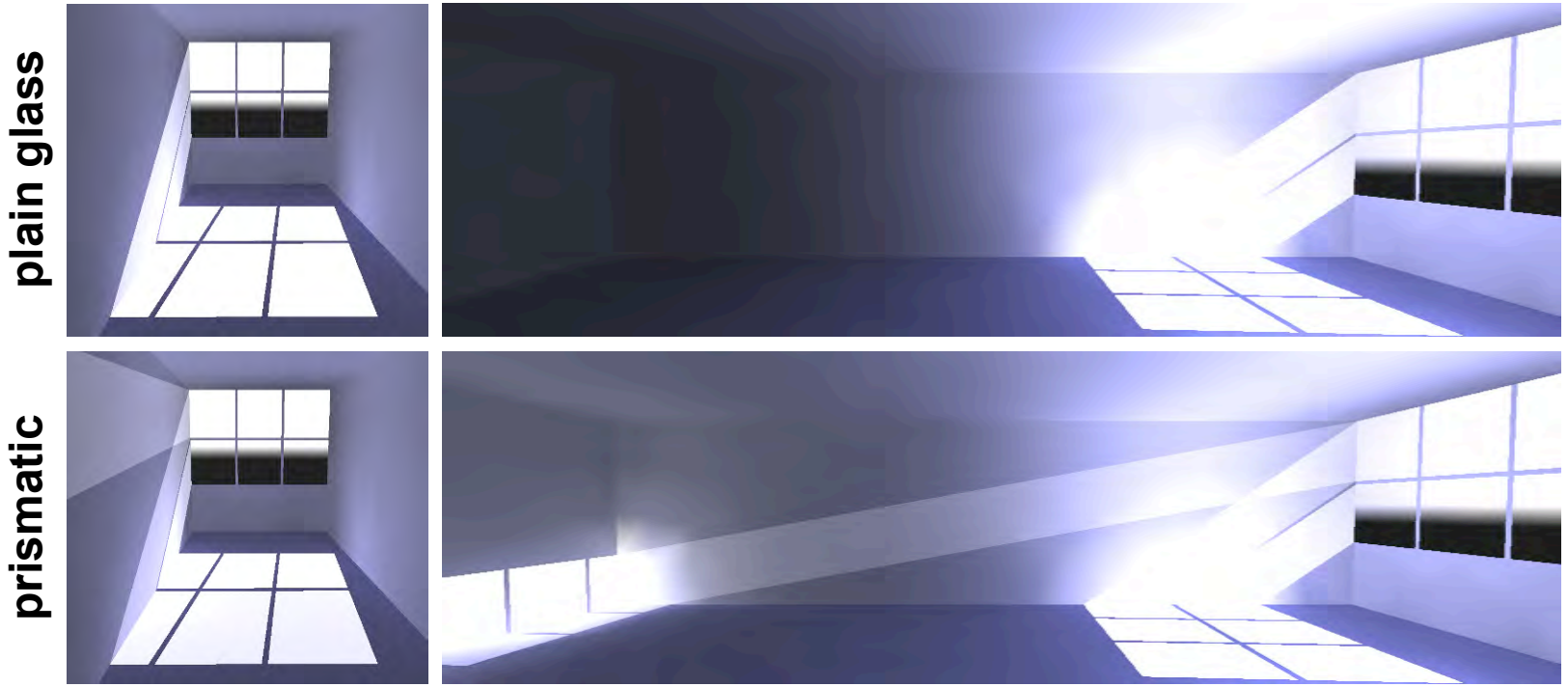
Ongoing and Future Work

- Formal user studies
- Robust image processing, e.g., ignore users' hands
- Table surfaces, curved walls, sloped ceilings
- Consider dynamic range of projectors
- Complex fenestration (window) materials
- Compensate for secondary scattering of projected imagery

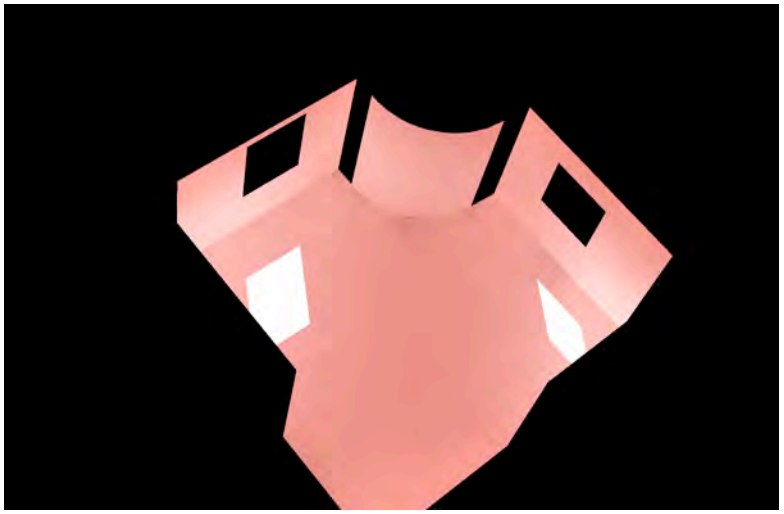
Light-Redirecting Materials



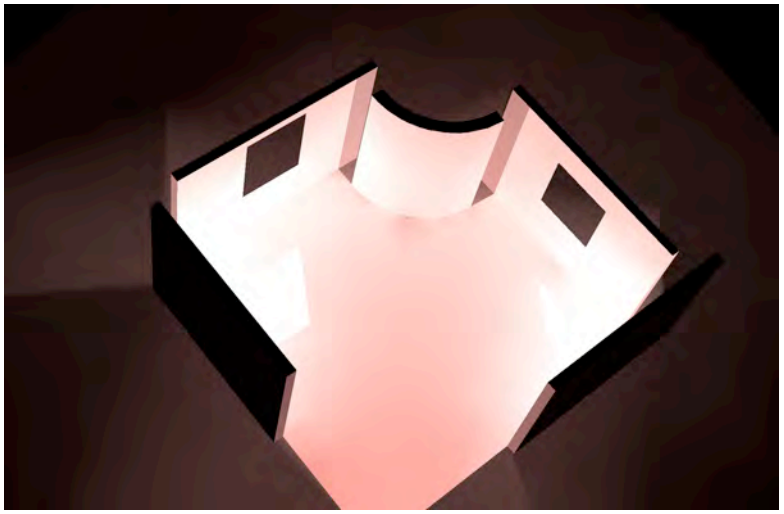
Prismatic panels available in late 1800's, but lost popularity when electric lighting was introduced



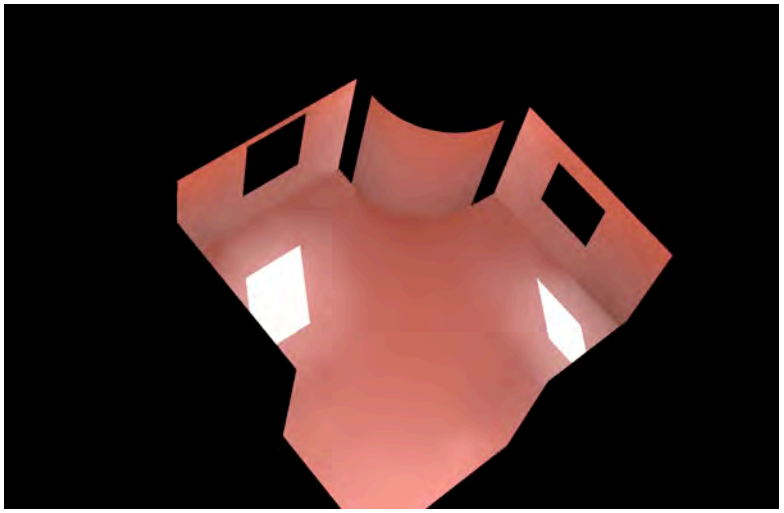
Secondary Scattering Compensation



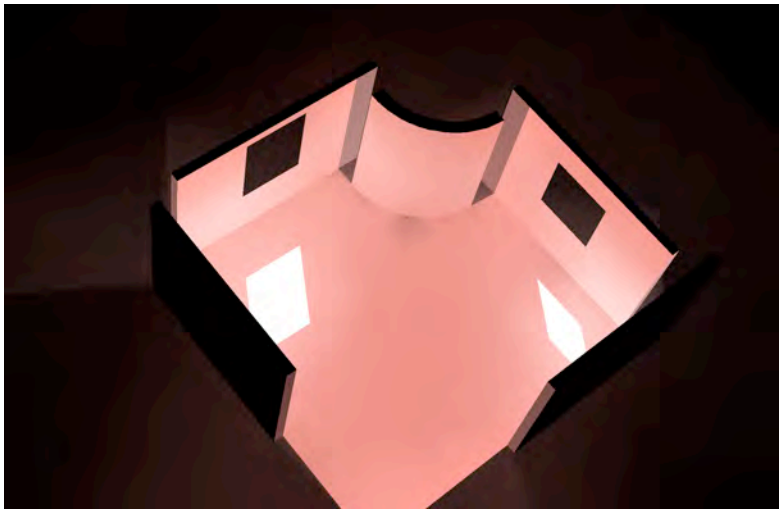
Desired illumination



Naïve projection



Compensated



Compensated projection

Thanks!

- *Collaborators:*
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  Mark Cabrinha
  Melissa Schroyer
- *RPI Computer Vision Research Group*
- *IBM & NSF*