Ph.D. Dissertation Talk

3D Modeling of Interior Building Environments and Objects from Noisy Sensor Suites

May 1, 2015

Eric Turner
Advisor: Avideh Zakhor

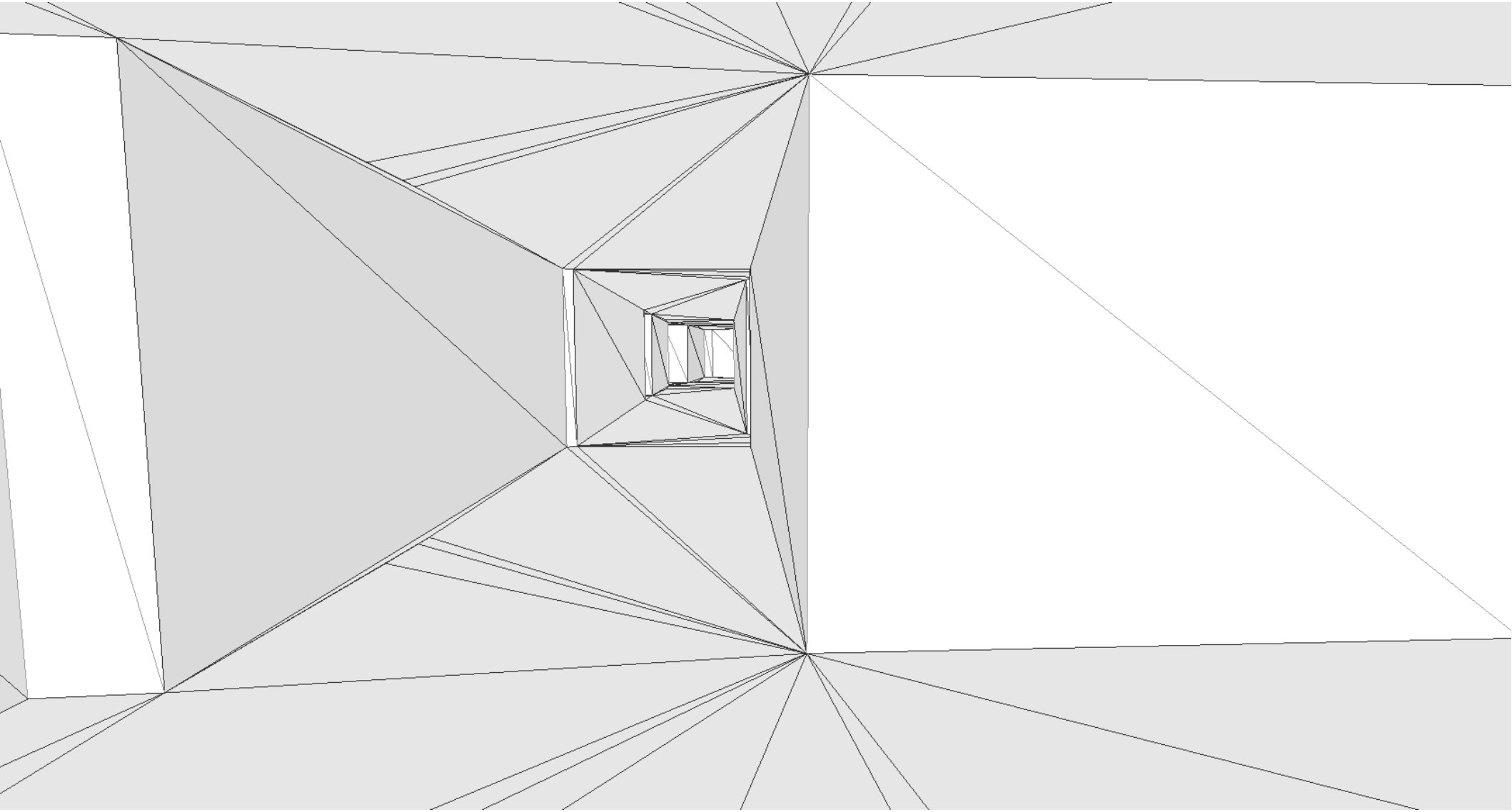
Outline

- Motivation
- Hardware and Preprocessing
- Modeling Techniques
  - 2D Floor Plans
  - 2.5D Simplified Models
  - 3D Complex Models
- Combining Modeling Techniques

Motivation: Types of Models

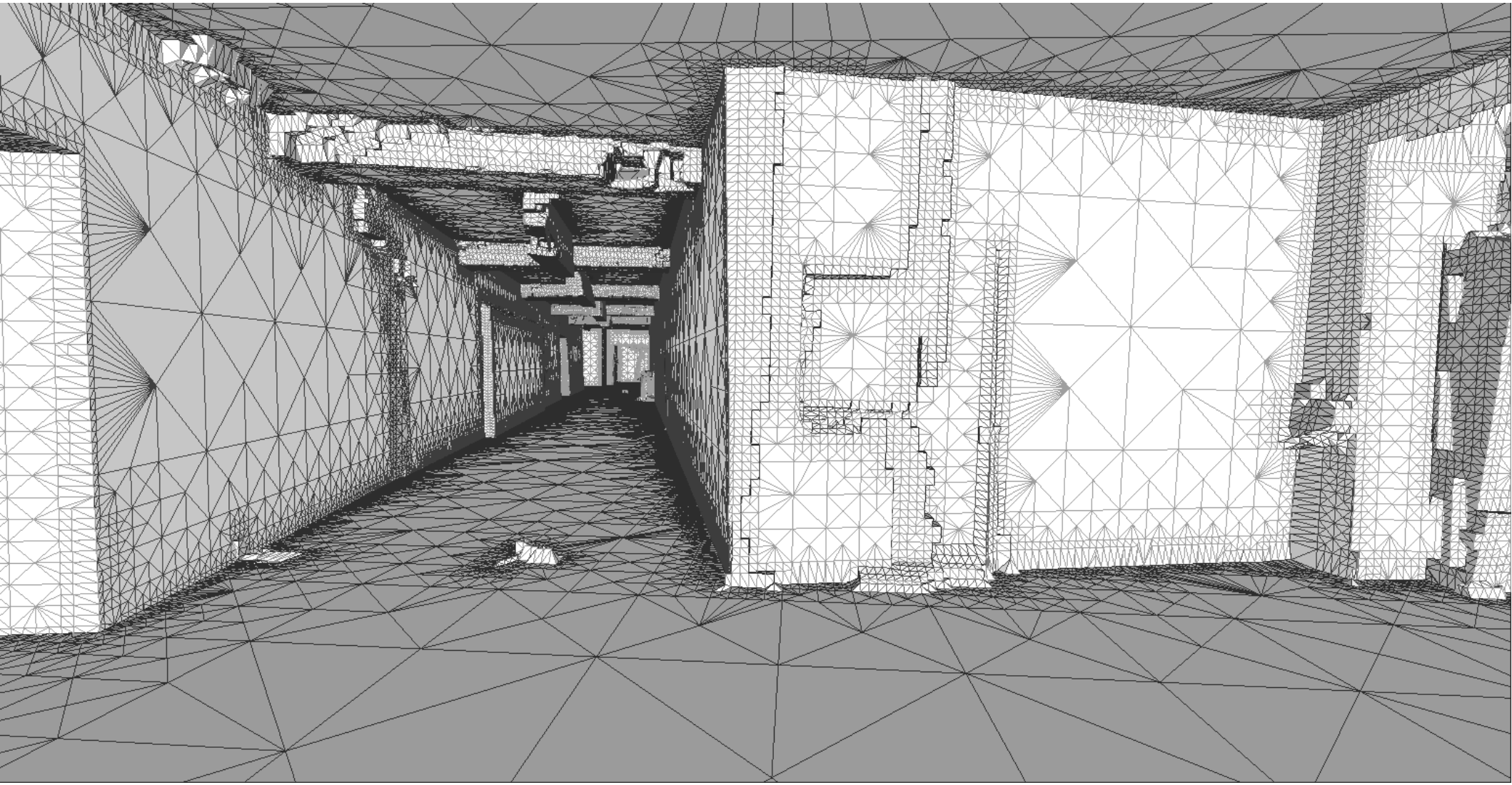
Photograph

Motivation: Types of Models



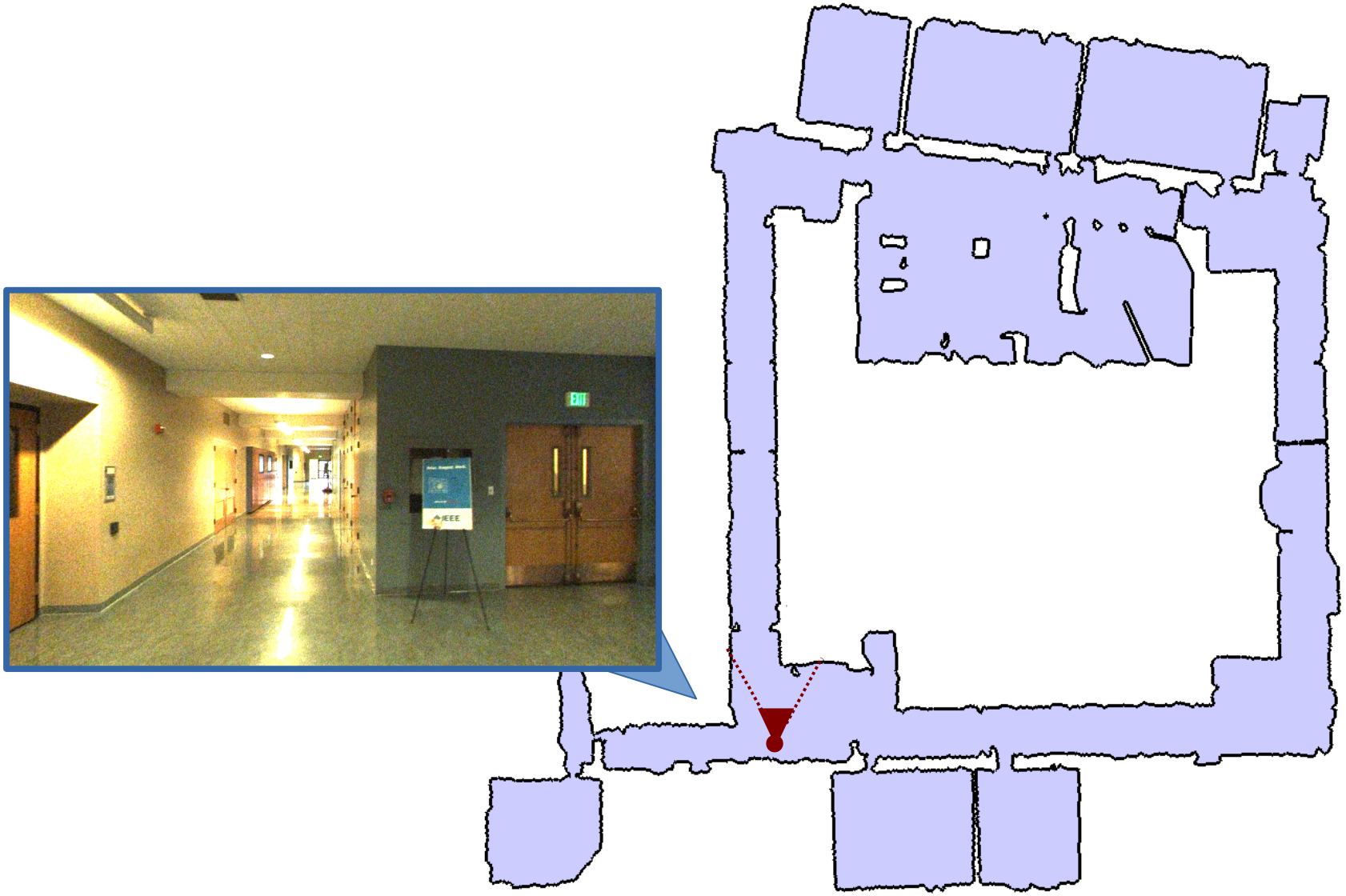
2.5D Simple Model

Motivation: Types of Models



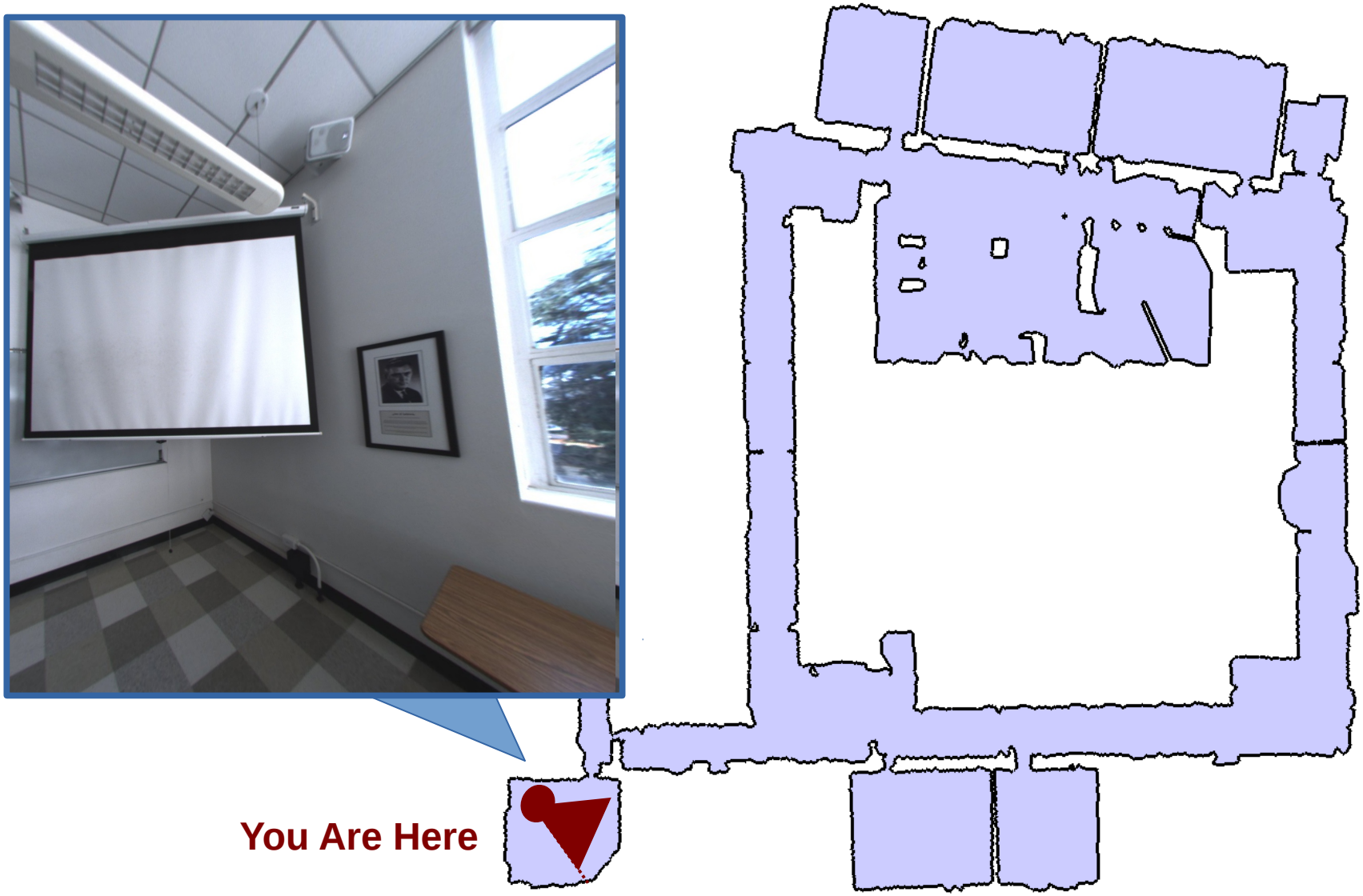
3D Complex Model

Motivation: Types of Models



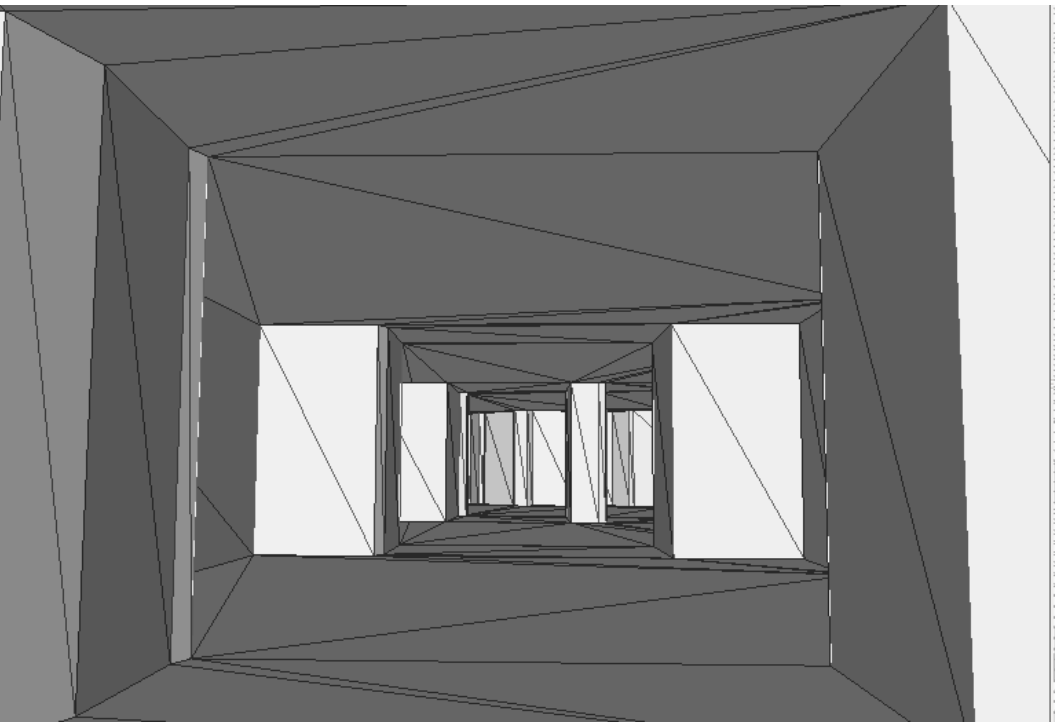
2D Floor Plan

Motivation: Types of Models

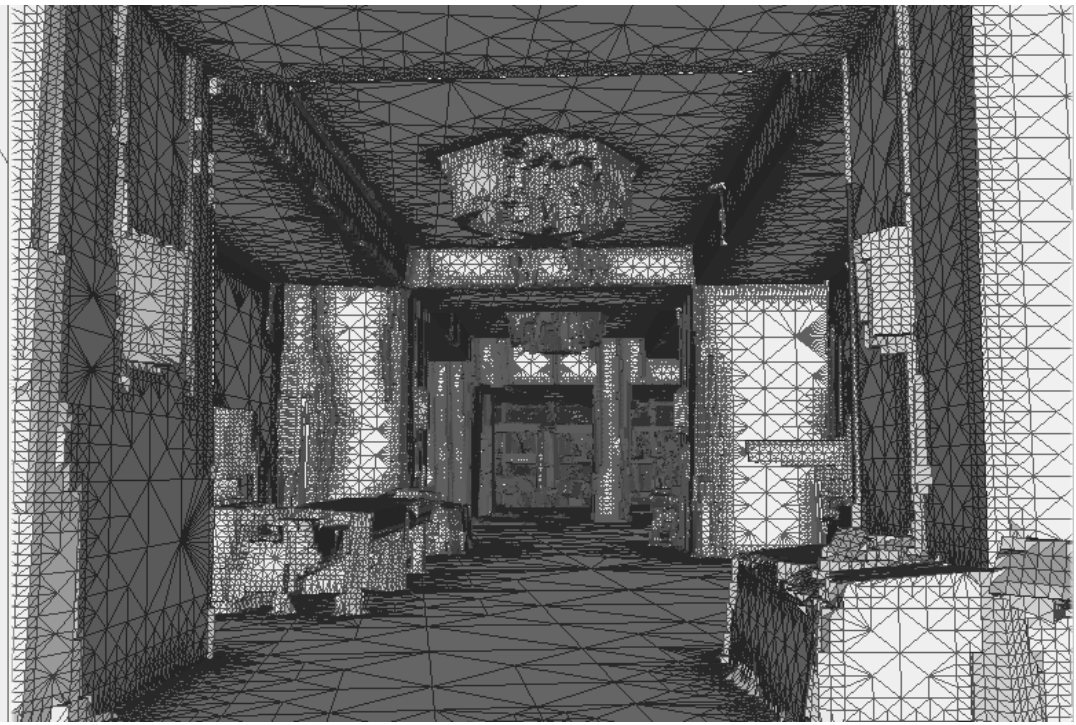


2D Floor Plan

Combining Models



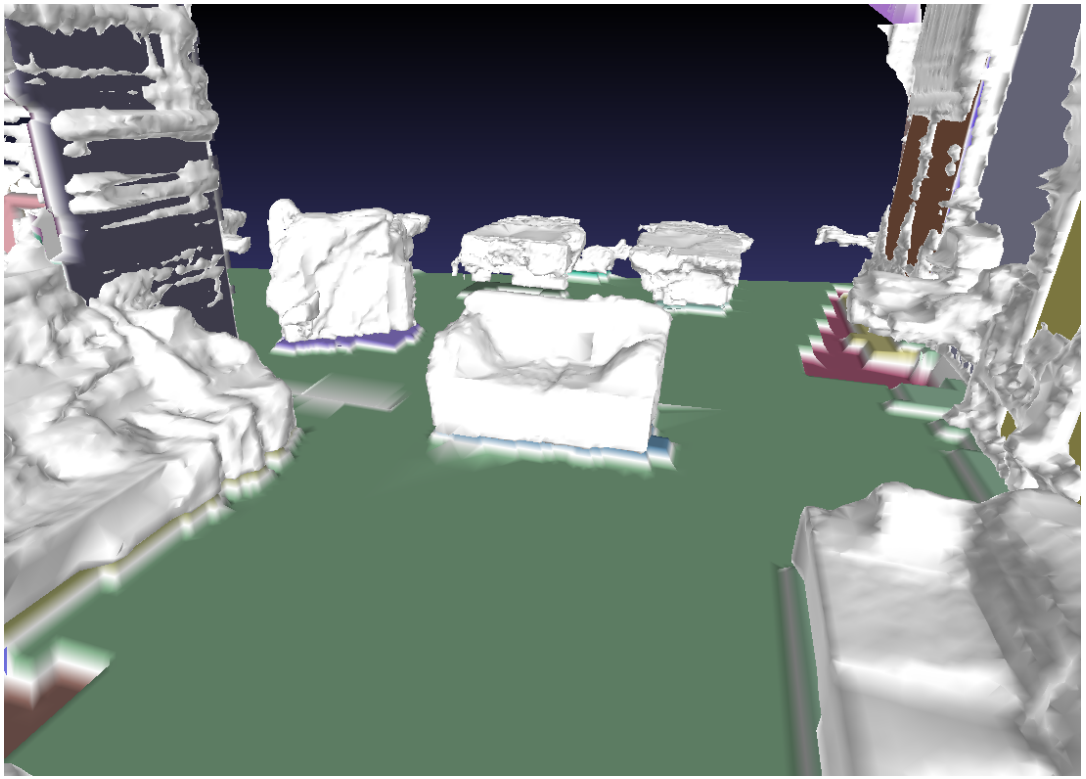
2.5D Model



3D Model

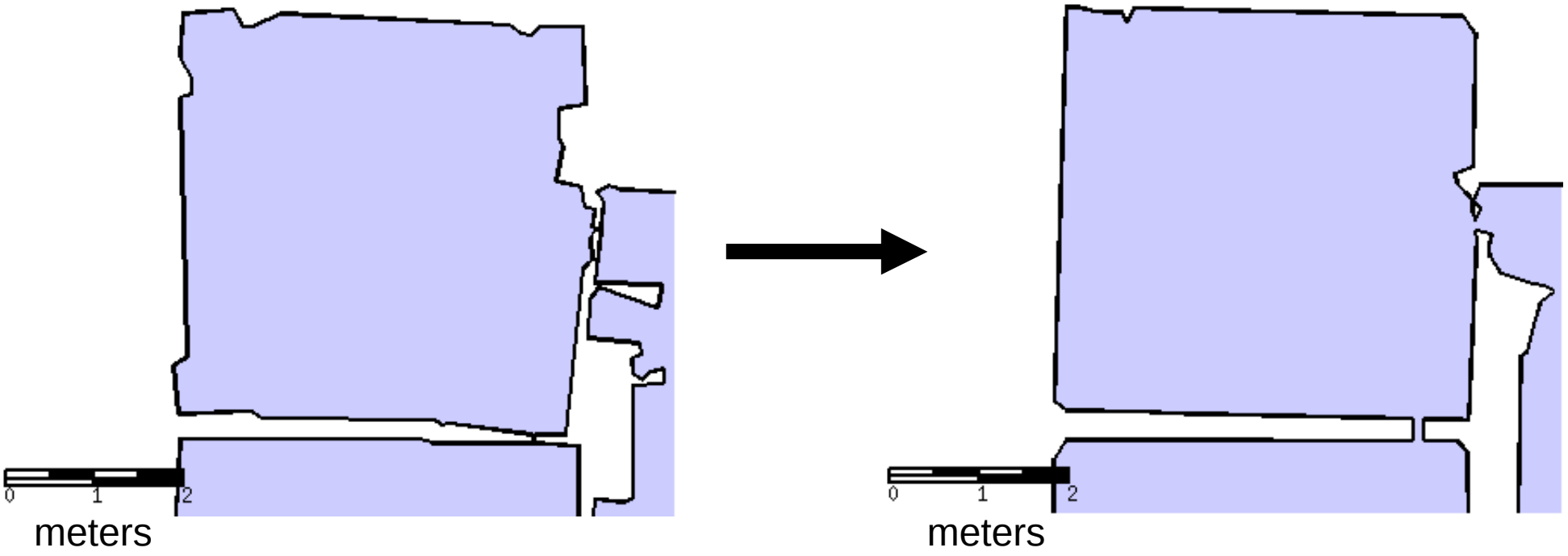
Combining Models

- Segmenting Furniture



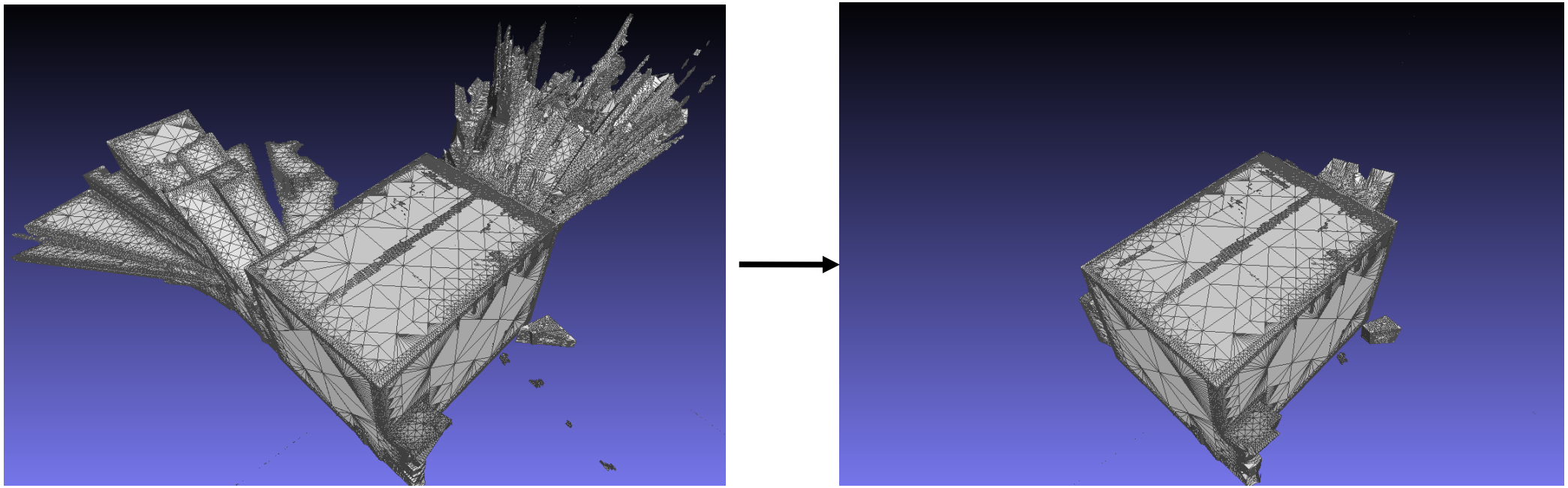
Combining Models

- Segmenting Furniture
- Improving Floor Plan Accuracy



Combining Models

- Segmenting Furniture
- Improving Floor Plan Accuracy
- Removing Modeling Artifacts



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Hardware

Hardware

2D Laser Scanner
(horizontal)

2D Laser Scanners
(vertical)

Cameras

Inertial Measurement Unit (IMU)

Data Storage Computer

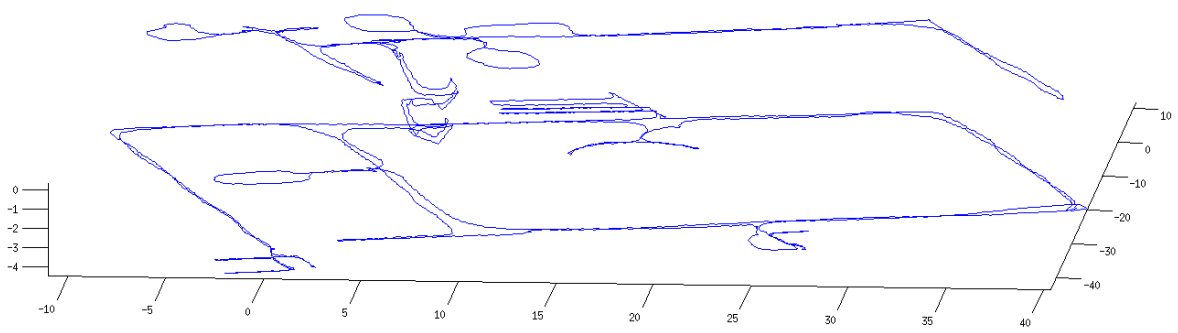
Batteries

Localization

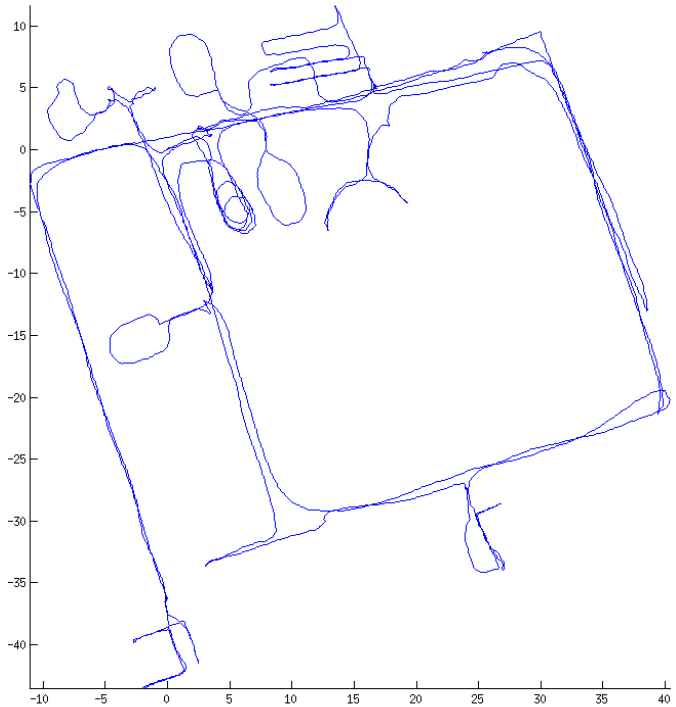
[54] *J. Kua, N. Corso, and A. Zakhor, "Automatic loop closure detection using multiple cameras for 3d indoor localization," IS&T/SPIE Electronic Imaging, pp. 82 960V–82 960V, January 2012.*

[55] *N. Corso and A. Zakhor, "Indoor Localization Algorithms for an Ambulatory Human Operated 3D Mobile Mapping System," Remote Sensing 2013, vol. 5, no. 12, pp. 6611-6646*

Localization 3D Path

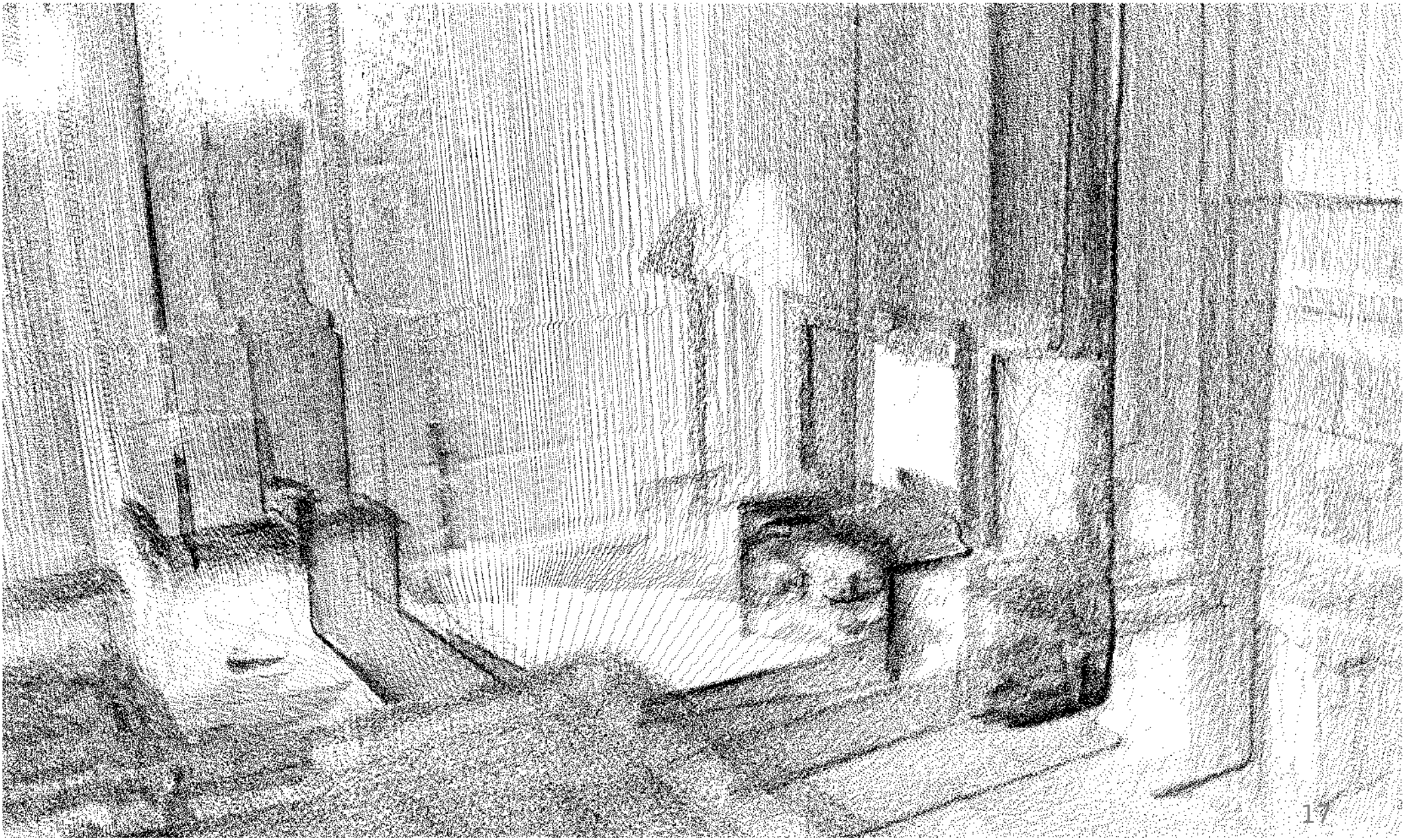


Side View

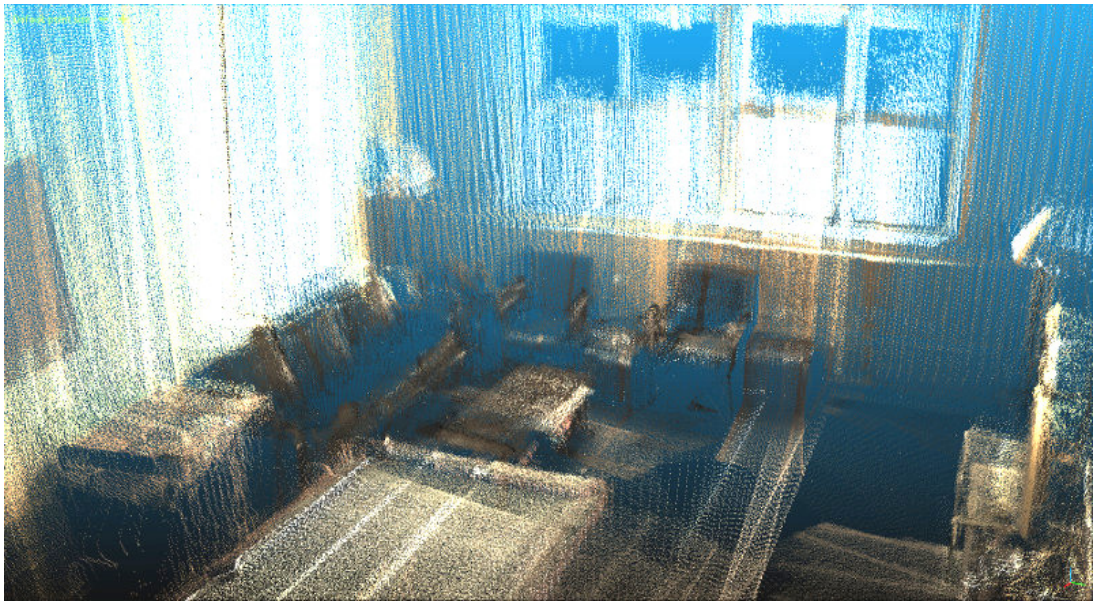


Top View

Point Cloud Scans



Coloring Point Clouds



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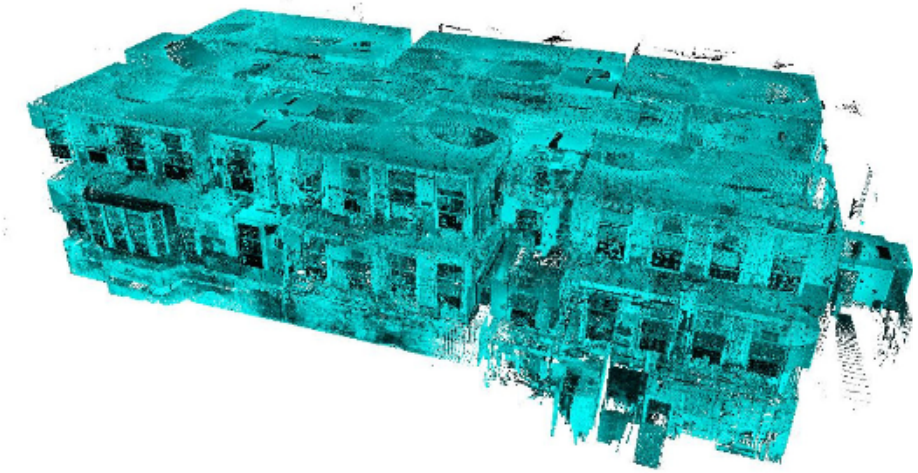
Floor Plan Techniques

[57] C. Weiss and A. Zell, "Automatic generation of indoor vr models by a mobile robot with a laser range finder and a color camera," Autonome Mobile Systeme 2005, pp. 107–113, 2006.

[44] A. Adan and D. Huber, "3d reconstruction of interior wall surfaces under occlusion and clutter," 3DIMPVT, pp. 275–281, May 2011.

[56] B. Okorn, X. Xiong, B. Akinci, and D. Huber, "Toward automated modeling of floor plans," 3DPVT, 2009.



3D Point Cloud

2D Floor Plan (not watertight)

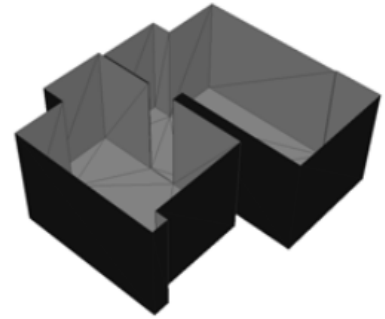
Floor Plan Techniques

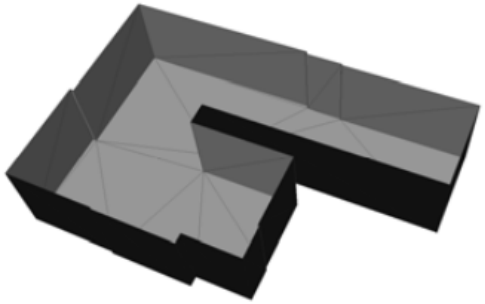
[71] S. Oesau, F. Lagarge, and P. Alliez, "Indoor scene reconstruction using primitive driven space partitioning and graph-cut," Eurographics Workshop on Urban Data Modelling and Visualization, 2013.

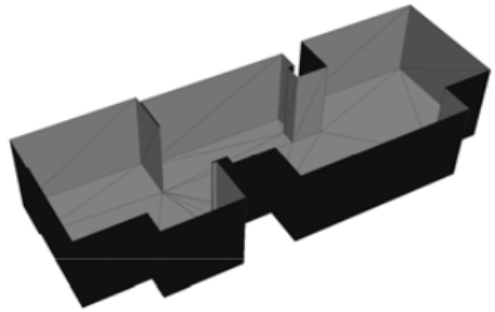
[70] J. Xiao and Y. Furukawa, "Reconstructing the world's museums," EECV 2012 Lectures in Computer Science, vol. 7572, pp. 668–681, 2012

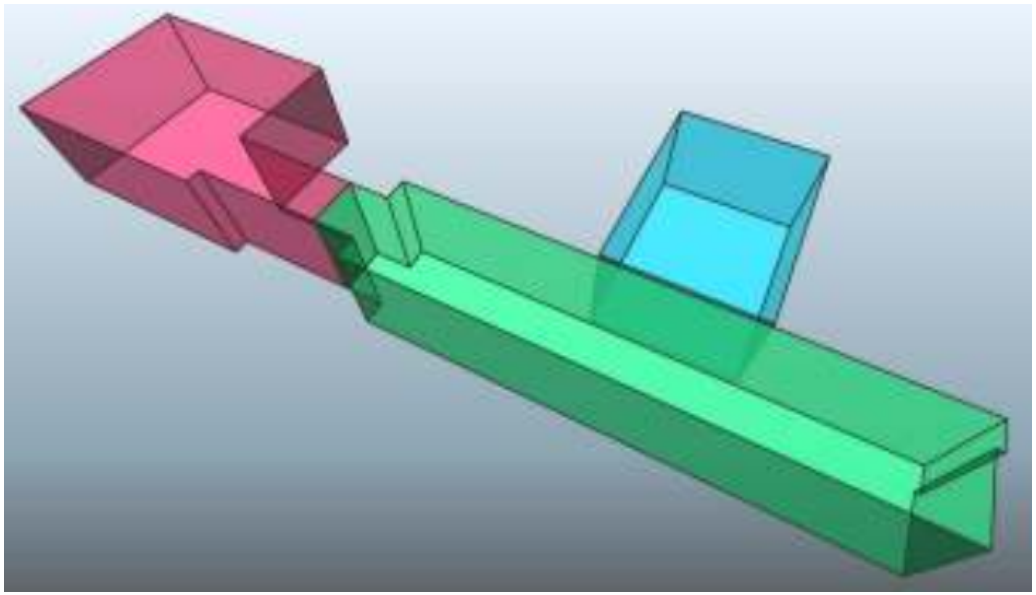
[68] R. Cabral and Y. Furukawa, "Piecewise planar and compact floorplan reconstruction from images," Computer Vision and Pattern Recognition (CVPR), pp. 628–635, 2014.

[67] C. Mura, O. Mattausch, A. J. Villanueva, E. Gobbetti, and R. Pajarola, "Automatic room detection and reconstruction in cluttered indoor environments with complex room layouts," Computers and Graphics, vol. 44, pp. 20–32, November 2014.









Watertight, extruded floor plans

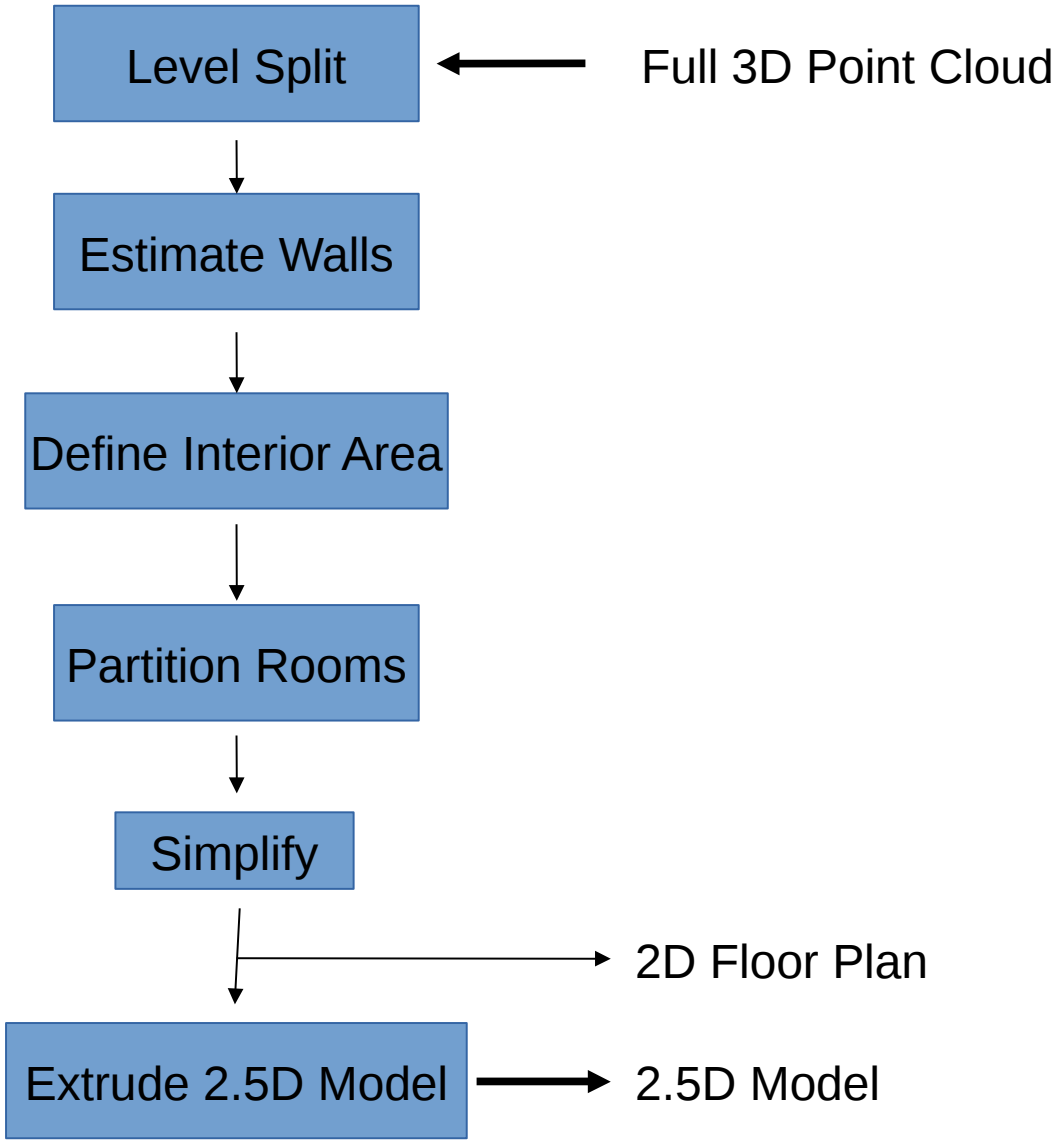
Floor Plan Techniques

Goals:

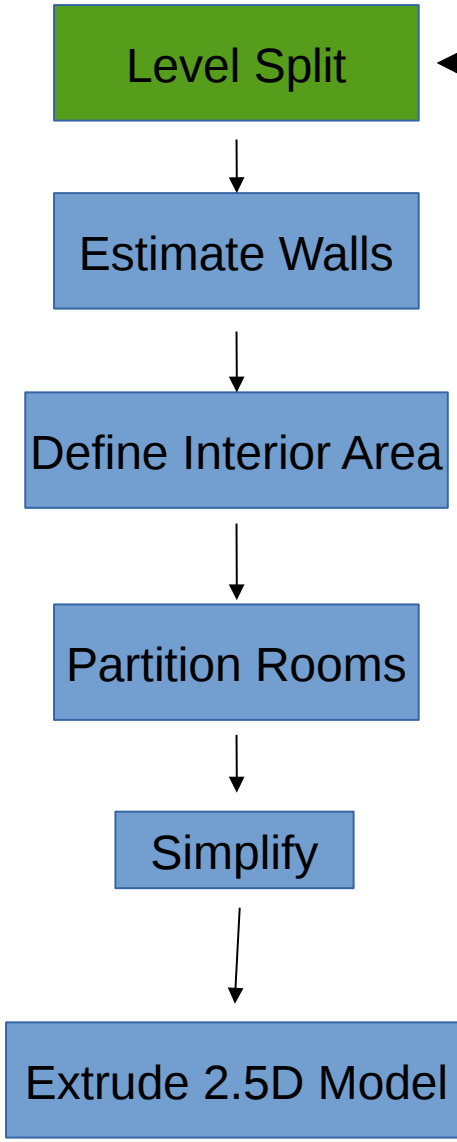
- *Watertight*
- *Simplified*
- *Scalable*
- *Minimal Assumptions*

Our Floor Plan Technique

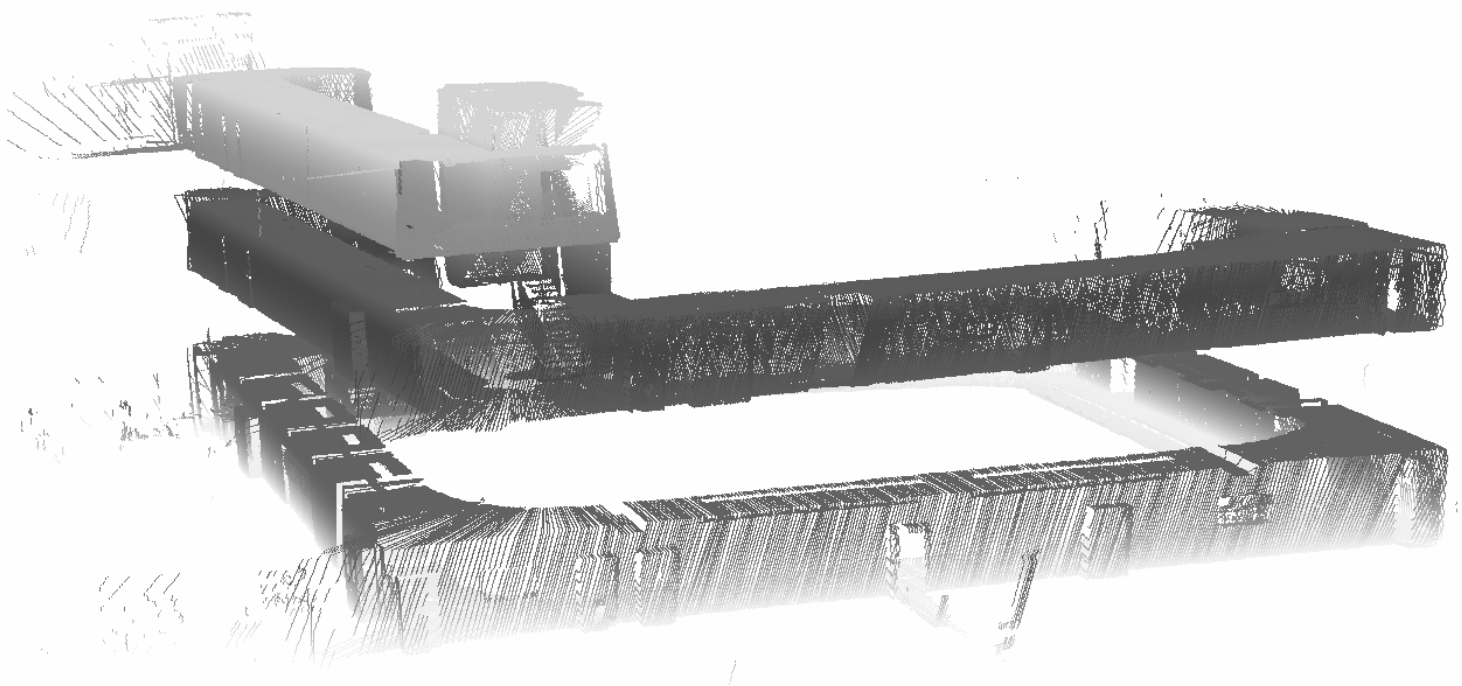
[62] E. Turner and A. Zakhor, "Floor plan generation and room labeling of indoor environments from laser range data," International Conference on Computer Graphics Theory and Applications, no. 9, January 2014.



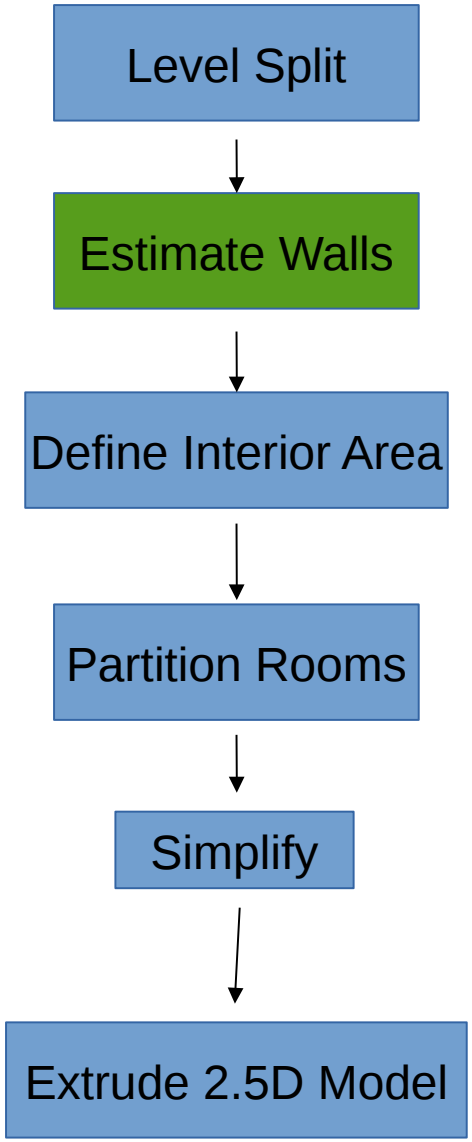
Our Floor Plan Technique

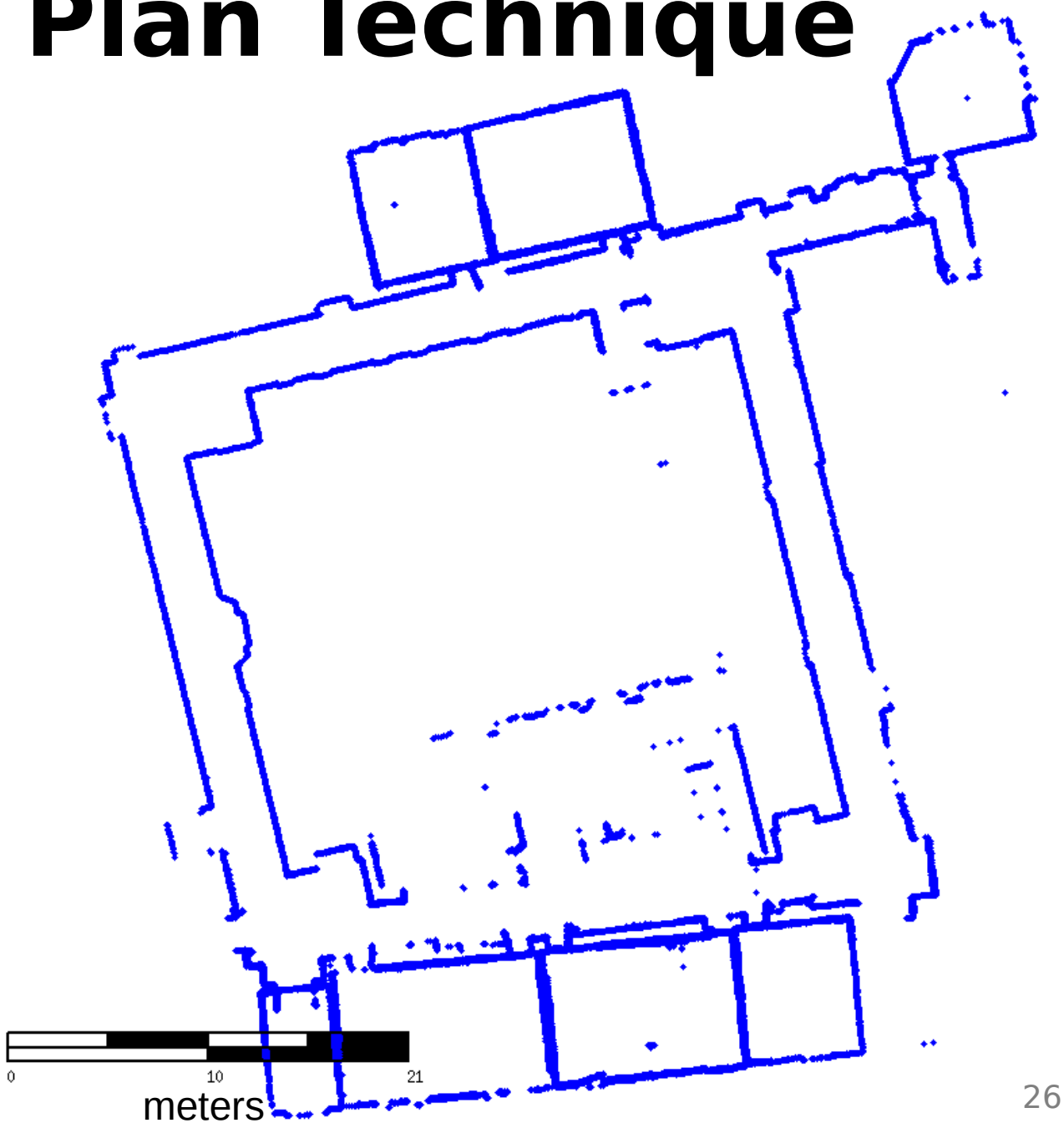


Full 3D Point Cloud

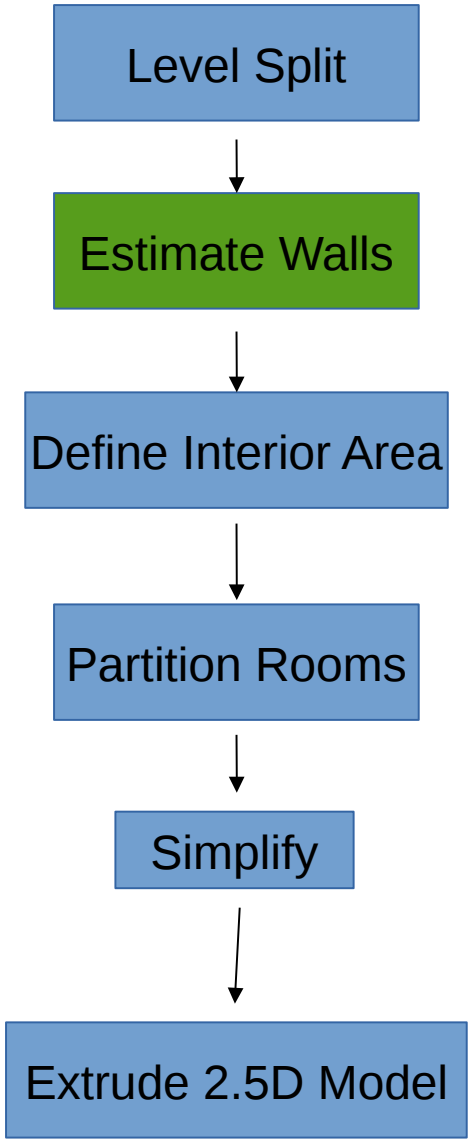


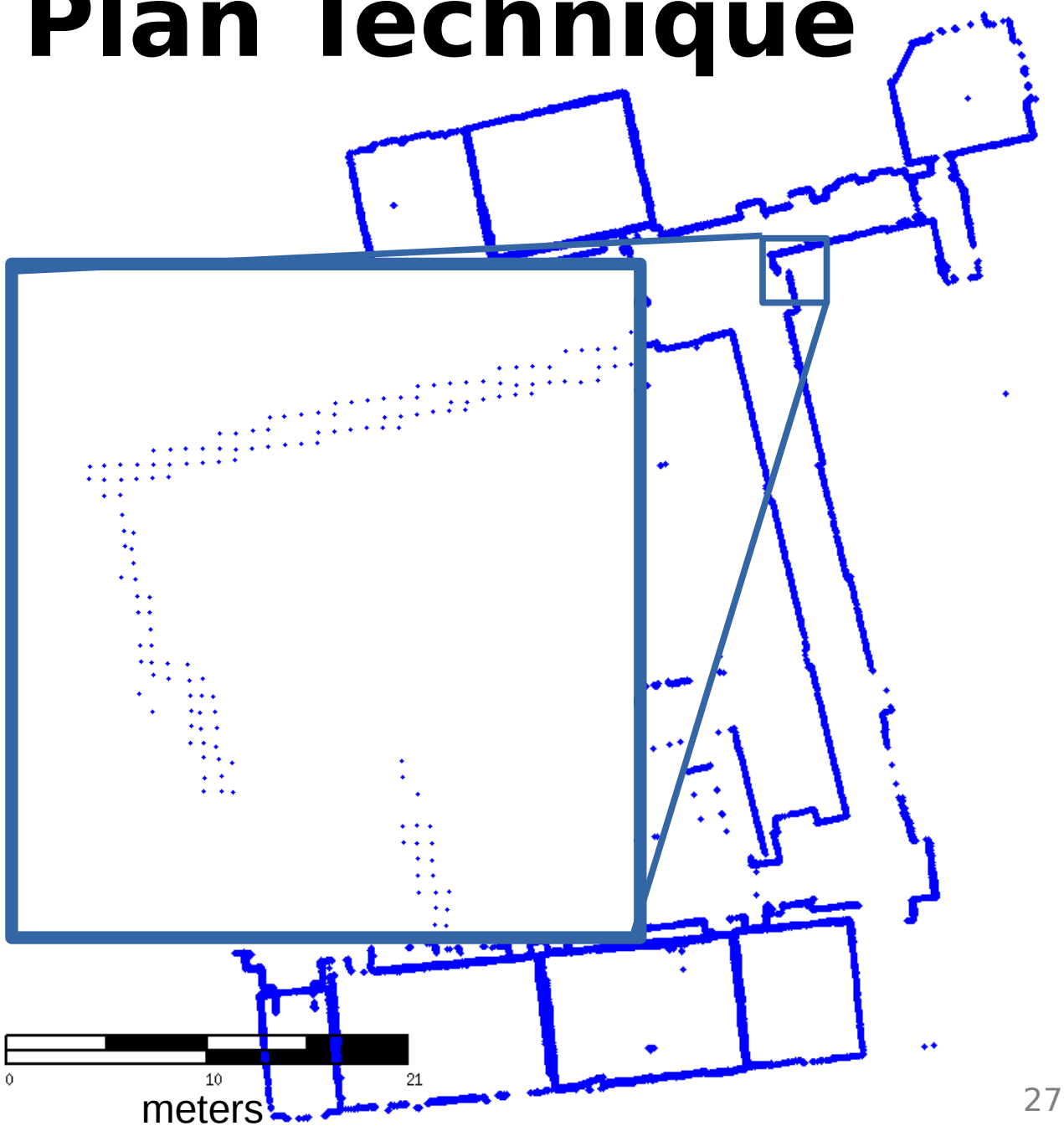
Our Floor Plan Technique



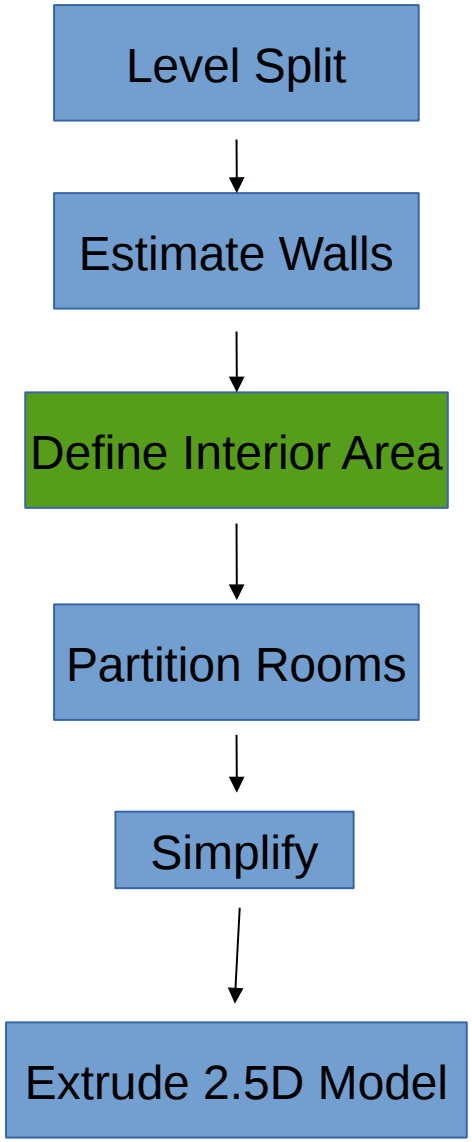


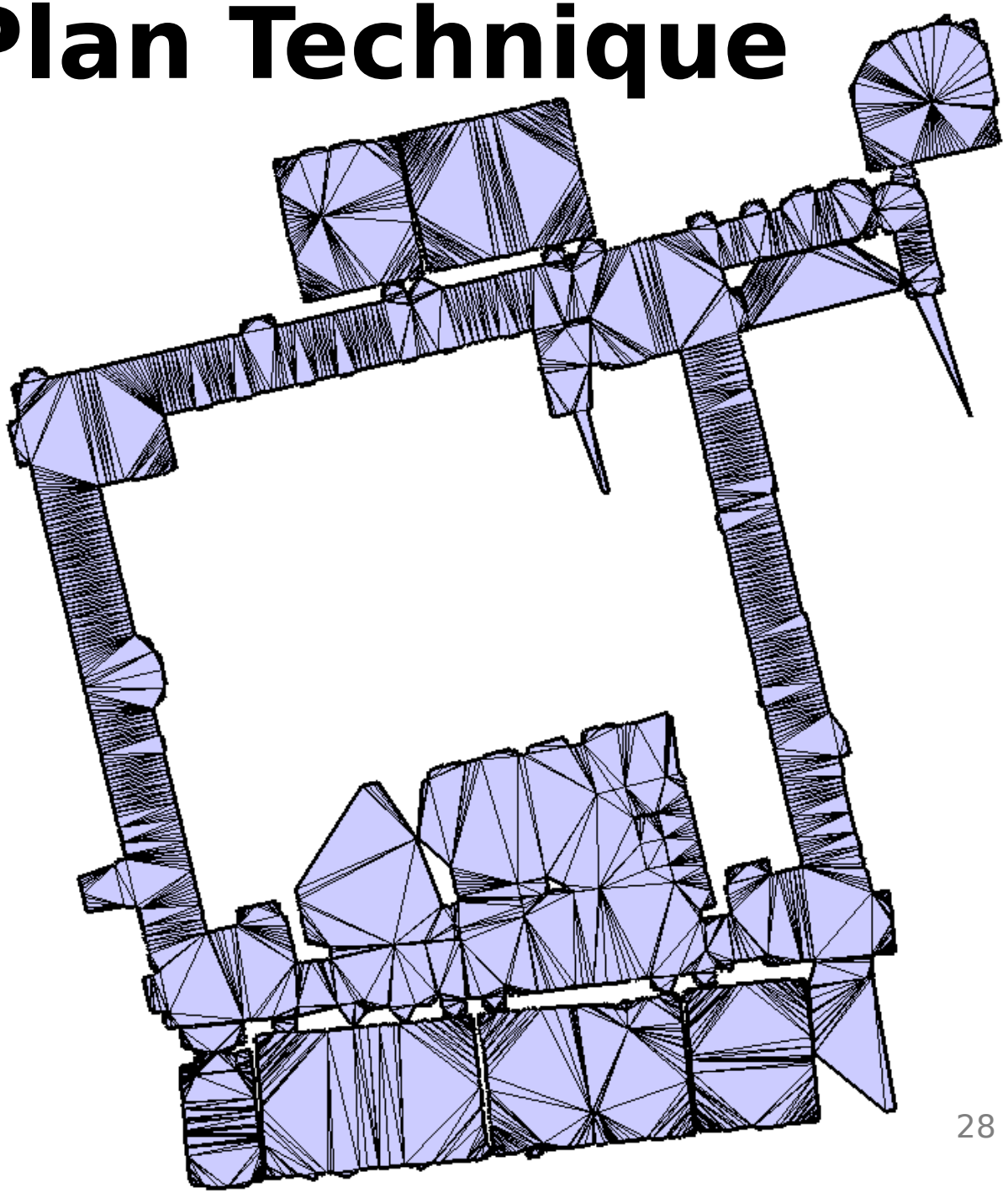
Our Floor Plan Technique





Our Floor Plan Technique





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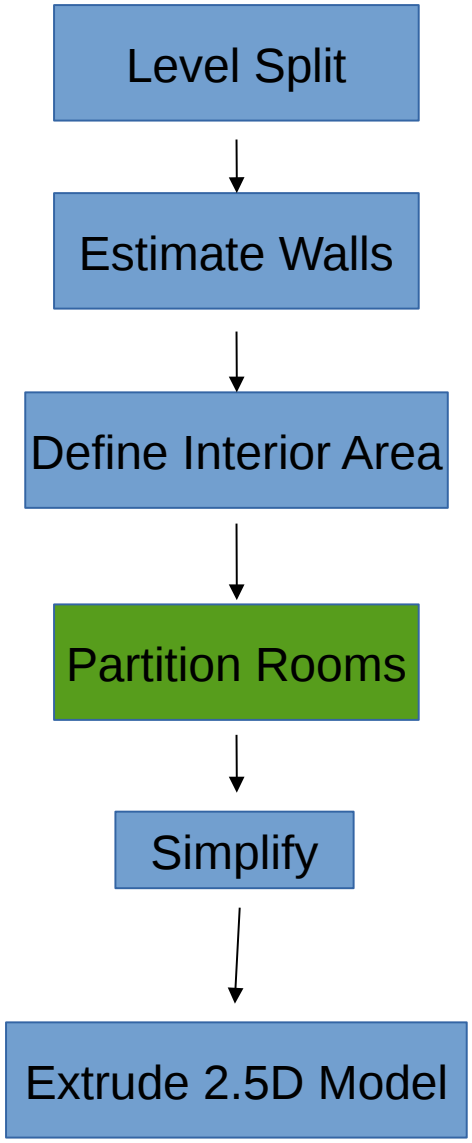

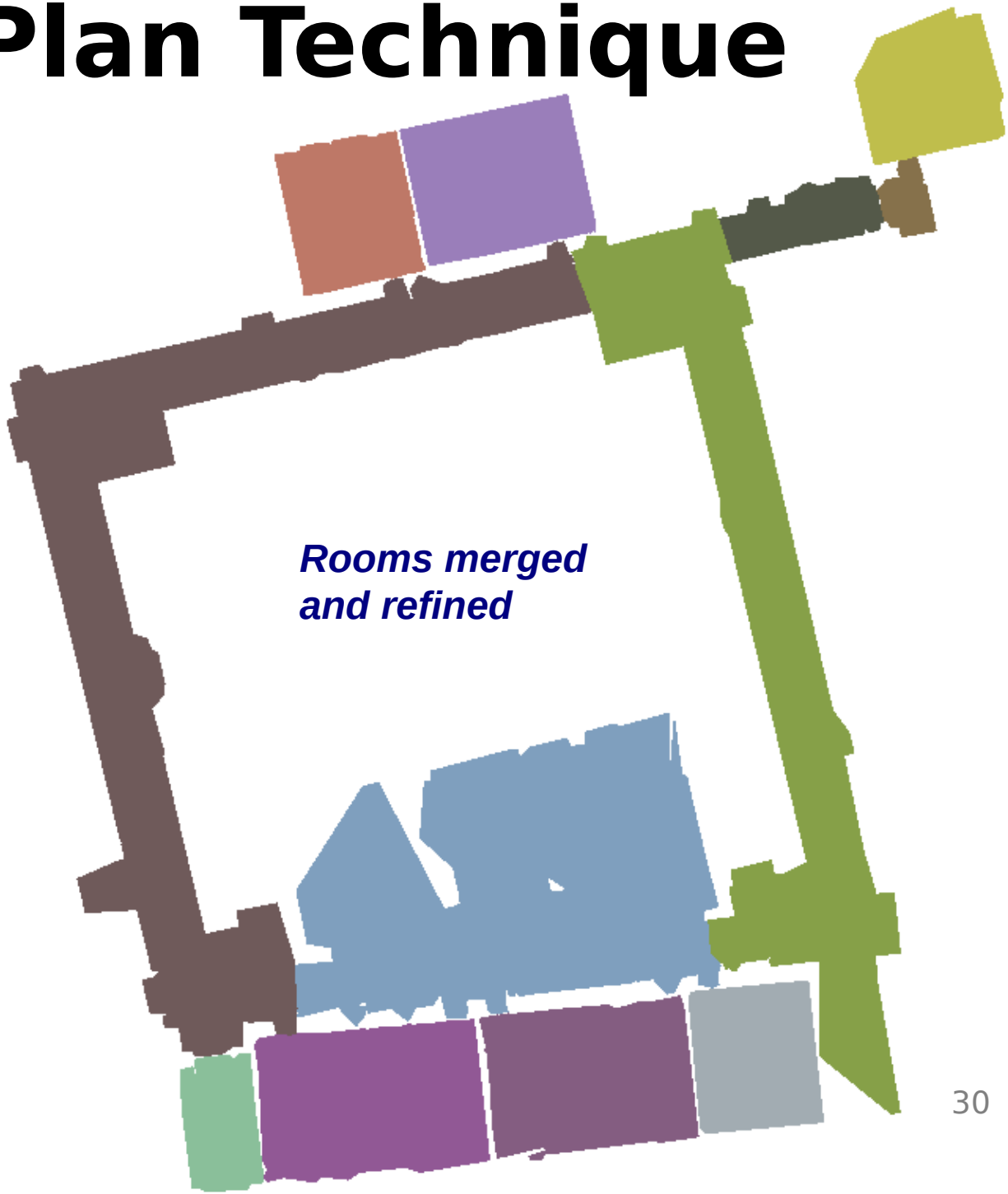

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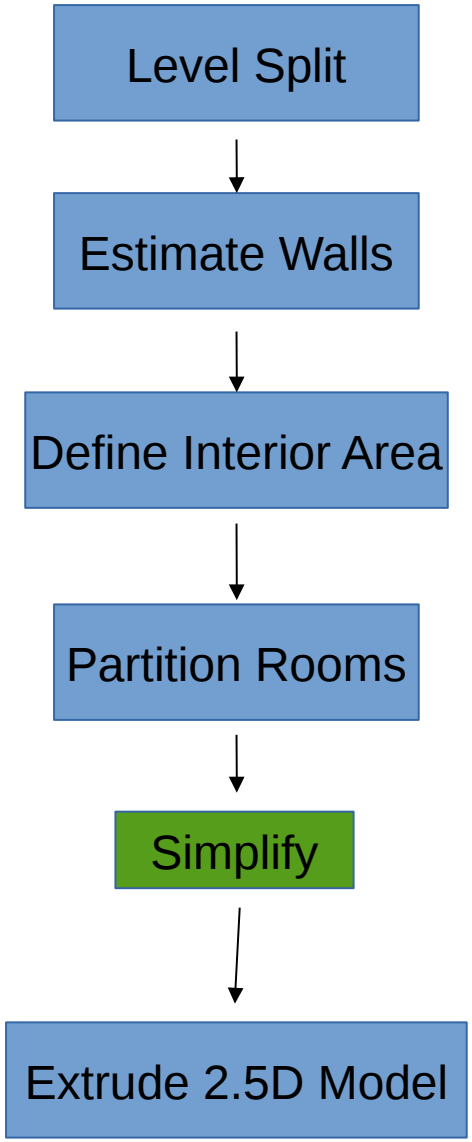
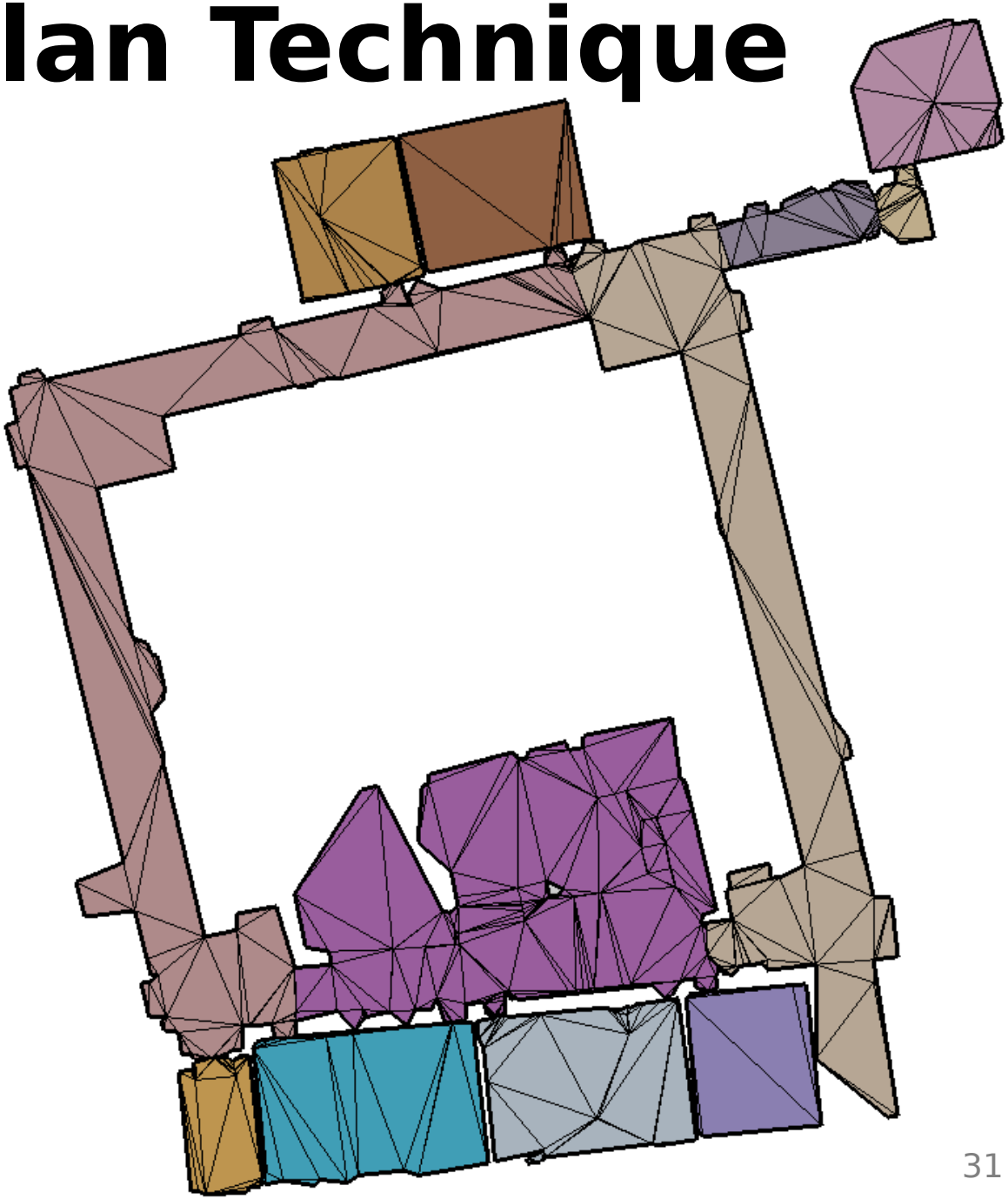
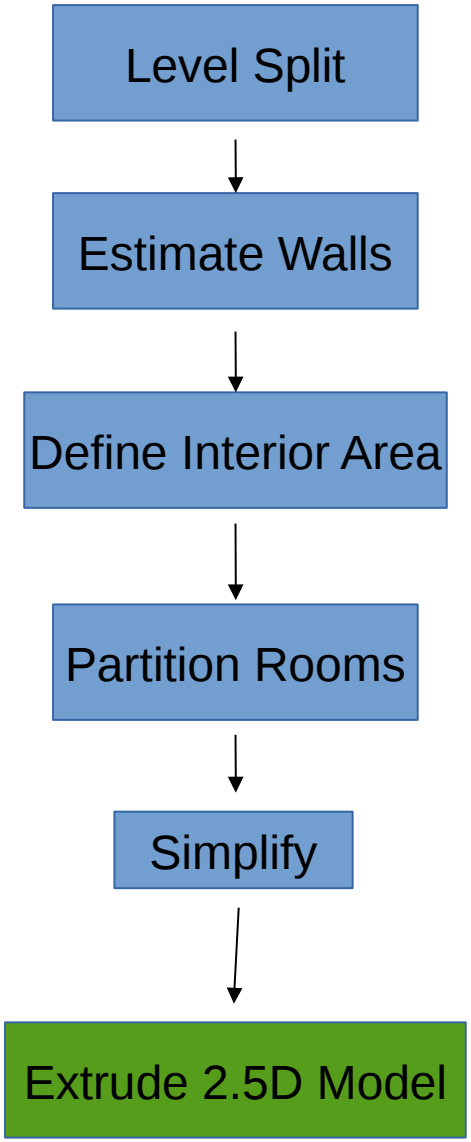
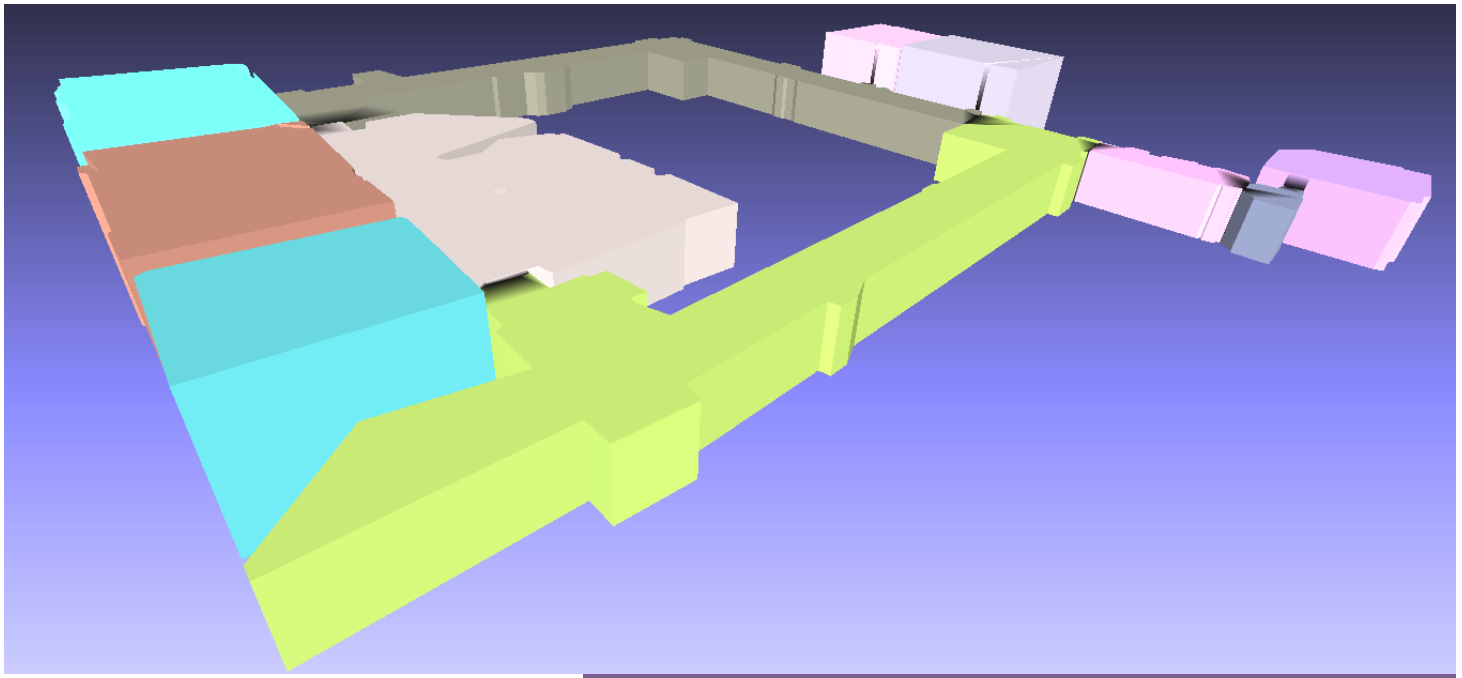


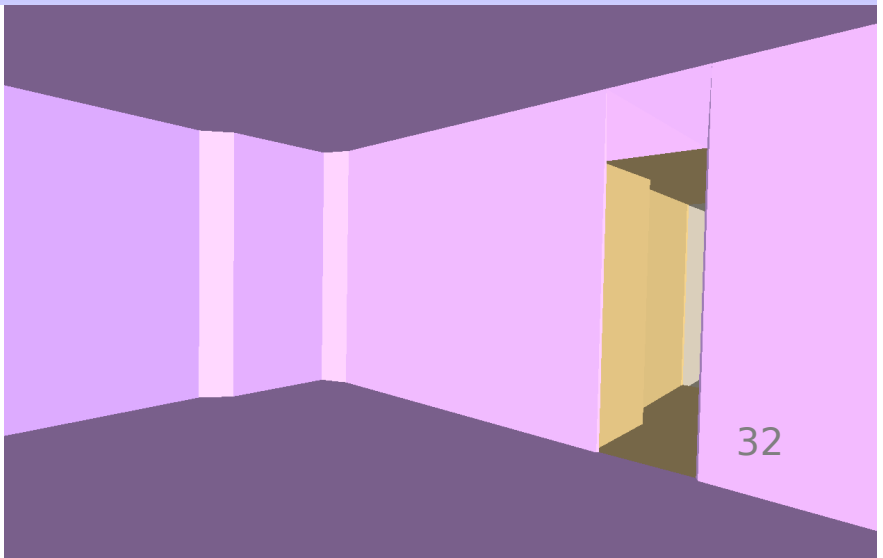


10,037 triangles → 938 triangles

Our Floor Plan Technique

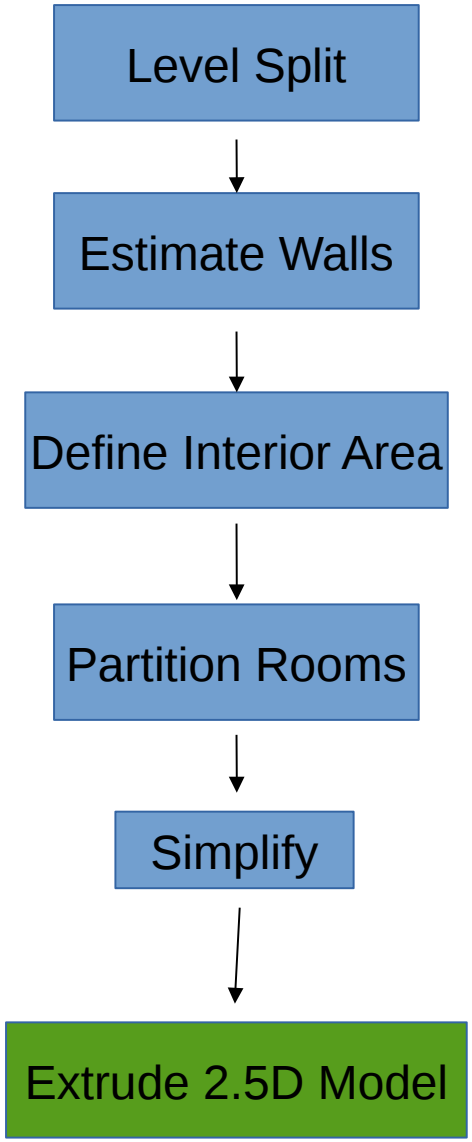


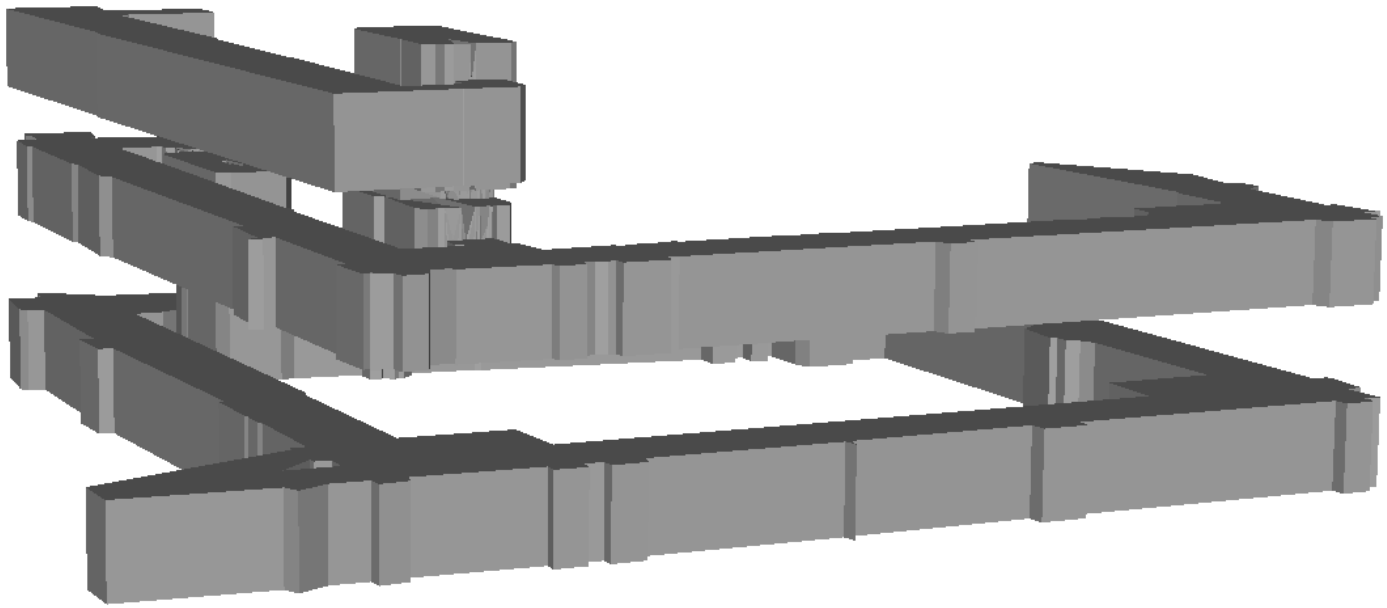




Interior view

Our Floor Plan Technique





Simplified Mesh for All Building Levels

Limitations

Texture-mapped via [91] P. Cheng, M. Anderson, S. He, and A. Zakhor, "Texture mapping 3d planar models of indoor environments with noisy camera poses," SPIE Electronic Imaging Conference, February 2013.

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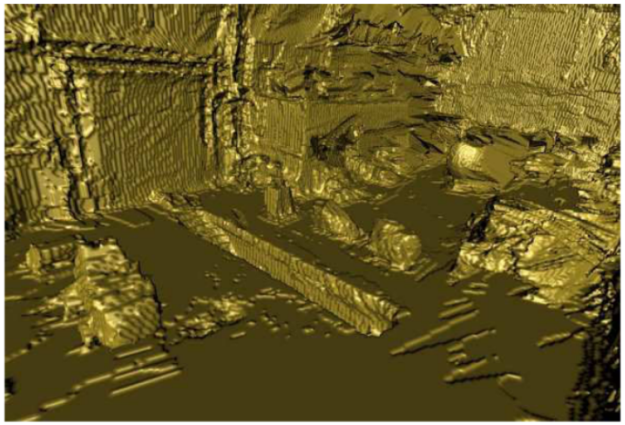
3D Modeling Techniques

[5] C. Holenstein, R. Zlot, and M. Bosse, "Watertight surface reconstruction of caves from 3d laser data," IEEE/RSJ International Conference on Intelligent Robots and Systems, September 2011.

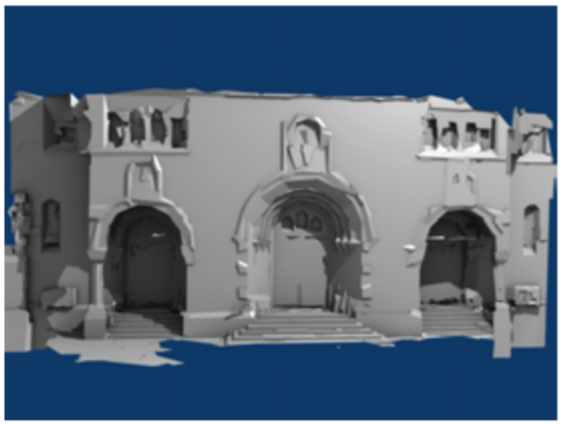


(c) Industrial building

(d) Photo of the same area

[45] S. A. A. Shukor, K. W. Young, and E. J. Rushforth, "3d modeling of indoor surfaces with occlusion and clutter," International Conference on Mechatronics, pp. 282–287, April 2011

[36] A. Chauve, P. Labatut, and J. Pons, "Robust piecewise-planar 3d reconstruction and completion from large-scale unstructured point data," CVPR, 2010.



3D Modeling Techniques

[76] R. Newcombe, A. Davison, S. Izadi, P. Kohli, O. Hilliges, J. Shotton, D. Molyneaux, S. Hodges, D. Kim, and A. Fitzgibbon, "Kinectfusion: Real-time dense surface mapping and tracking," Mixed and Augmented Reality (ISMAR), pp. 127–136, 2011.

[77] M. Kaess, M. Fallon, H. Johannsson, and J. J. Leonard, "Kintinuous: Spatially extended kinectfusion," CSAIL Technical Reports, July 2012.

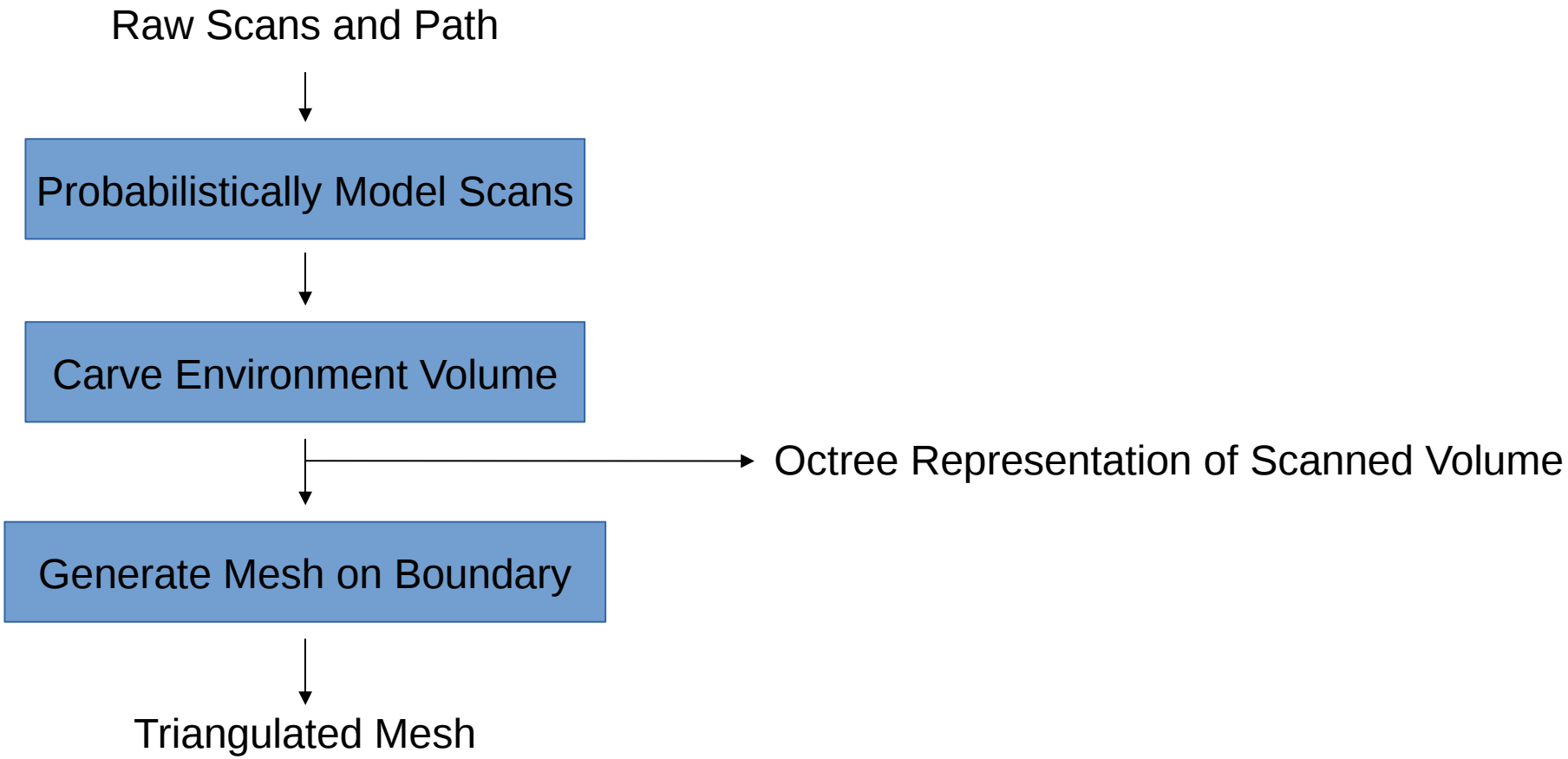
Image taken from:

[74] A. Karpathy, S. Miller, and L. Fei-Fei, "Object discovery in 3d scenes via shape analysis," IEEE International Conference on Robotics and Automation, pp. 2088–2095, May 2013.

Our 3D Carving Modeling

[92] E. Turner and A. Zakhor, "Watertight planar surface meshing of indoor point-clouds with voxel carving," 3DV, June 2013.

E. Turner and A. Zakhor, "Automatic Indoor 3D Surface Reconstruction with Segmented Building and Object Elements", to be submitted to 3DV 2015, October 2015



Scan Carving

Raw Scans and Path

↓

Probabilistically Model Scans

↓

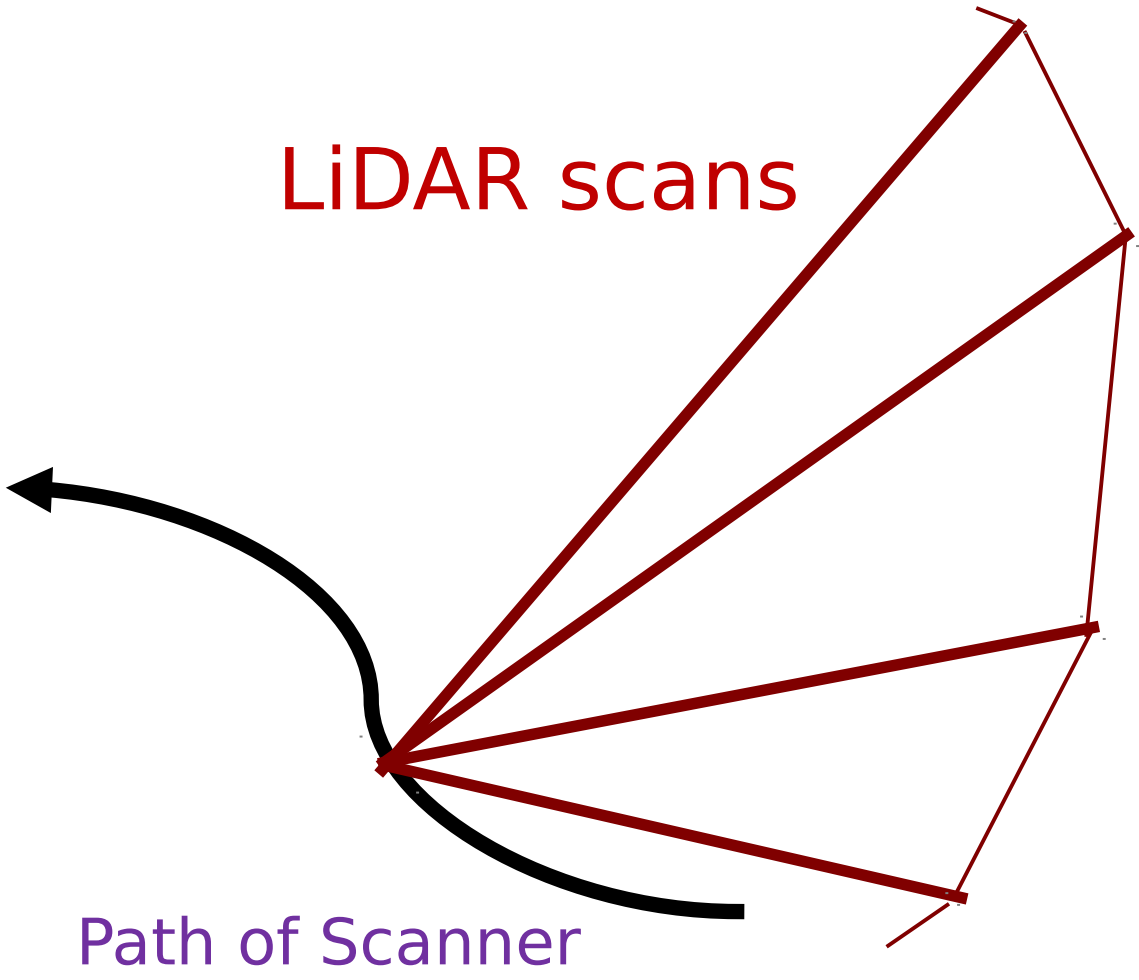
Carve Environment Volume

↓

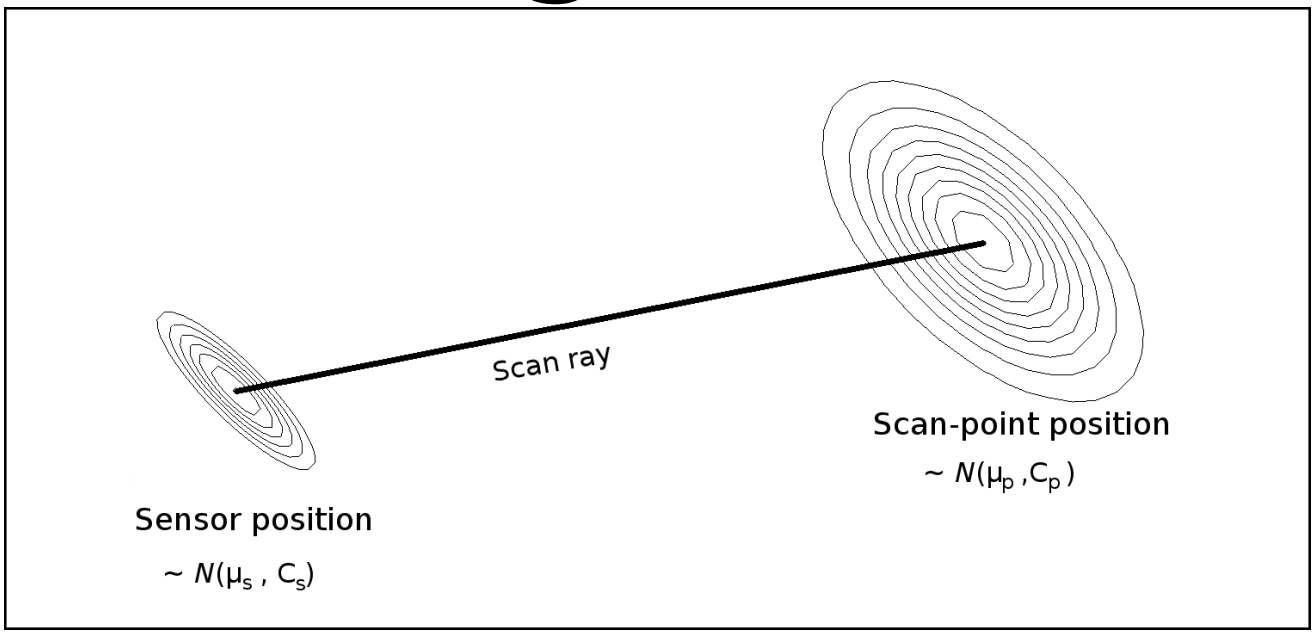
Generate Mesh on Boundary

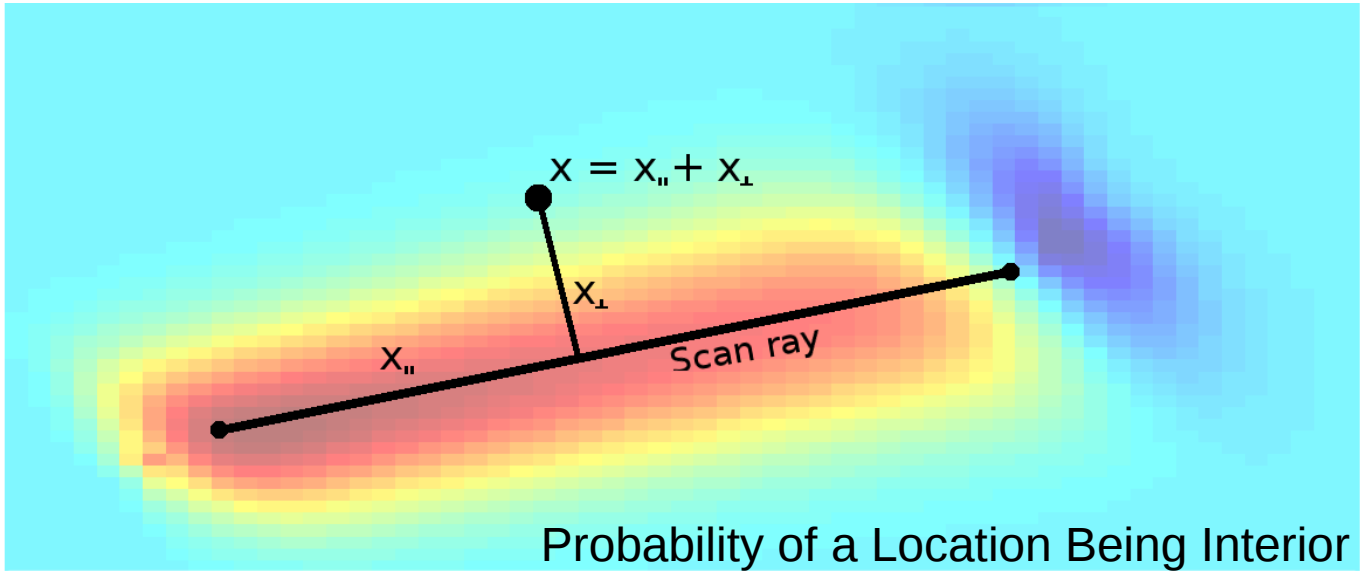
↓

Triangulated Mesh



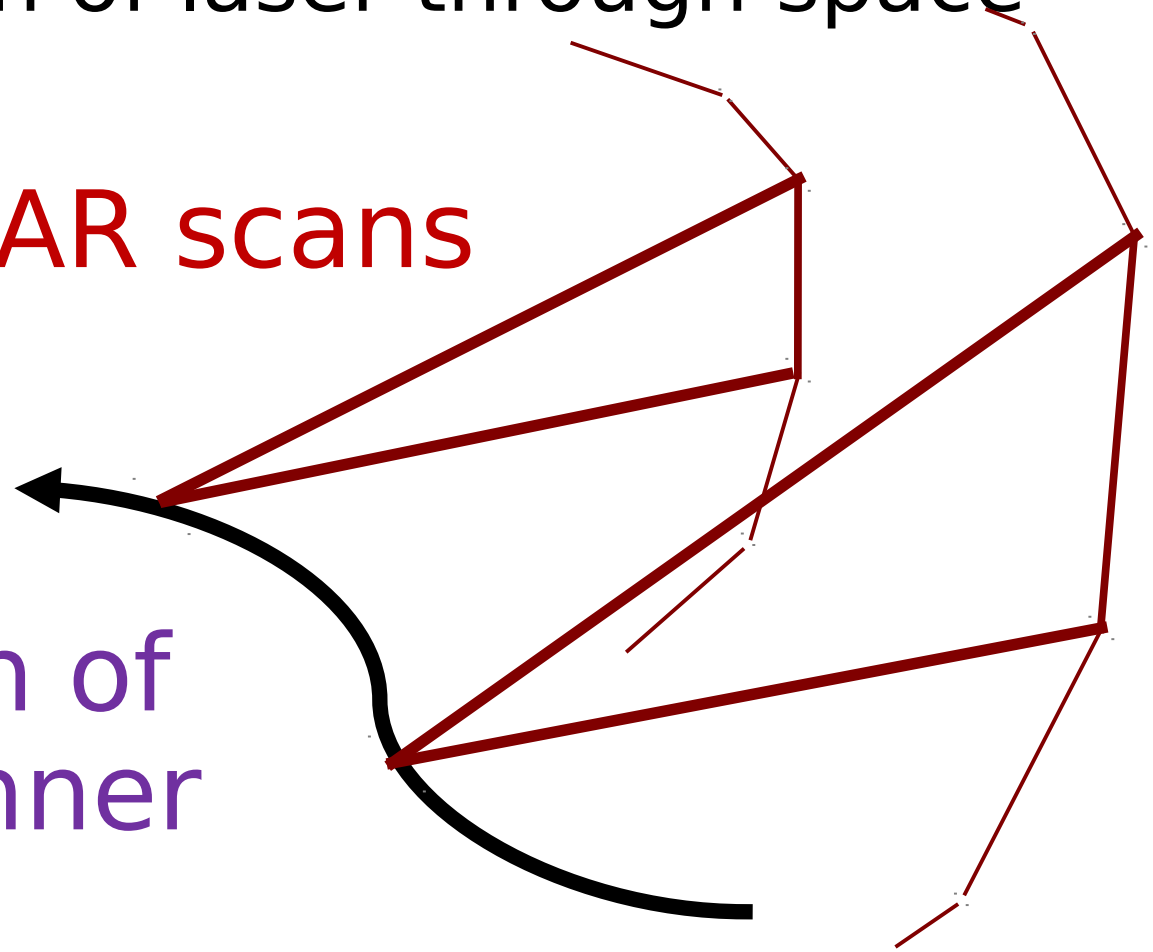
Scan Carving





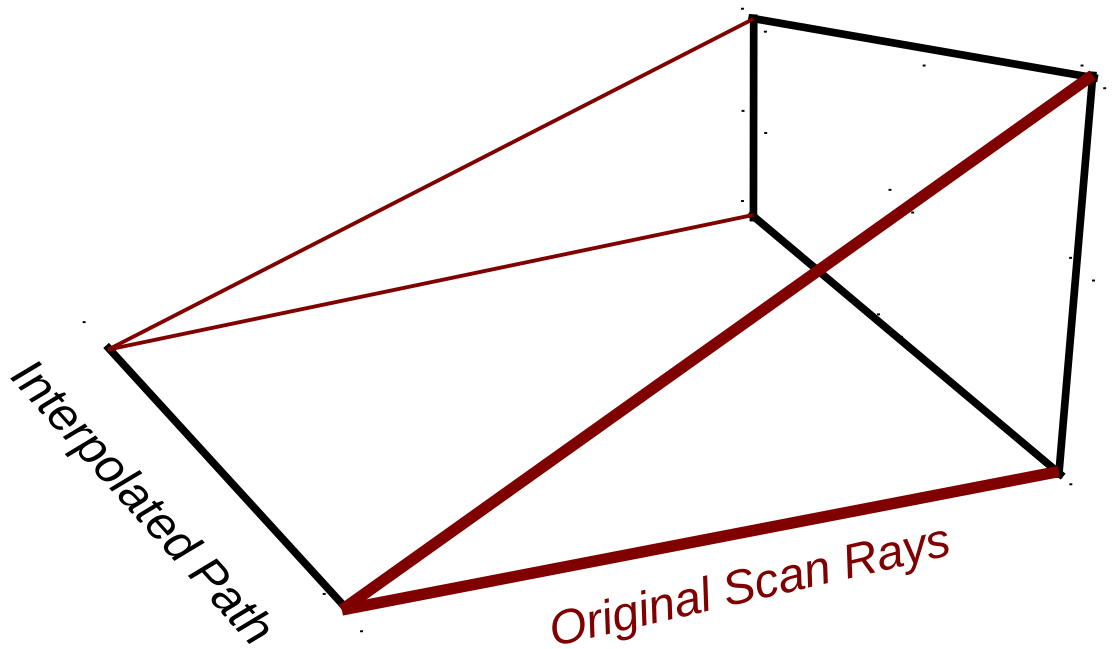
Scan Carving

- Trace path of laser through space



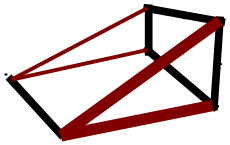
Scan Carving

- Perform carving with “wedges”



Our 3D Carving Modeling

Raw Scans and Path



Probabilistically Model Scans

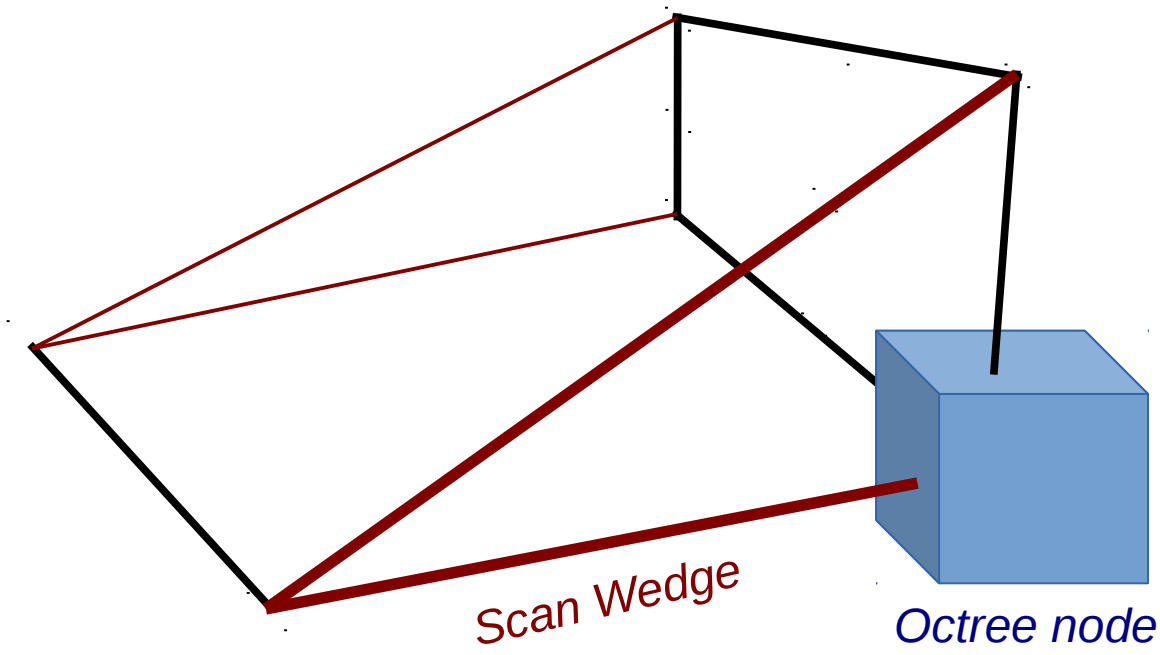
Carve Environment Volume

Generate Mesh on Boundary

Triangulated Mesh

Scan Carving

- Intersect against octree nodes

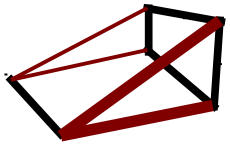


Generated Octree Boundary

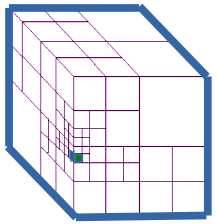
Reference Photo

Our 3D Carving Modeling

Raw Scans and Path



Probabilistically Model Scans

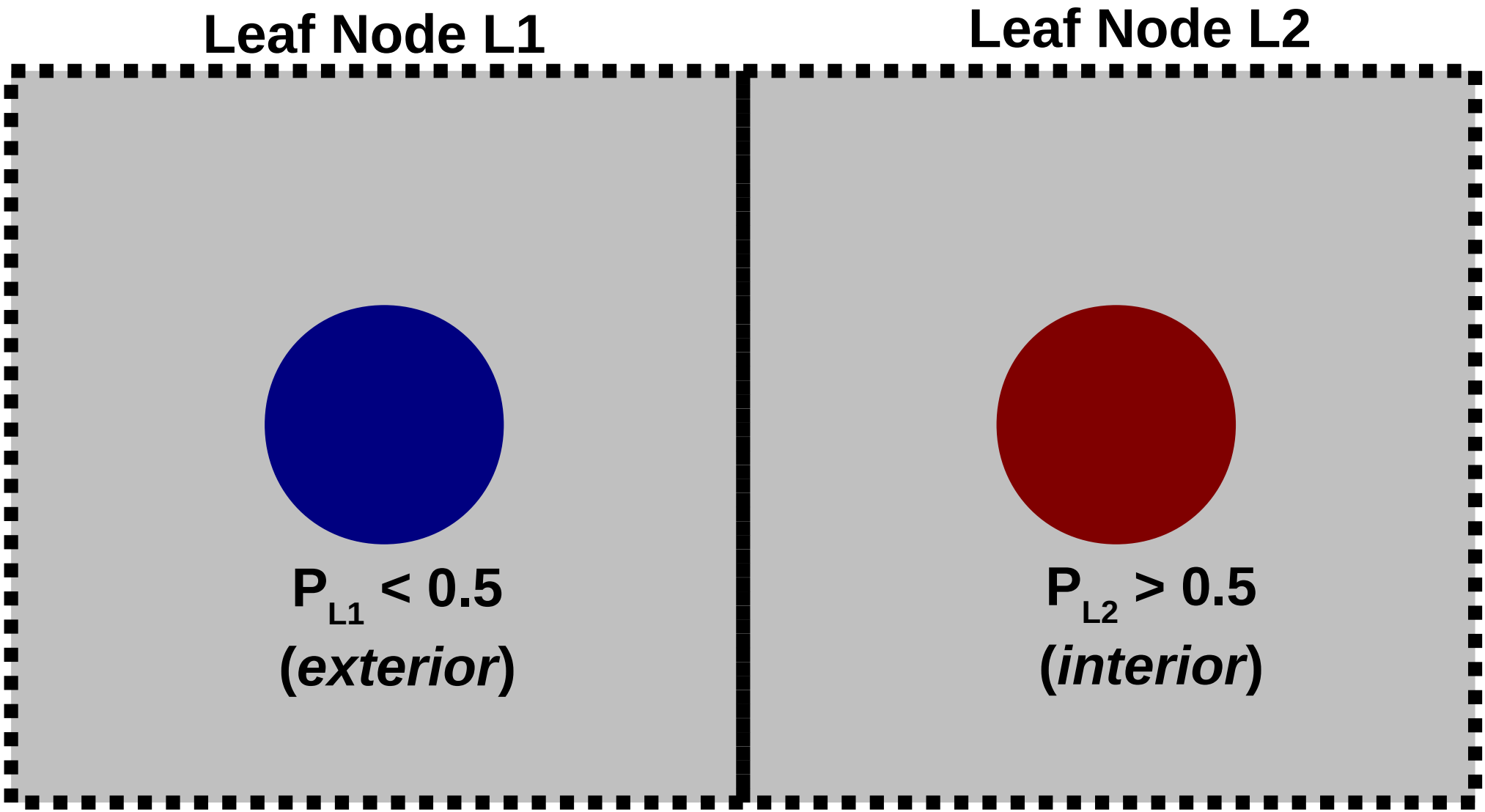


Carve Environment Volume

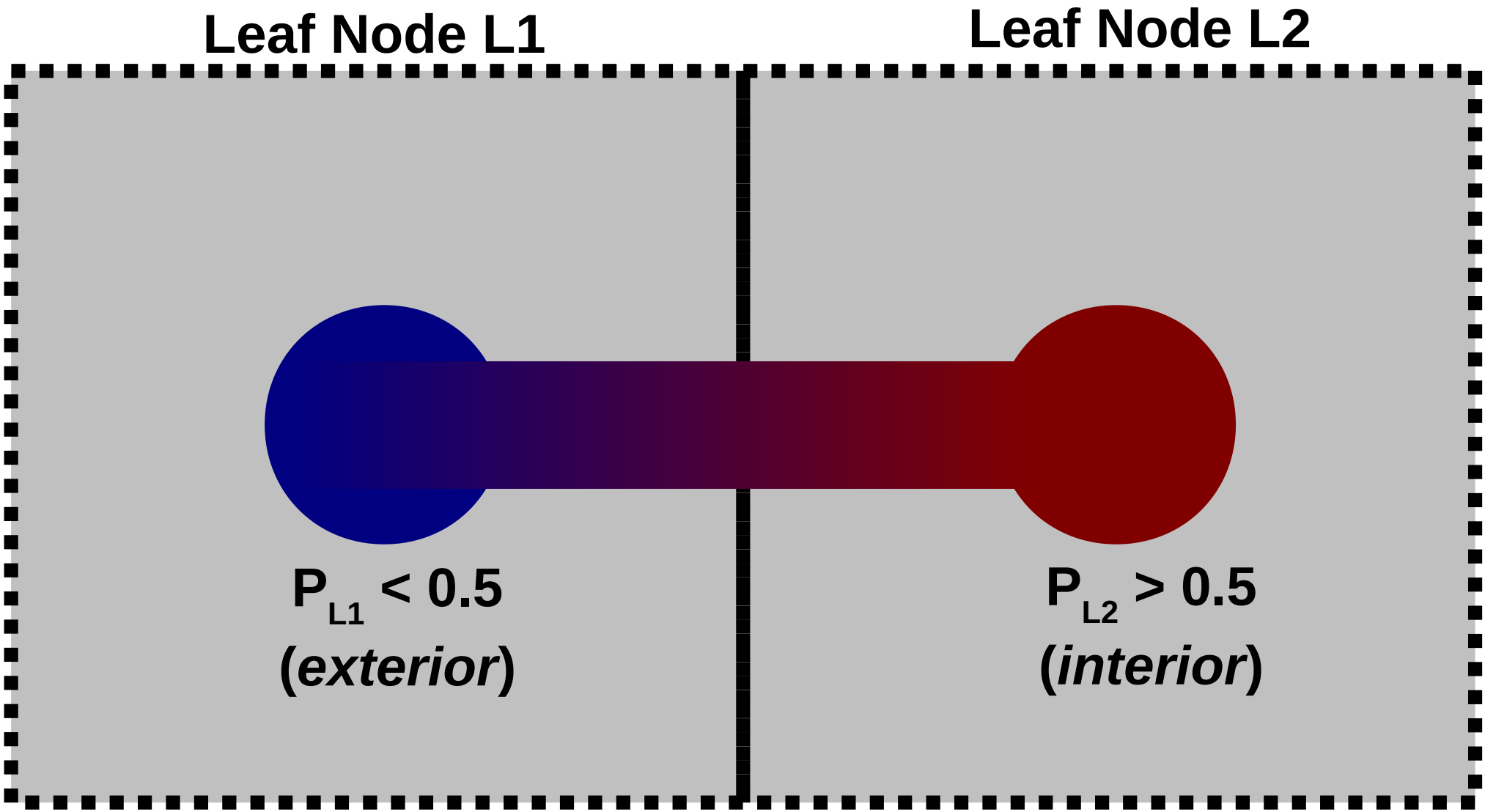
Generate Mesh on Boundary

Triangulated Mesh

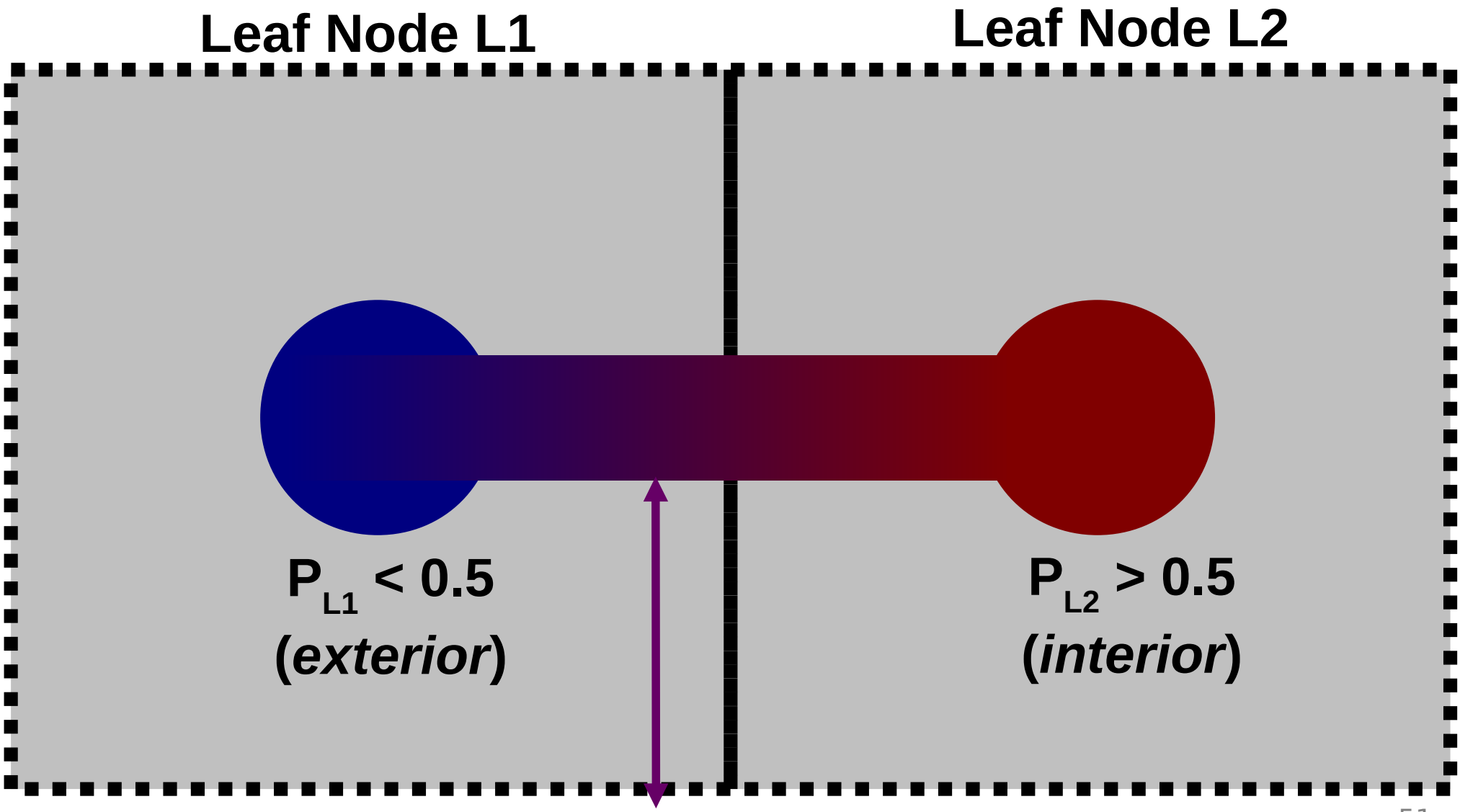
Refining Octree Boundary



Refining Octree Boundary

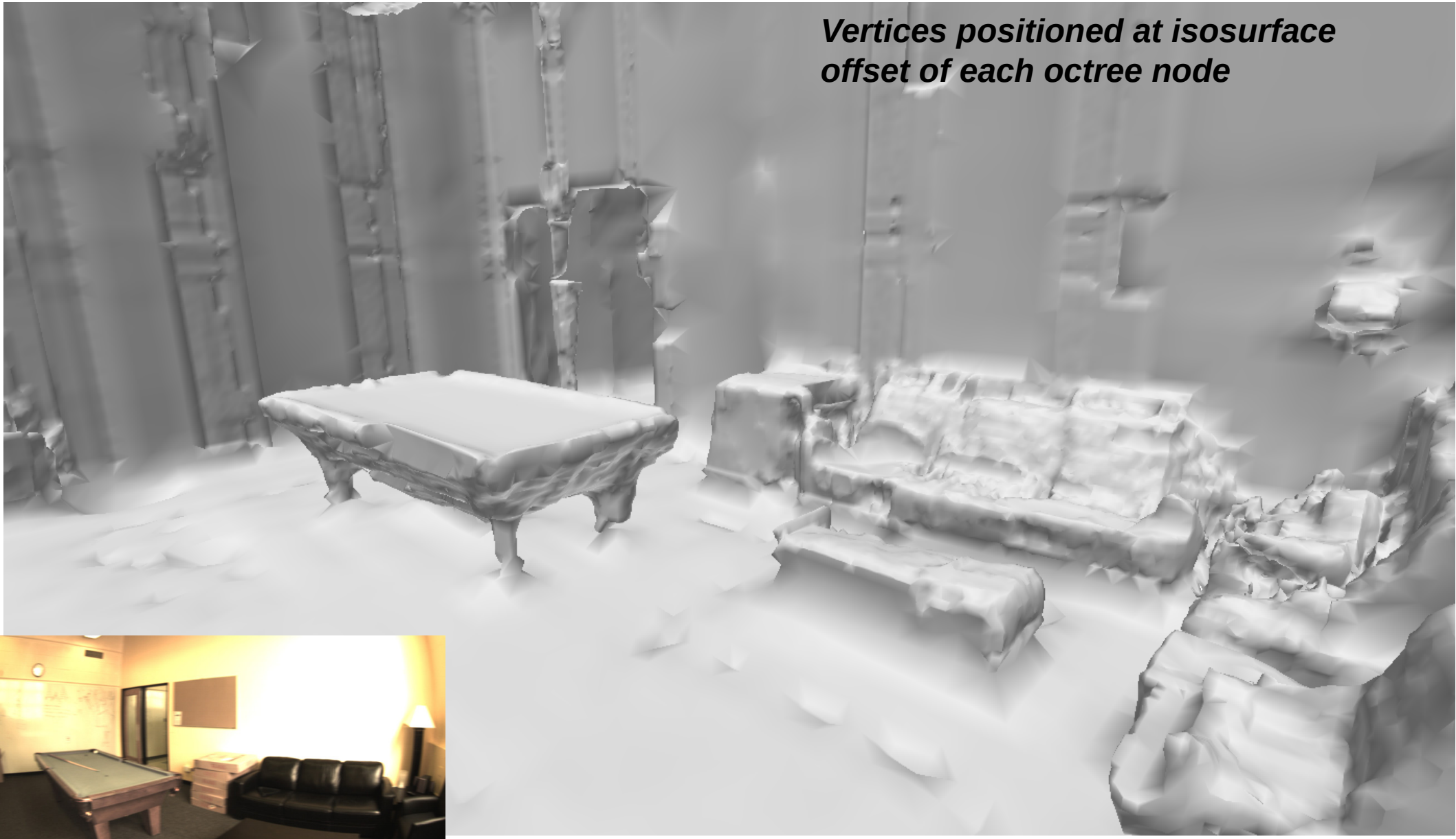


Refining Octree Boundary



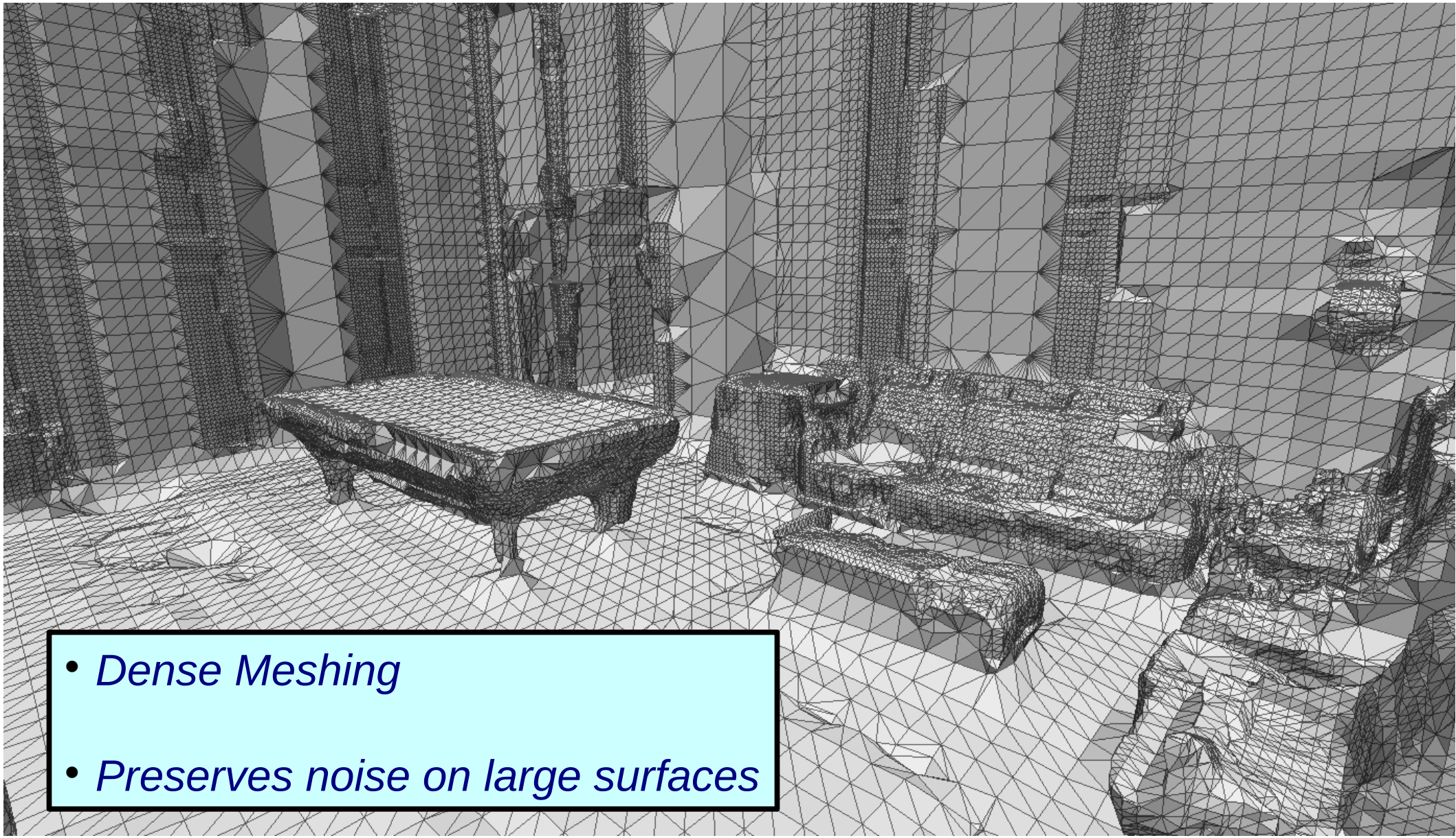
Interpolated $P_{avg} = 0.5$ isosurface

Meshed With Dual Contouring Variant



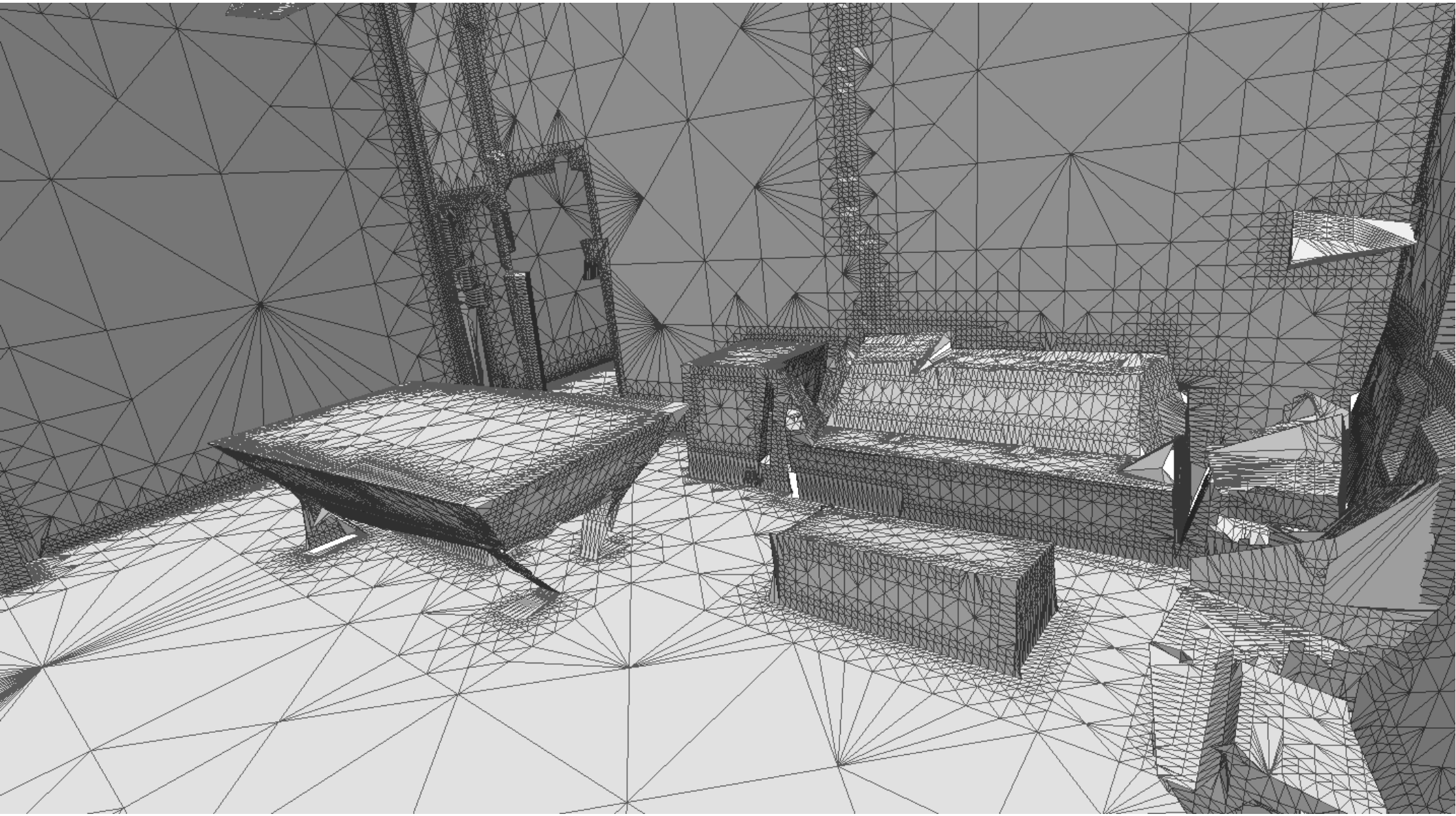
Reference Photo

Meshed With Dual Contouring Variant

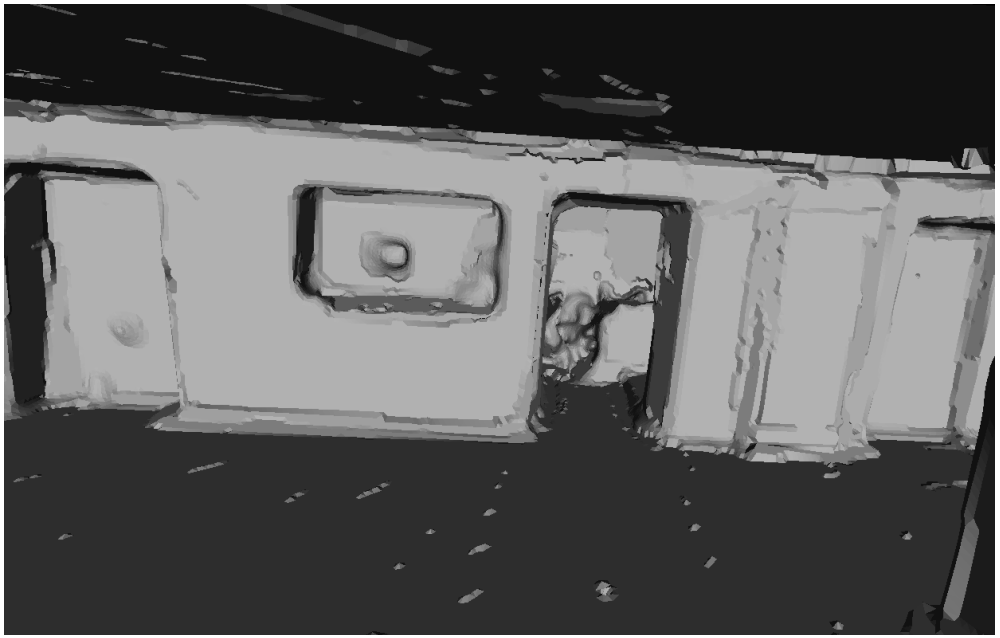


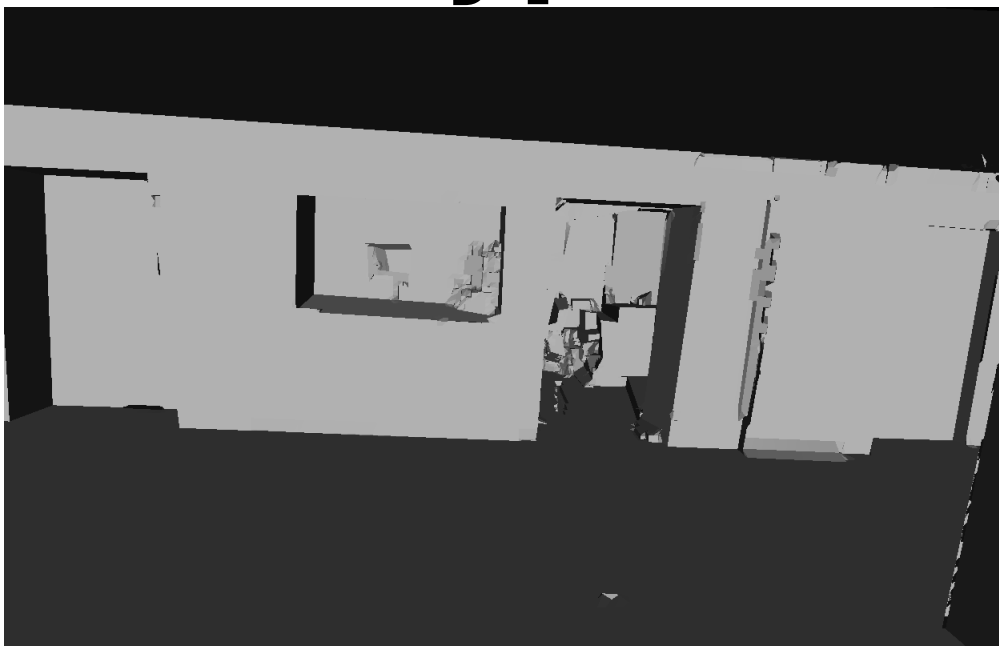
- *Dense Meshing*
- *Preserves noise on large surfaces*

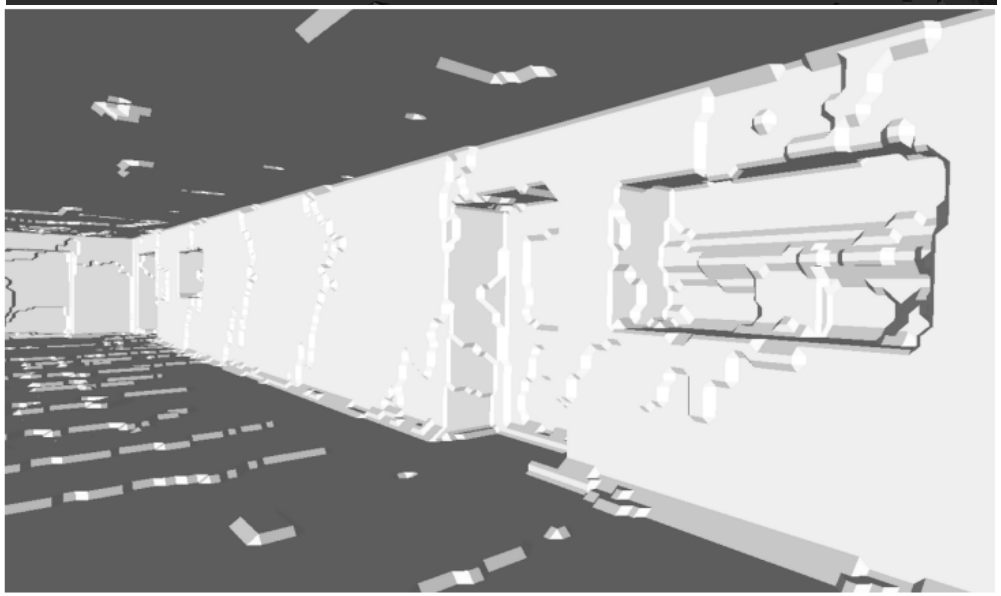
Meshed With Planar Region Fitting

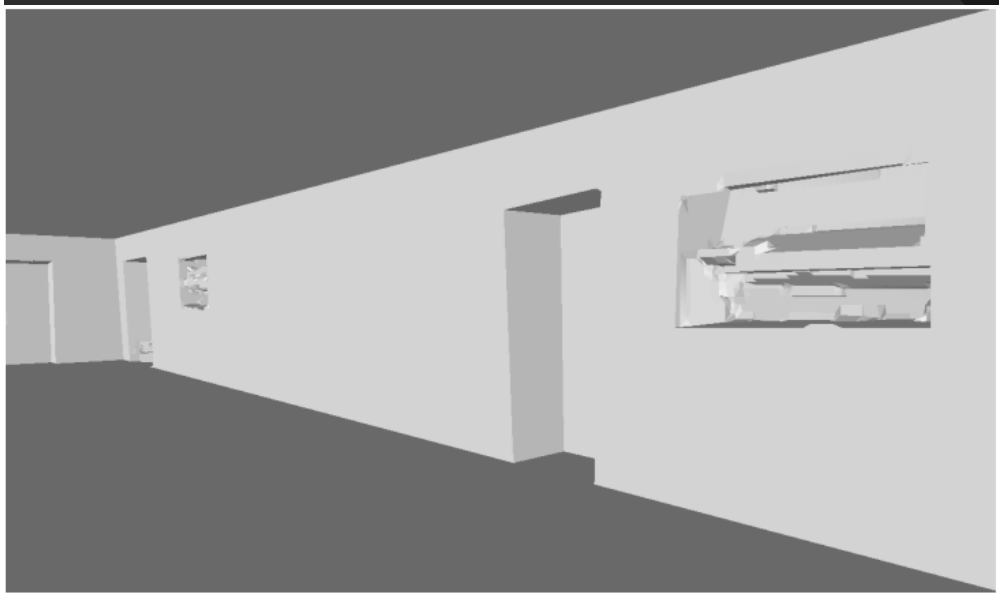


Comparison of Mesh Types



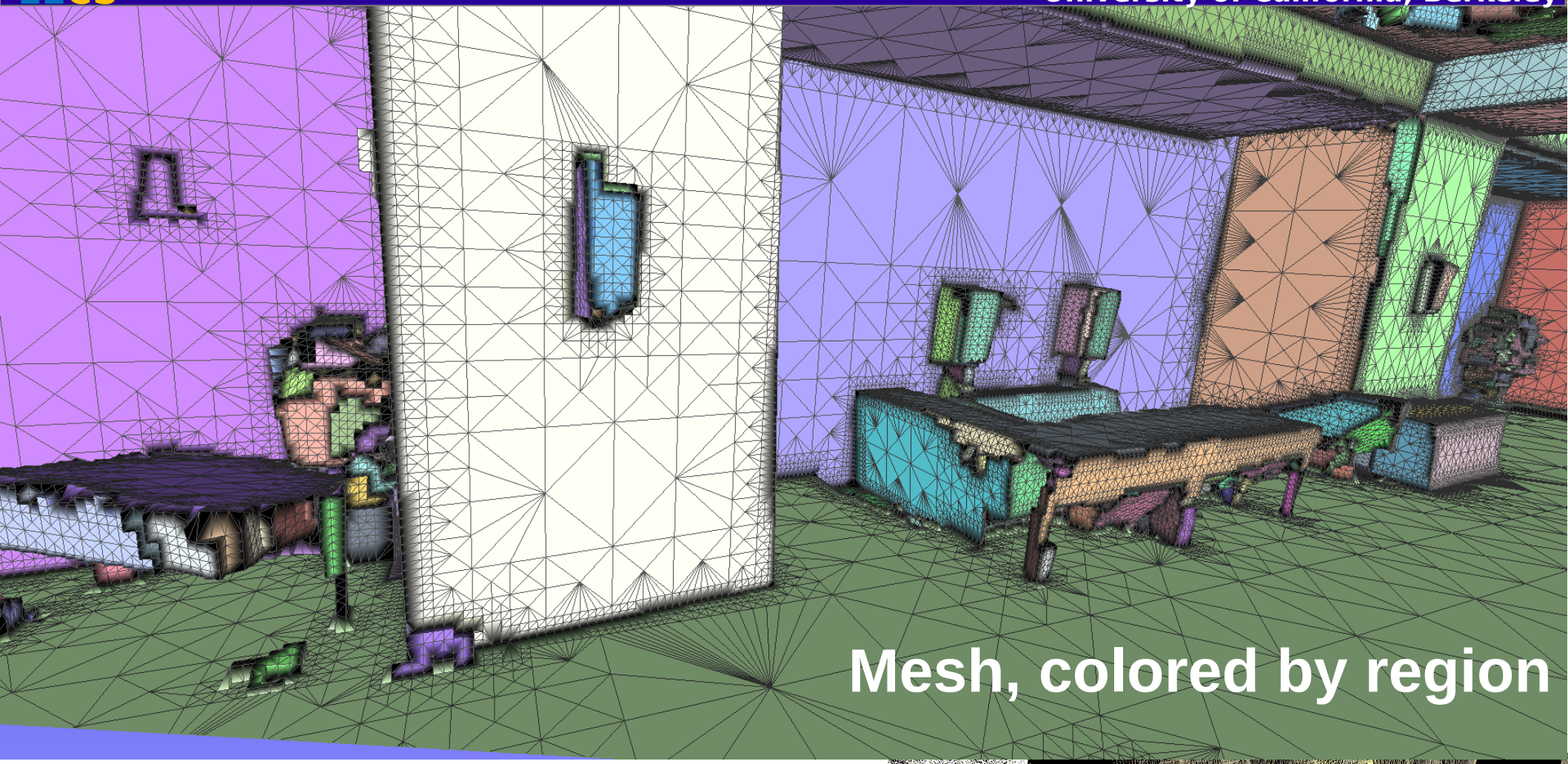






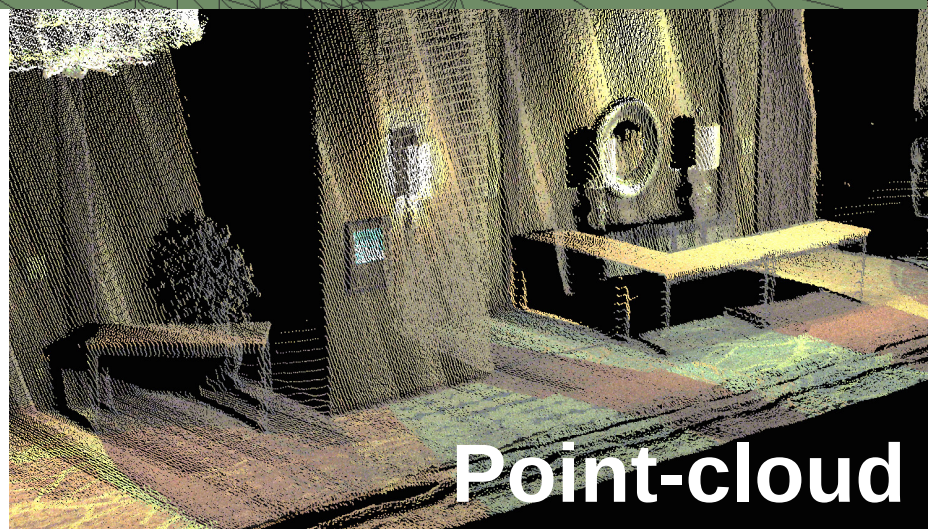
Dense Meshing

Planar Regions



Close up of hotel hallway

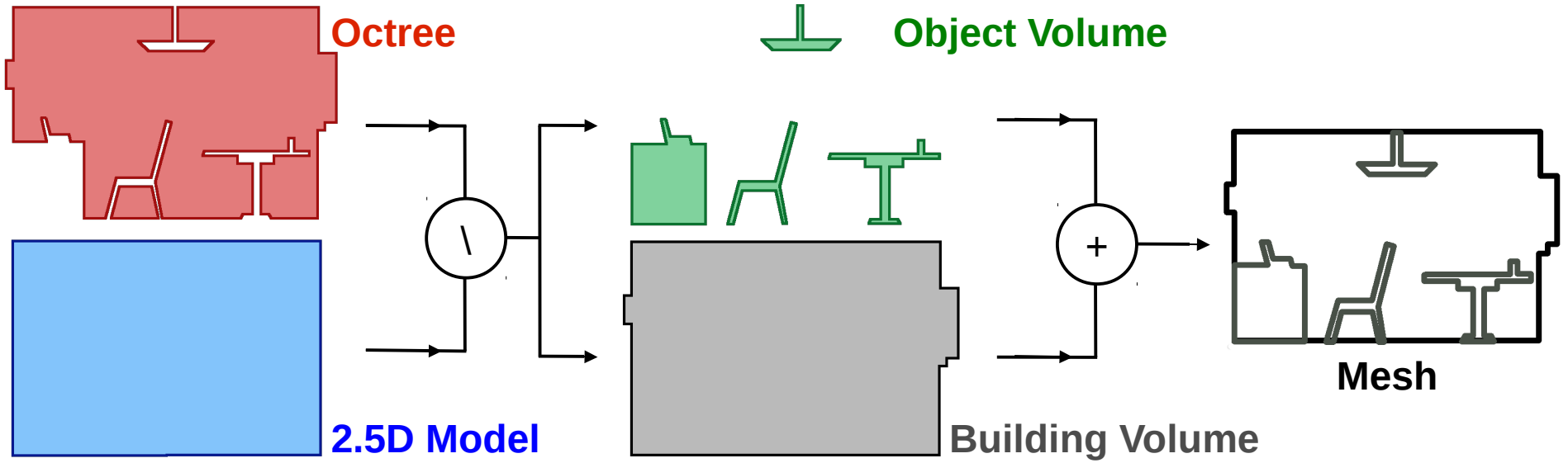
Viewing triangulation and planar regions



Outline

- Motivation
- Hardware and Preprocessing
- Modeling Techniques
  - 2D Floor Plans
  - 2.5D Simplified Models
  - 3D Complex Models
- **Combining Modeling Techniques**

Combining Modeling Types



Prior Furniture Segmentation Techniques

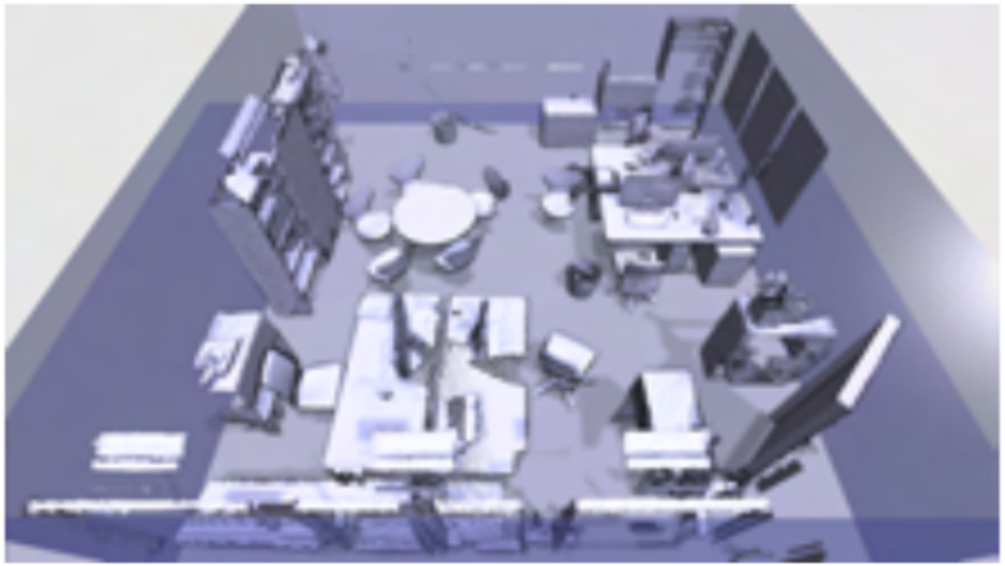
[72] L. Nan, K. Xie, and A. Sharf, "A search-classify approach for cluttered indoor scene understanding," ACM Transactions on Graphics - Proceedings of ACM SIGGRAPH Asia, vol. 31, no. 137, November 2012.

[73] Y. M. Kim, N. J. Mitra, D.-M. Yan, and L. Guibas, "Acquiring 3d indoor environments with variability and repetition," ACM Transactions on Graphics, vol. 31, no. 6, November 2012.

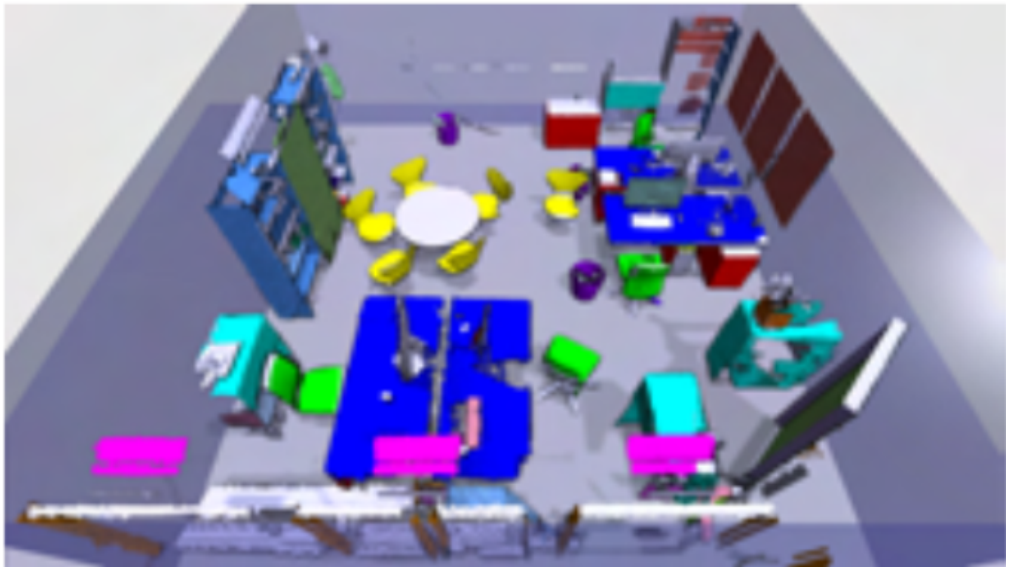
Prior Furniture Segmentation Techniques

[74] A. Karpathy, S. Miller, and L. Fei-Fei, "Object discovery in 3d scenes via shape analysis," IEEE International Conference on Robotics and Automation, pp. 2088–2095, May 2013.

[75] O. Mattausch, D. Panozzo, C. Mura, O. Sorkine-Hornug, and R. Pajarola, "Object detection and classification from large-scale cluttered indoor scans," Computer Graphics Forum, vol. 33, no. 2, pp. 11–21, 2014.

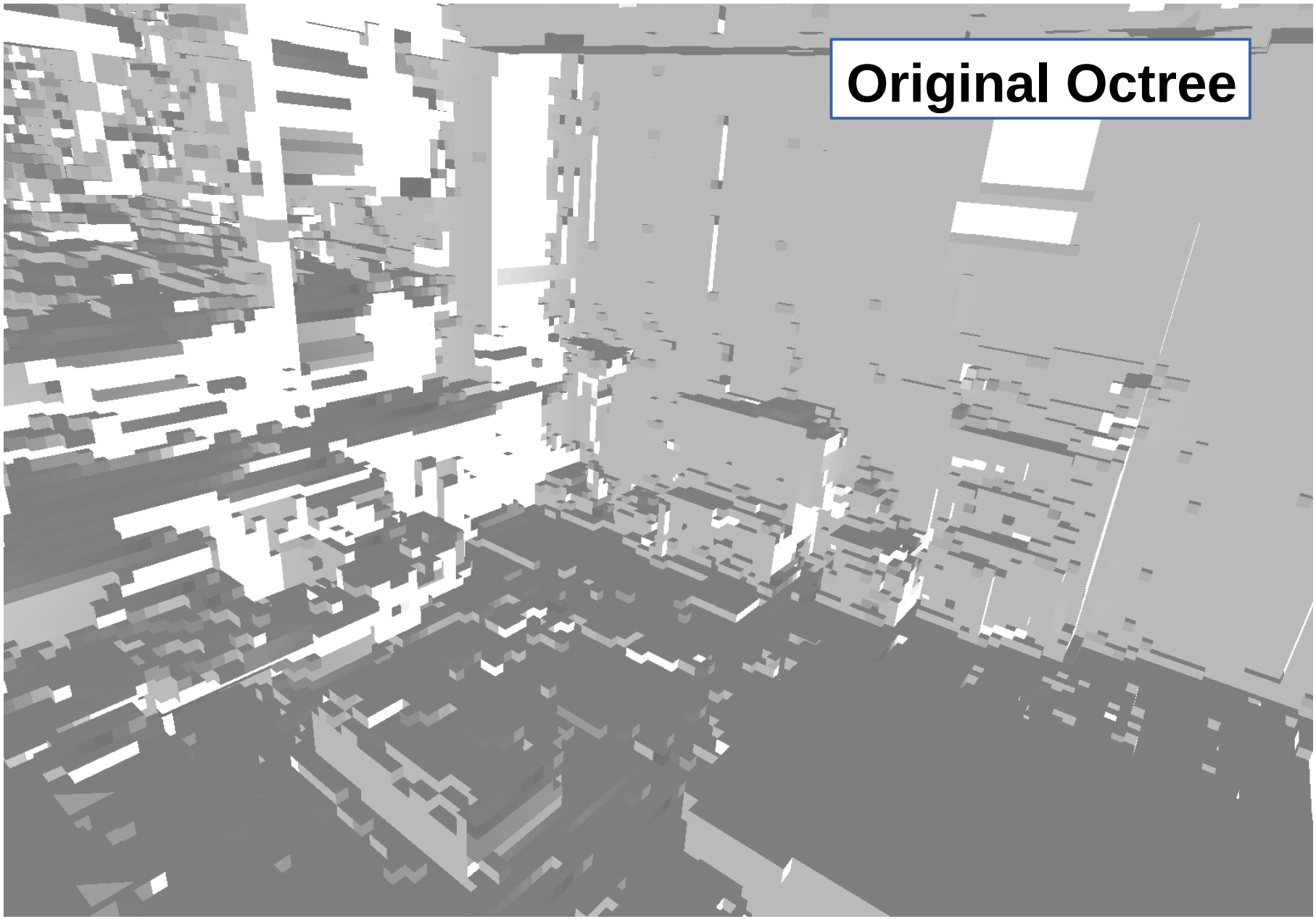


Point Cloud

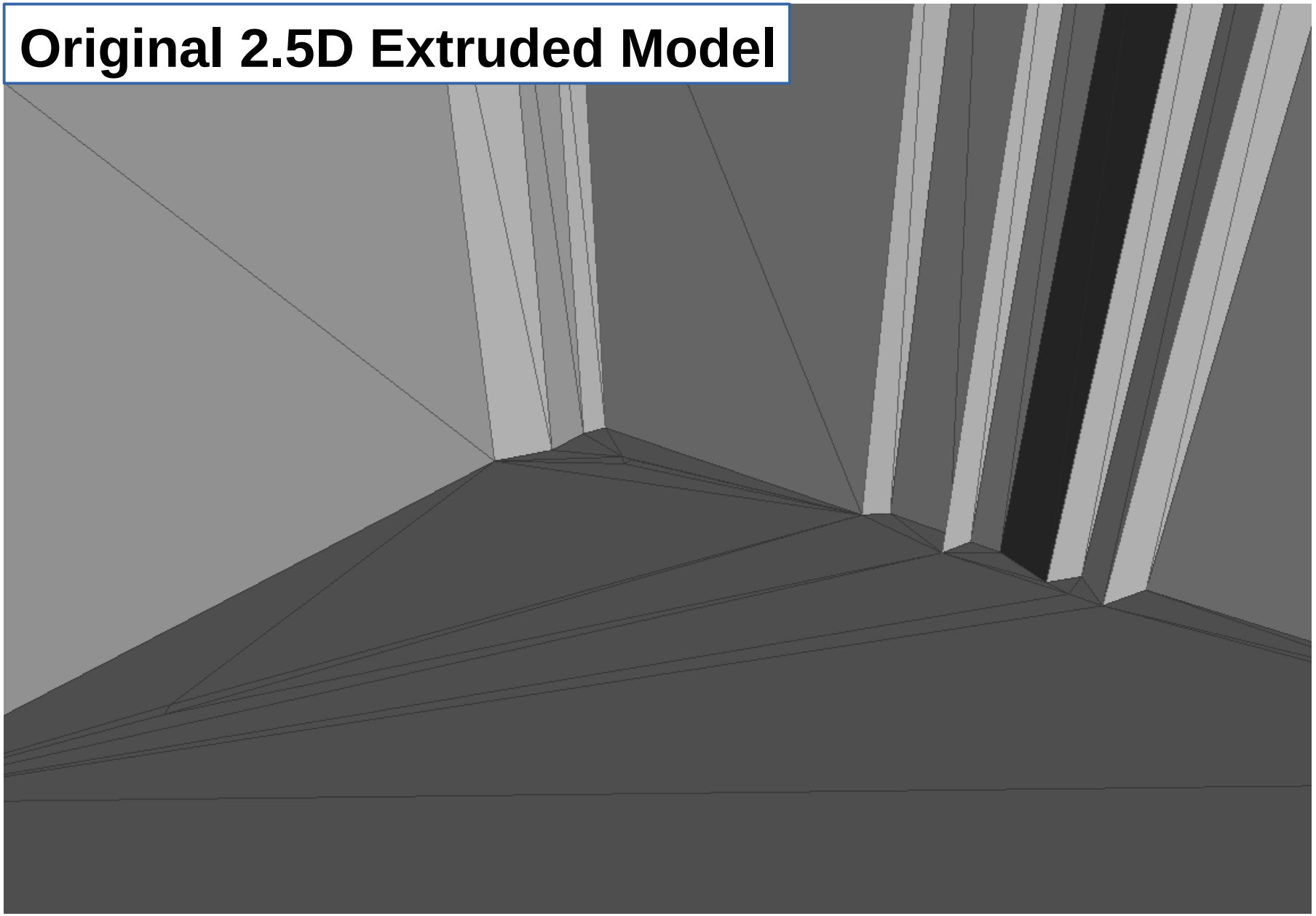


Classified Objects

Improving Floor Plans

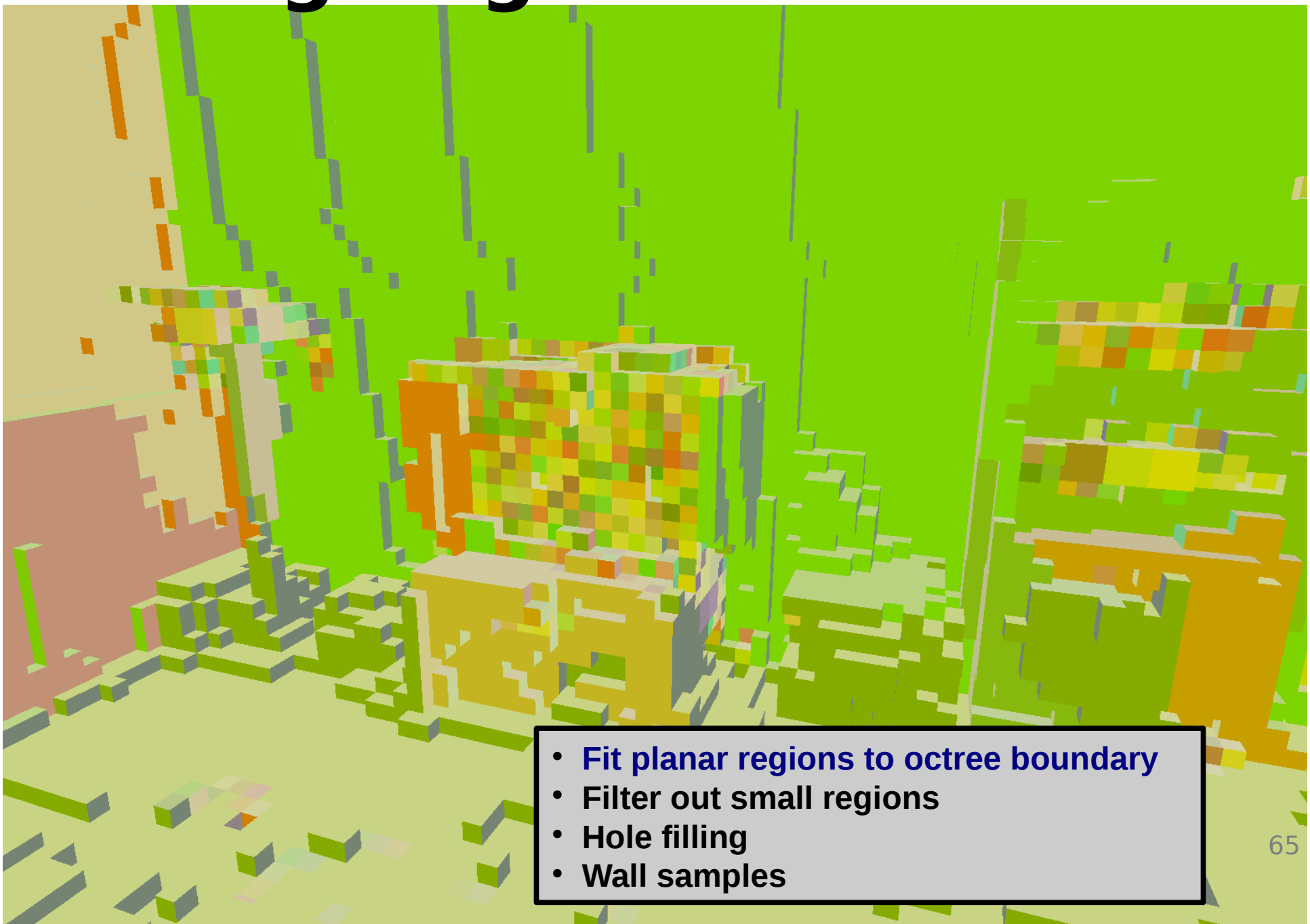


Improving Floor Plans



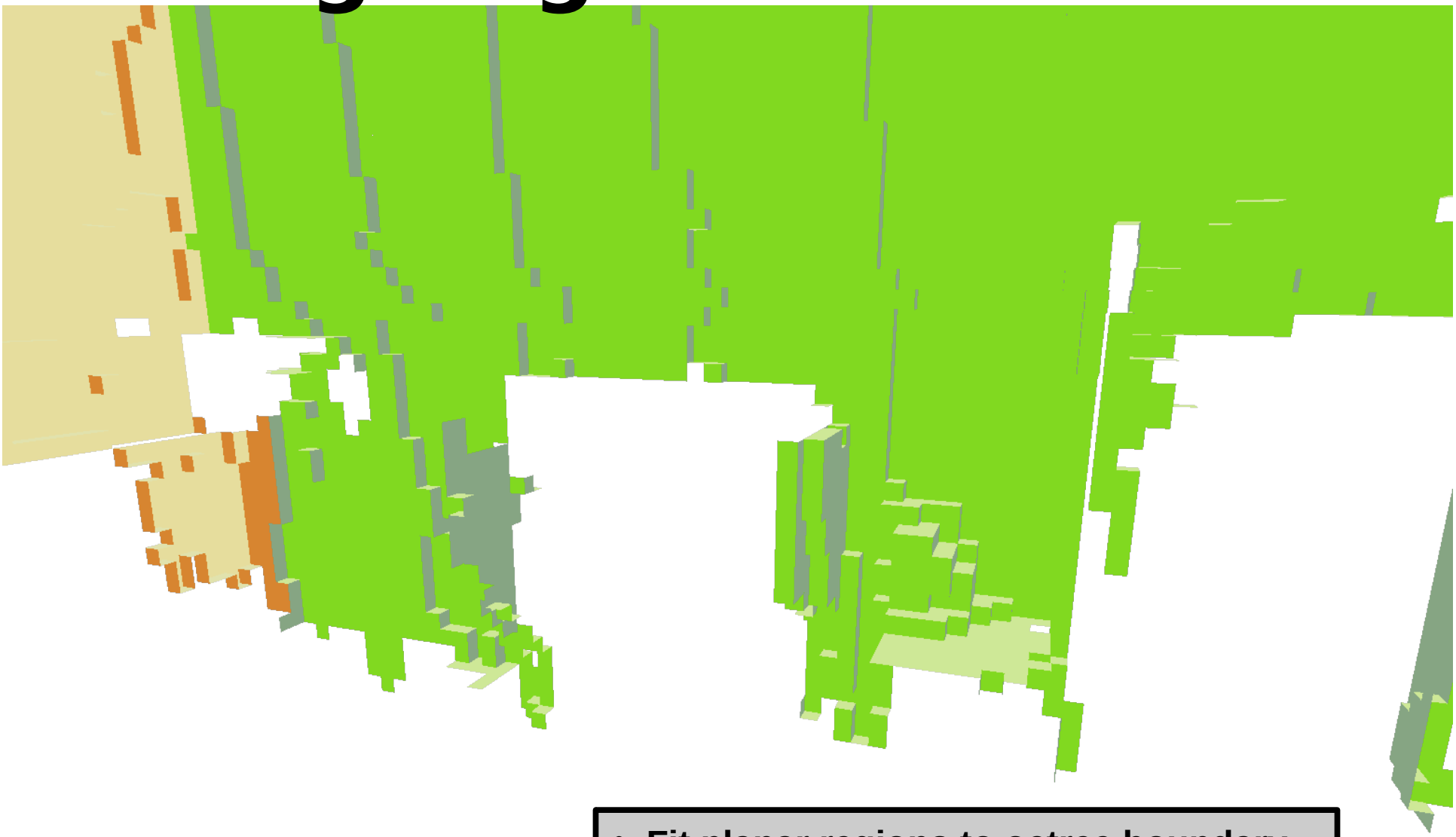
Improving Floor Plans

Making Aligned Floor Plans



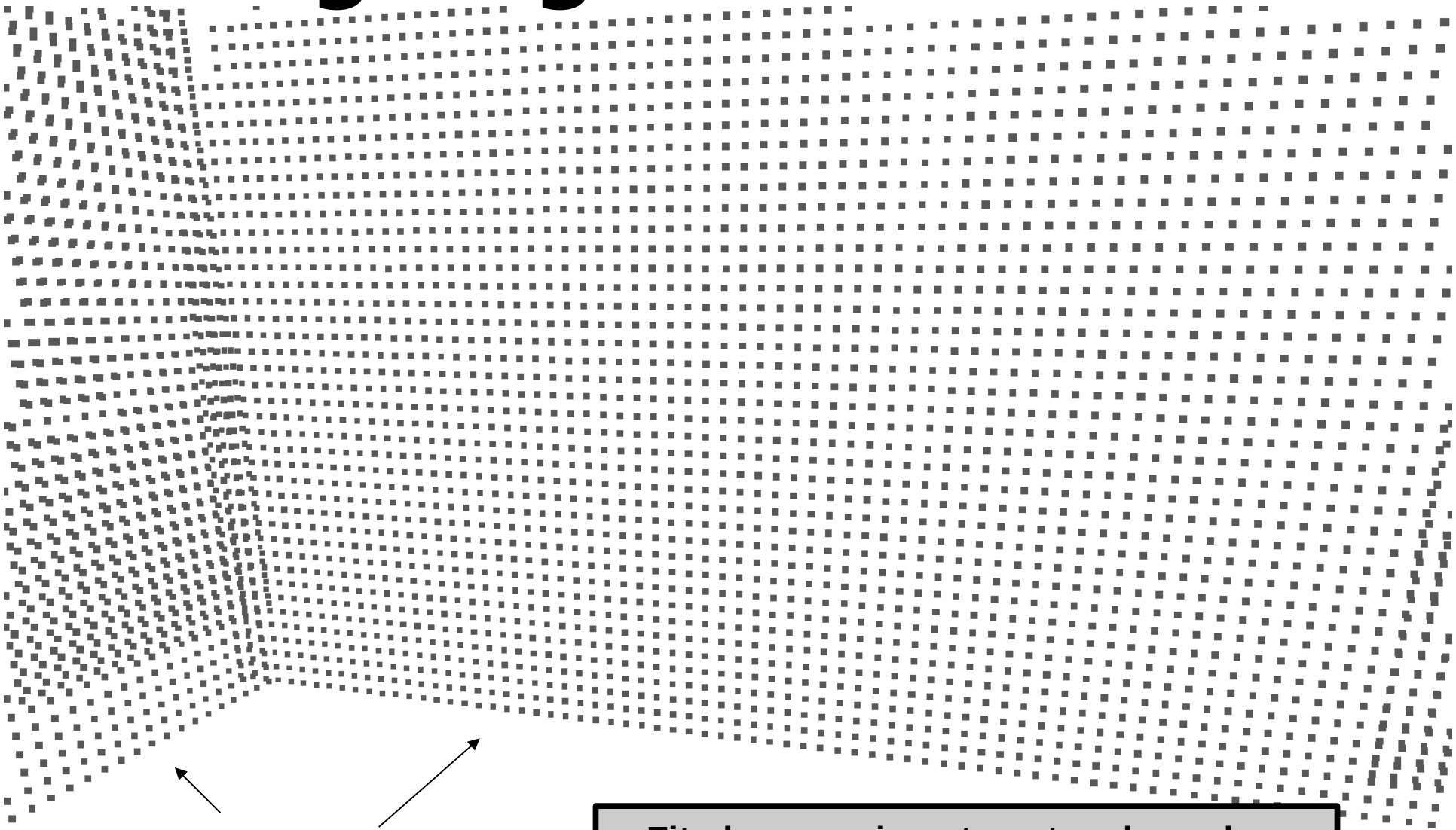
- Fit planar regions to octree boundary
- Filter out small regions
- Hole filling
- Wall samples

Making Aligned Floor Plans



- Fit planar regions to octree boundary
- Filter out small regions
- Hole filling
- Wall samples

Making Aligned Floor Plans

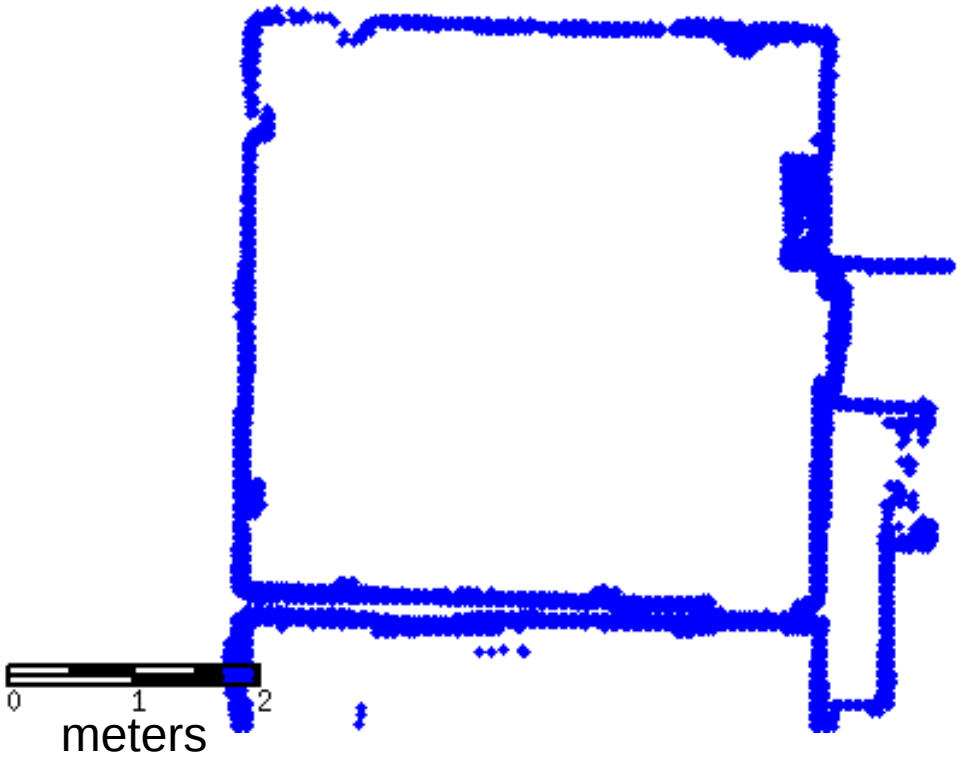


Edge position based on floor/ceiling planar regions

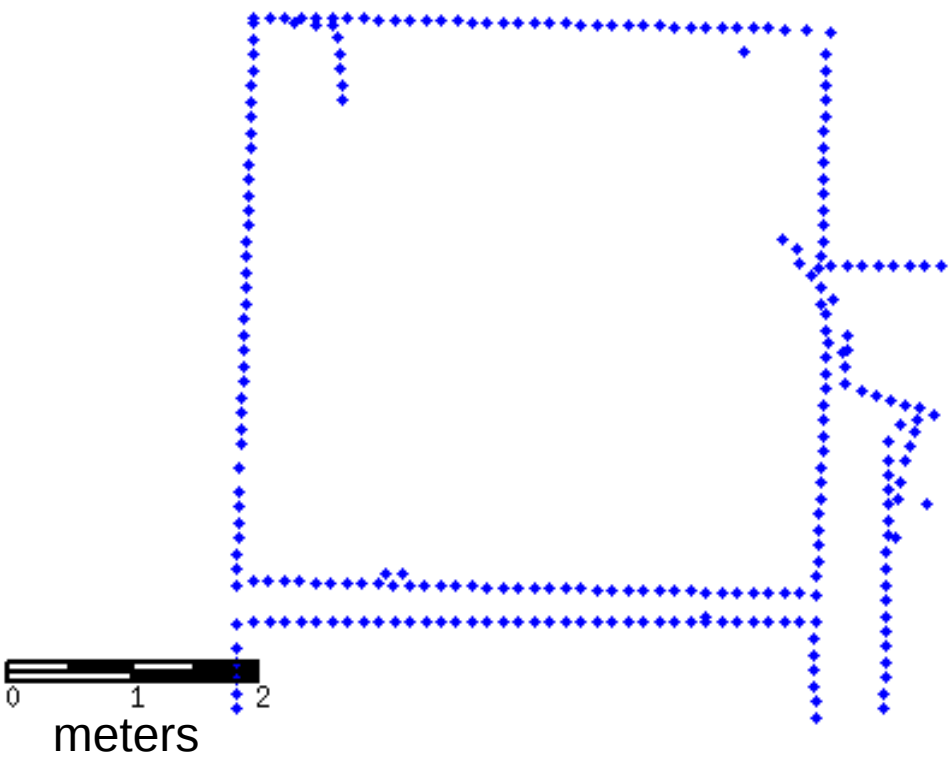
- Fit planar regions to octree boundary
- Filter out small regions
- **Hole filling**
- Wall samples

Making Aligned Floor Plans

Original Wall Samples



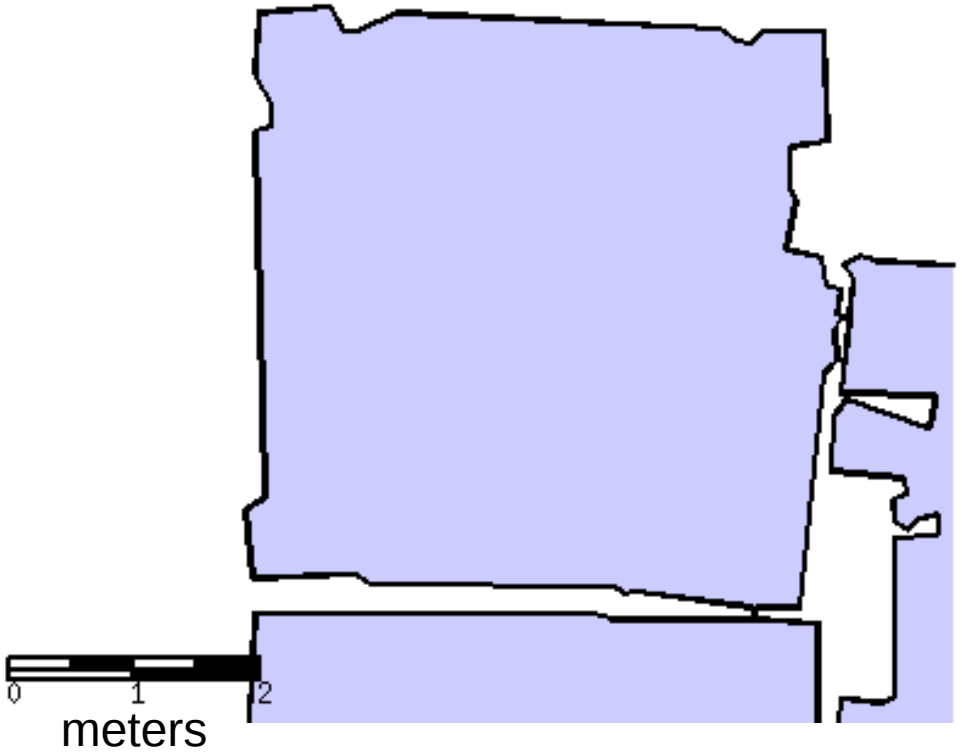
New Wall Samples



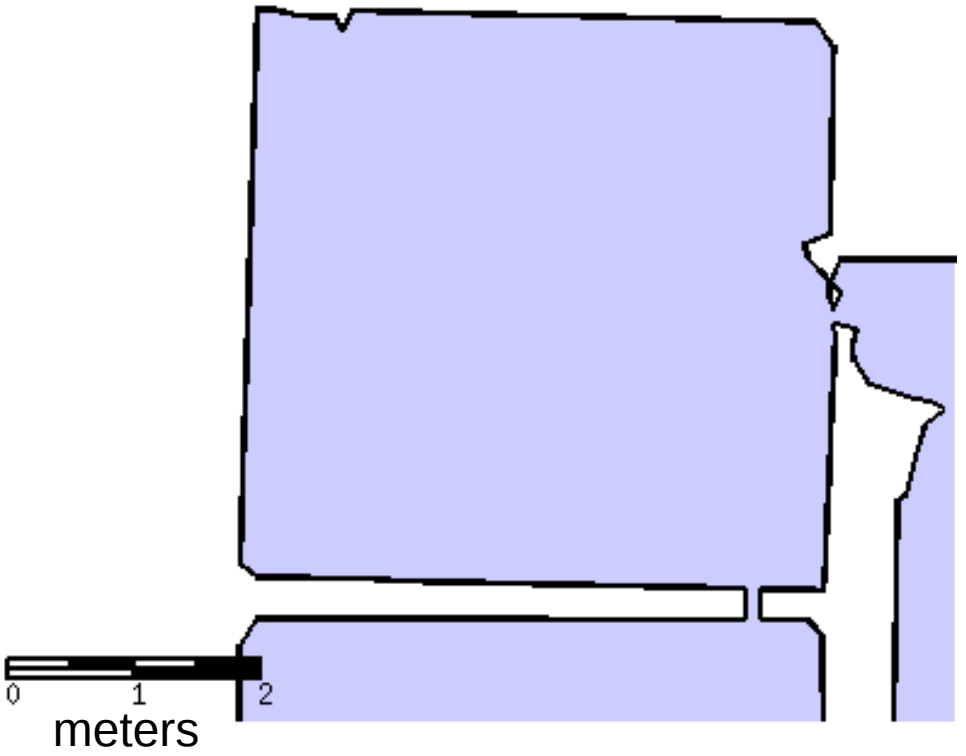
- Fit planar regions to octree boundary
- Filter out small regions
- Hole filling
- Wall samples

Making Aligned Floor Plans

Original Floor Plan

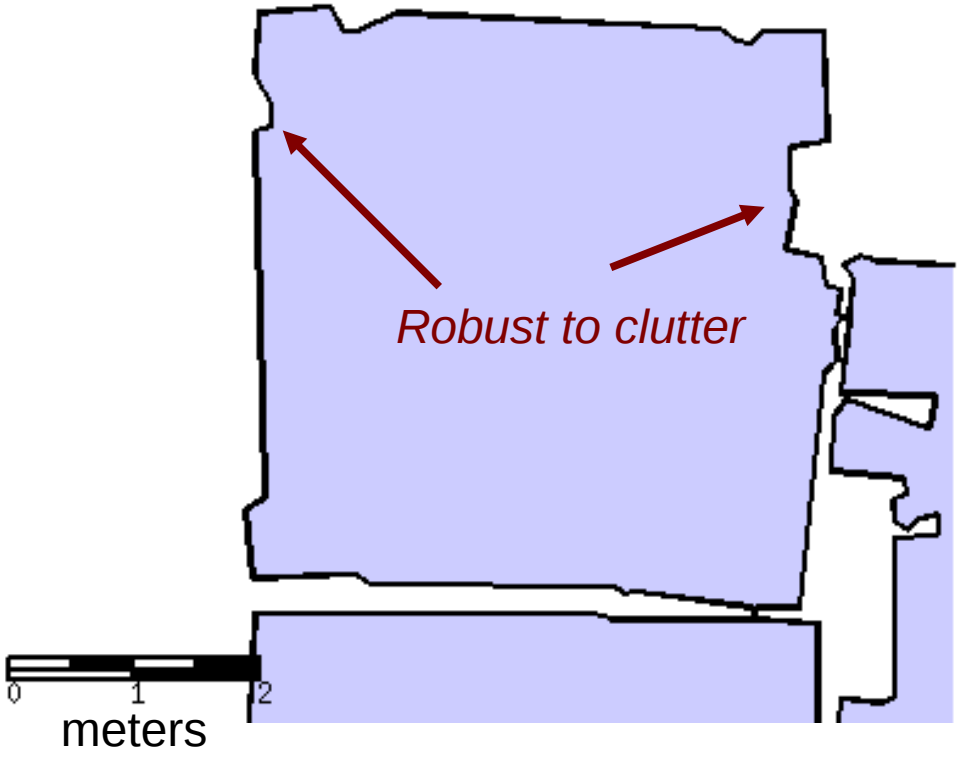


New Floor Plan

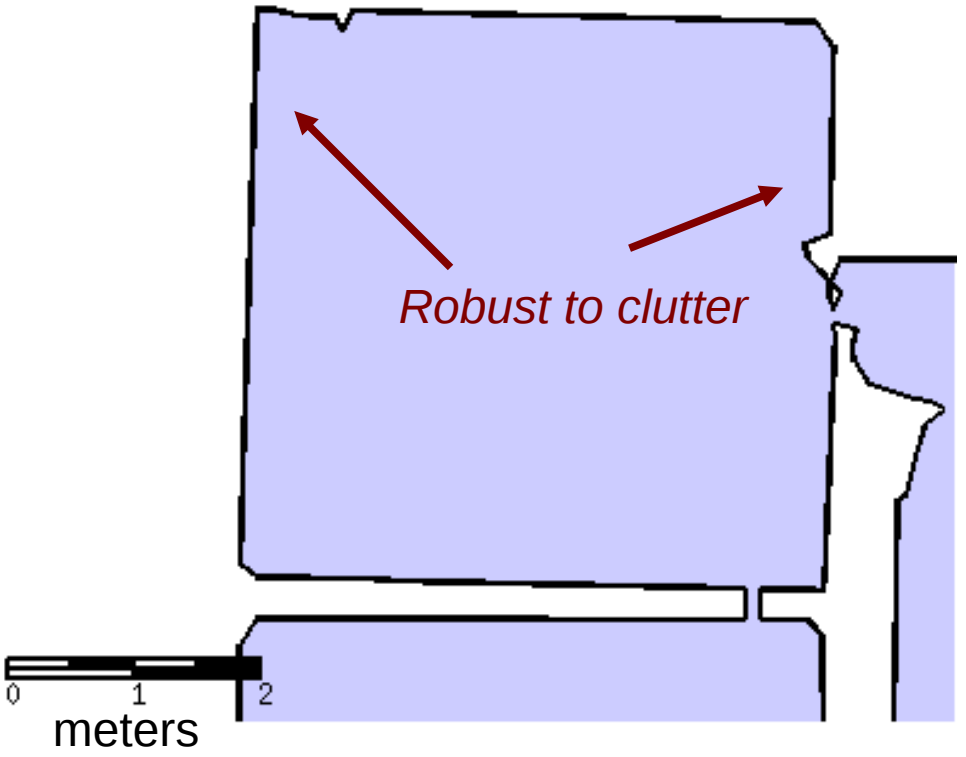


Making Aligned Floor Plans

Original Floor Plan



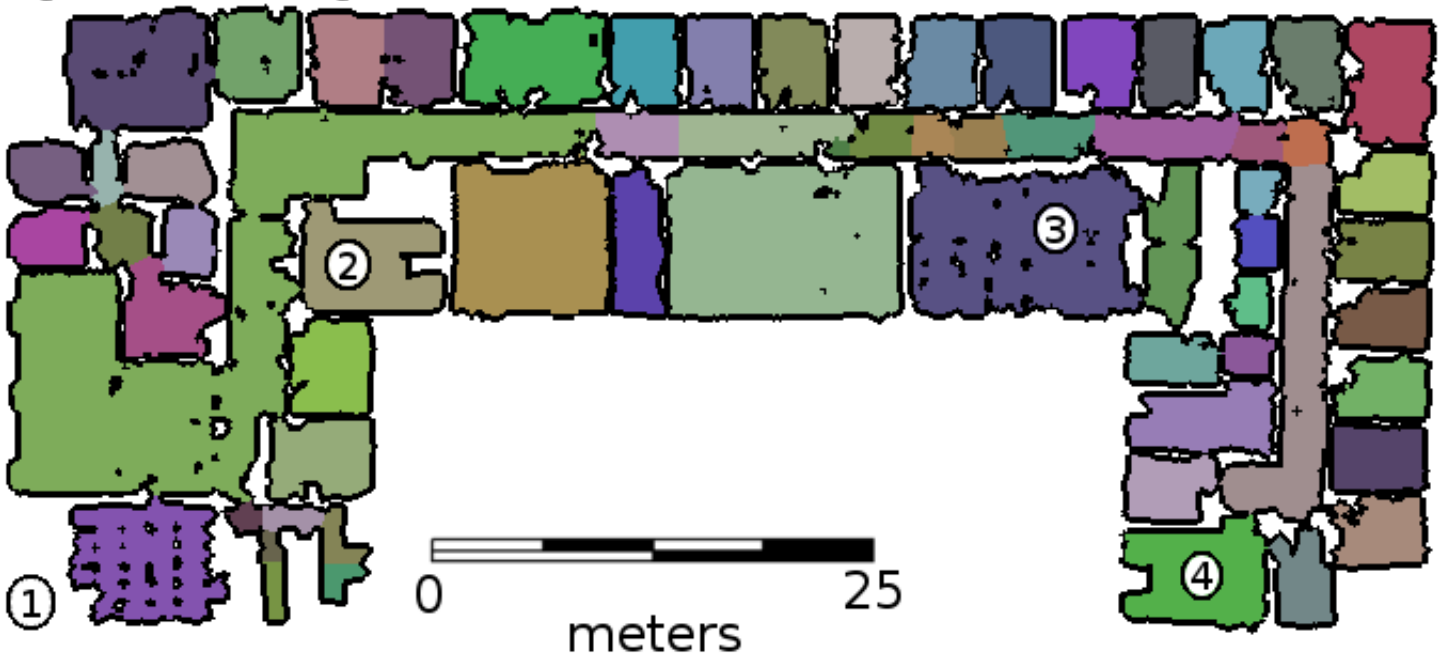
New Floor Plan



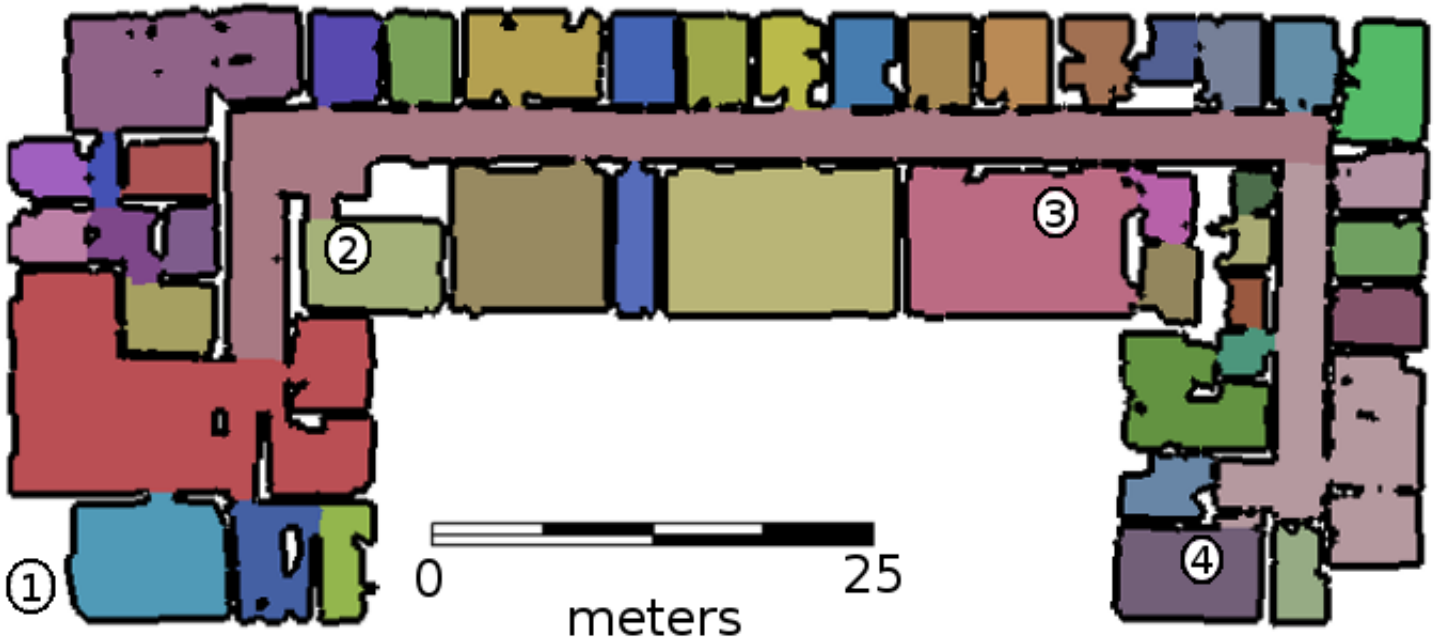
- **Aligned to octree geometry**
- **Less affected by clutter**
- **Aesthetically cleaner**

Making Aligned Floor Plans

Using Point Cloud



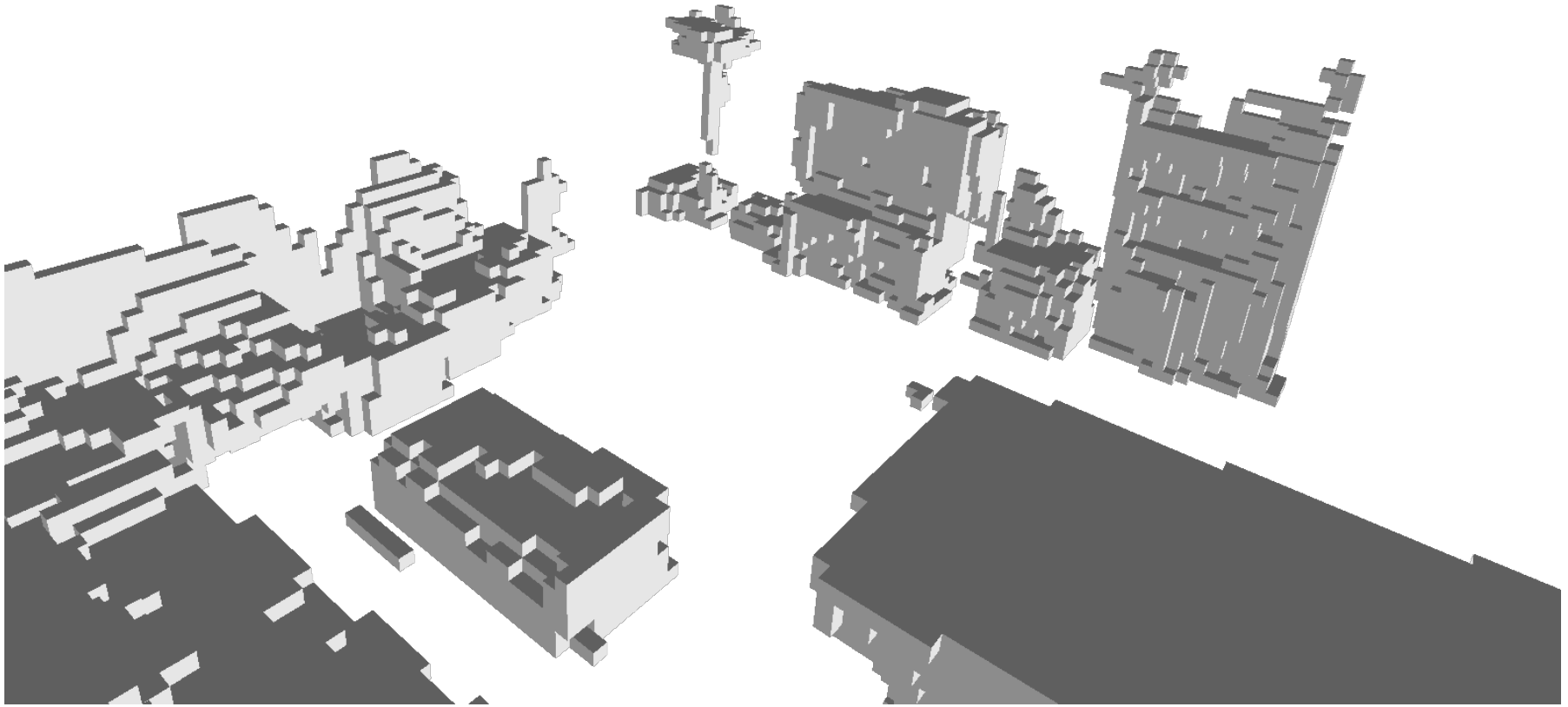
Using Octree



Improving Floor Plans

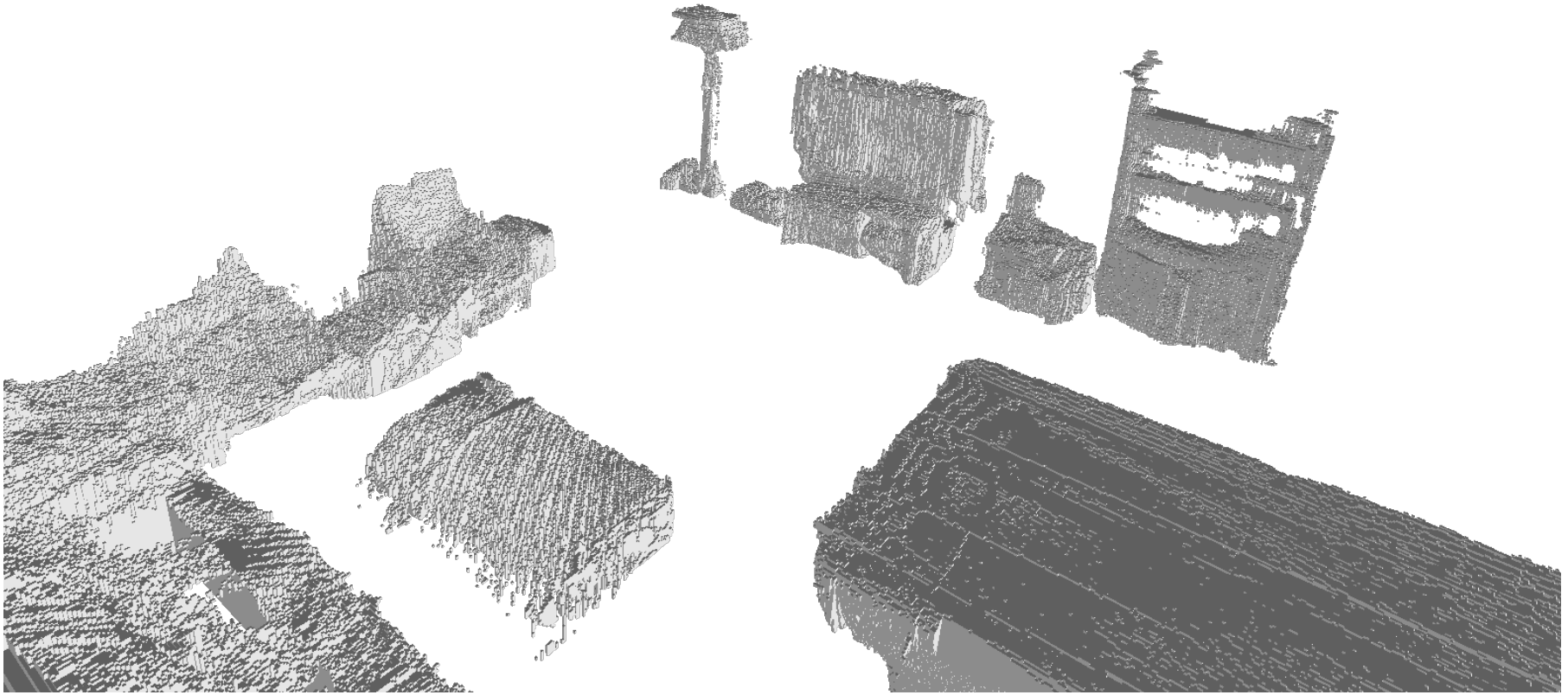
Improving Floor Plans

Aligned Set Difference

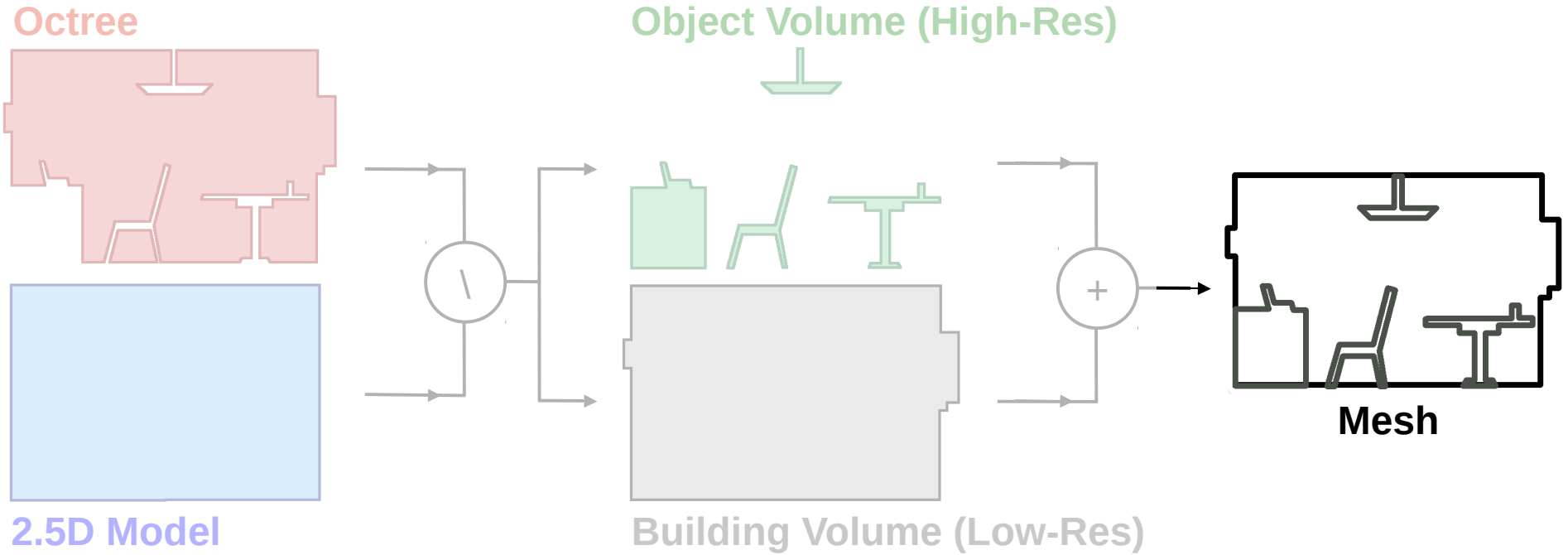


Improving Floor Plans

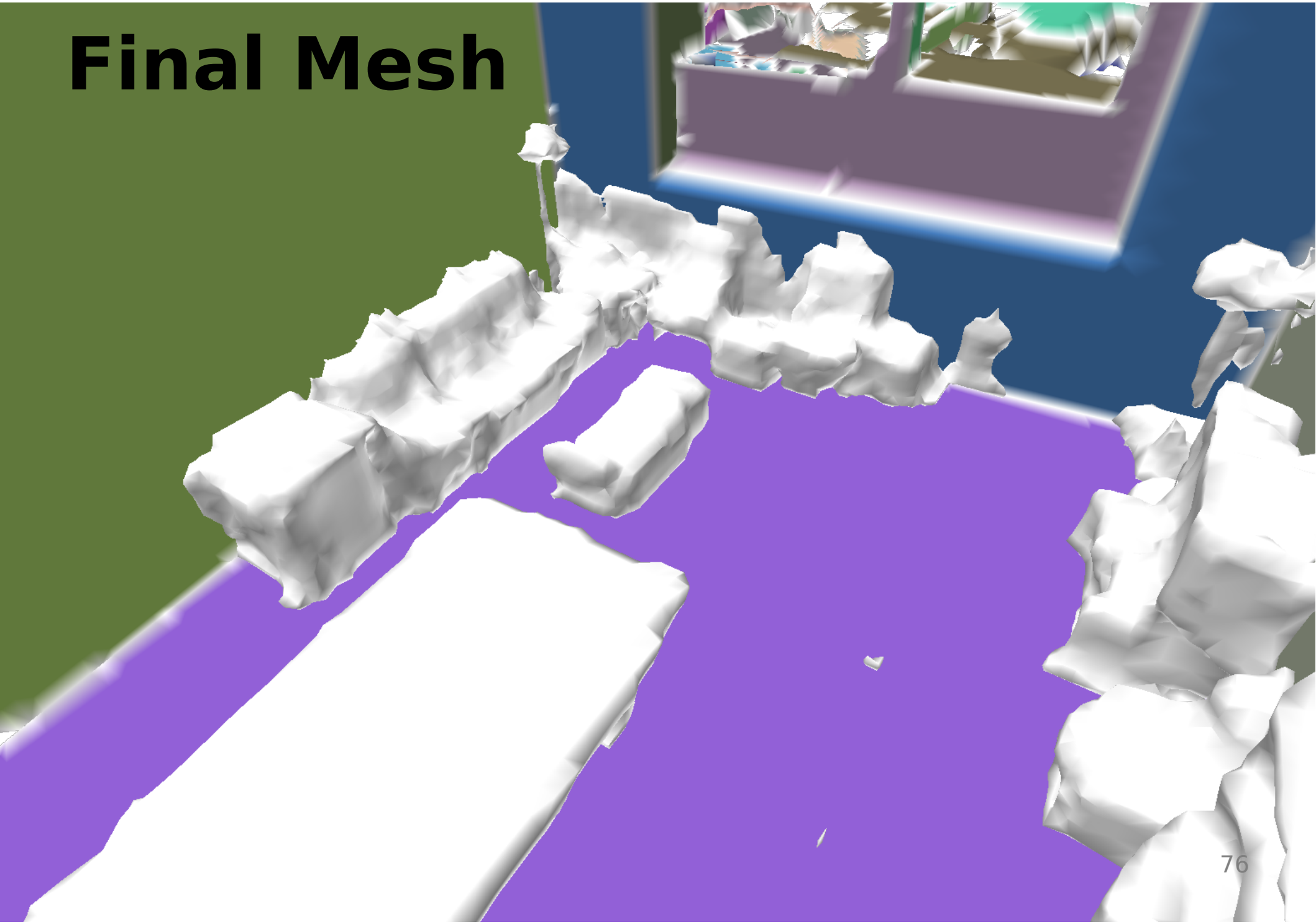
Refined Furniture Geometry



Combining Modeling Types



Final Mesh

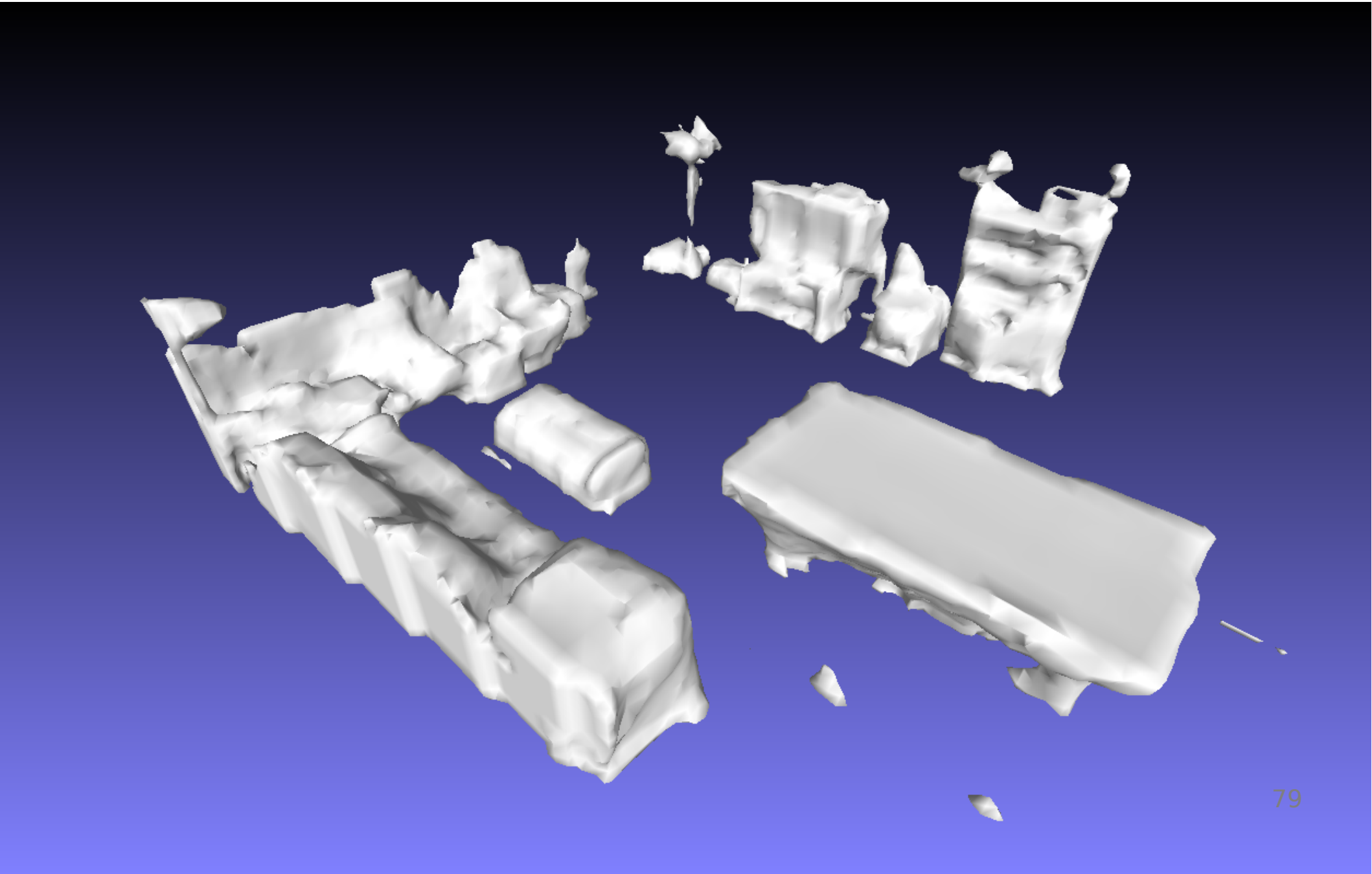


Final Mesh

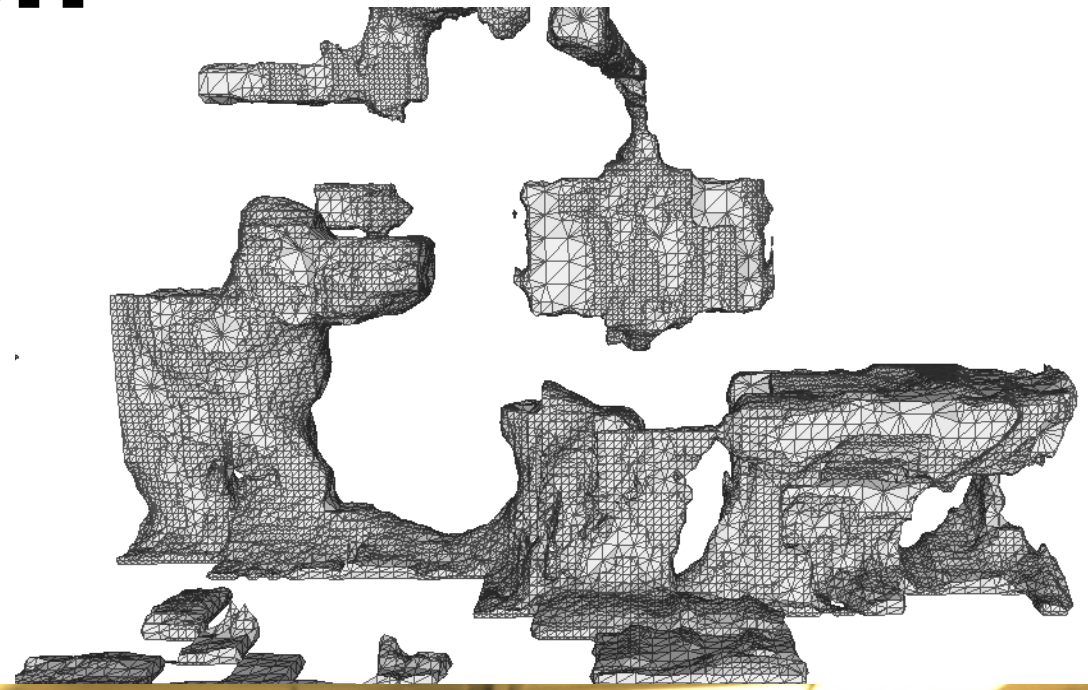
Just the room

Final Mesh

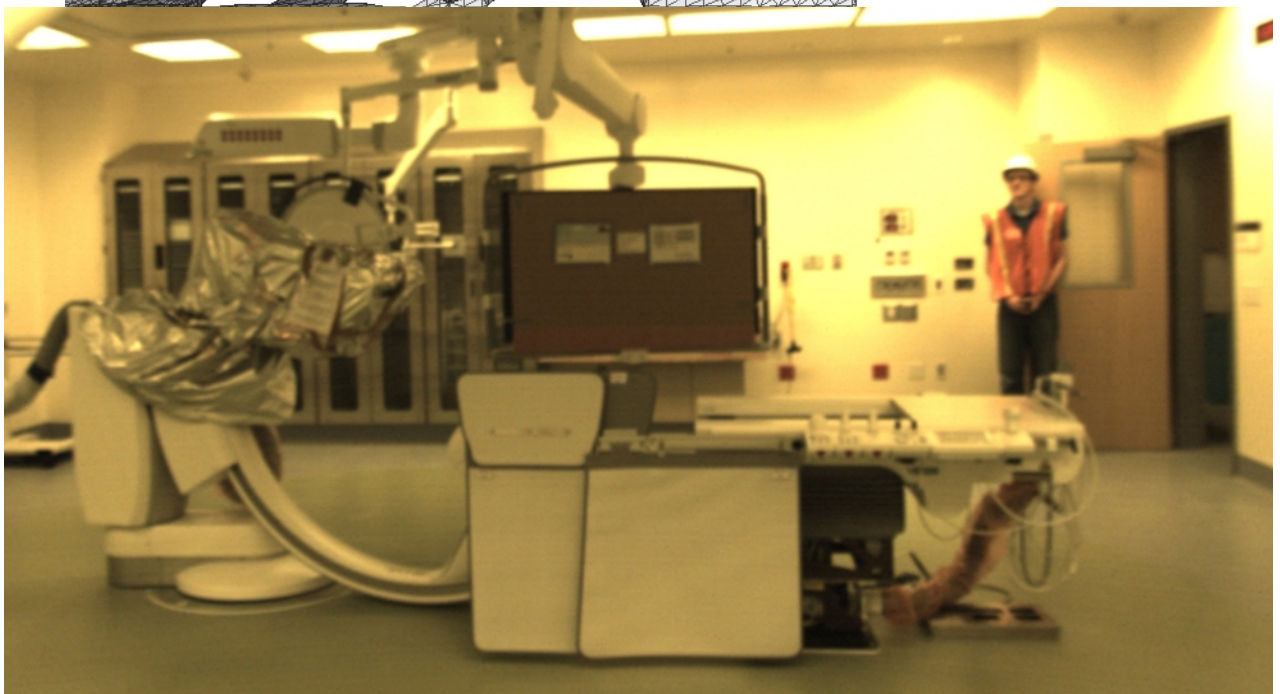
Just the furniture



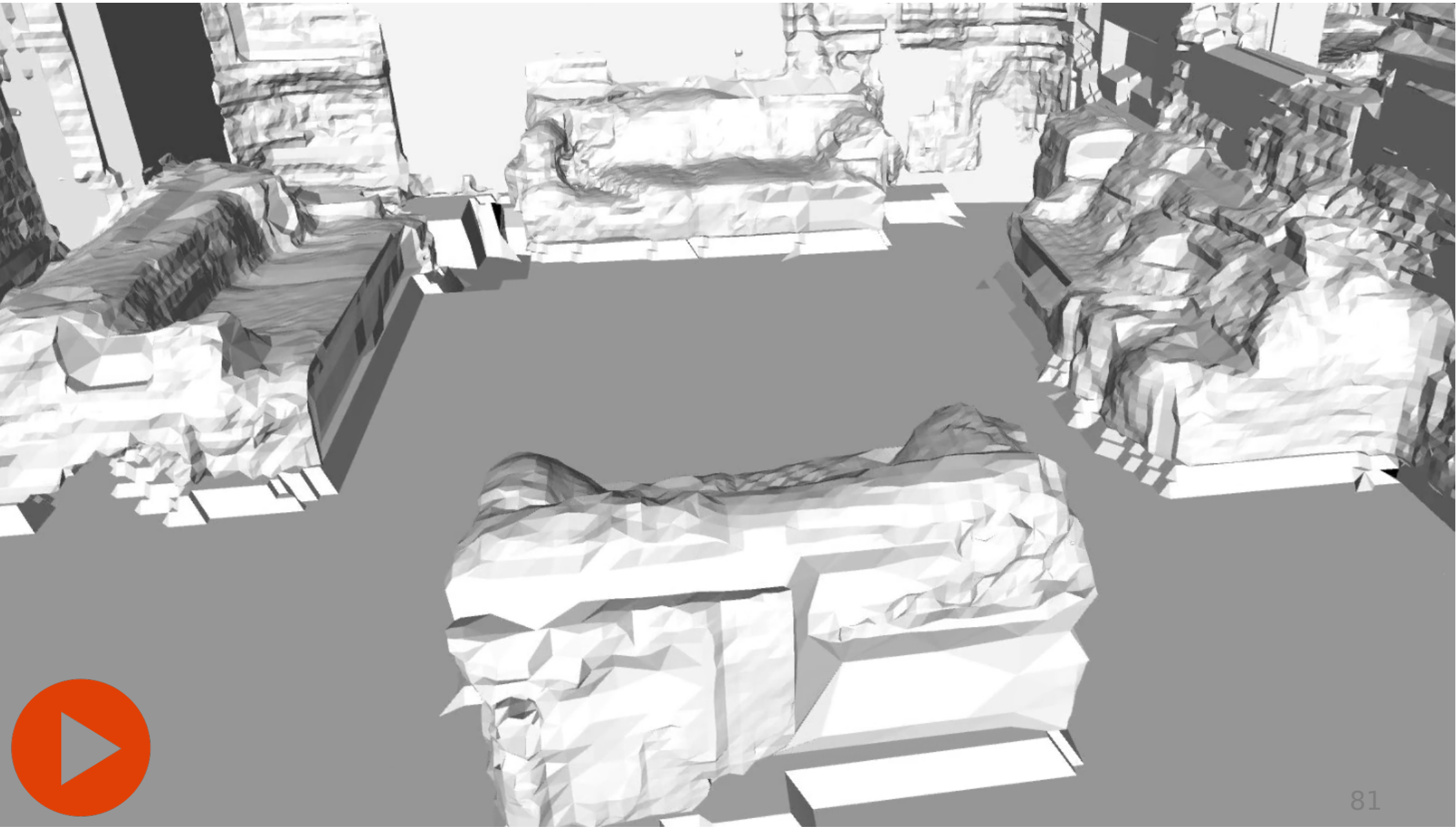
Final Mesh



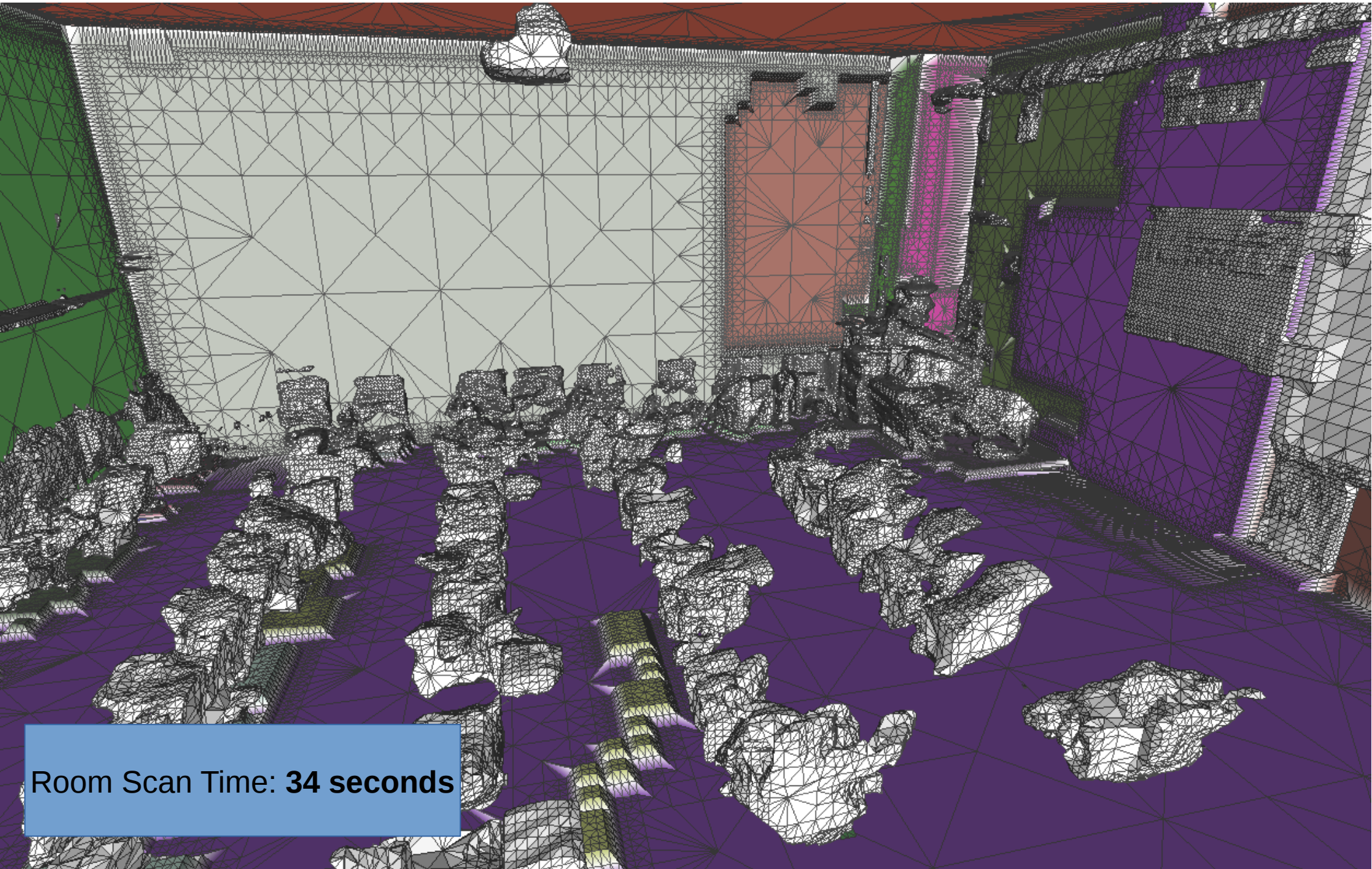
Hybrid Operating Room Table



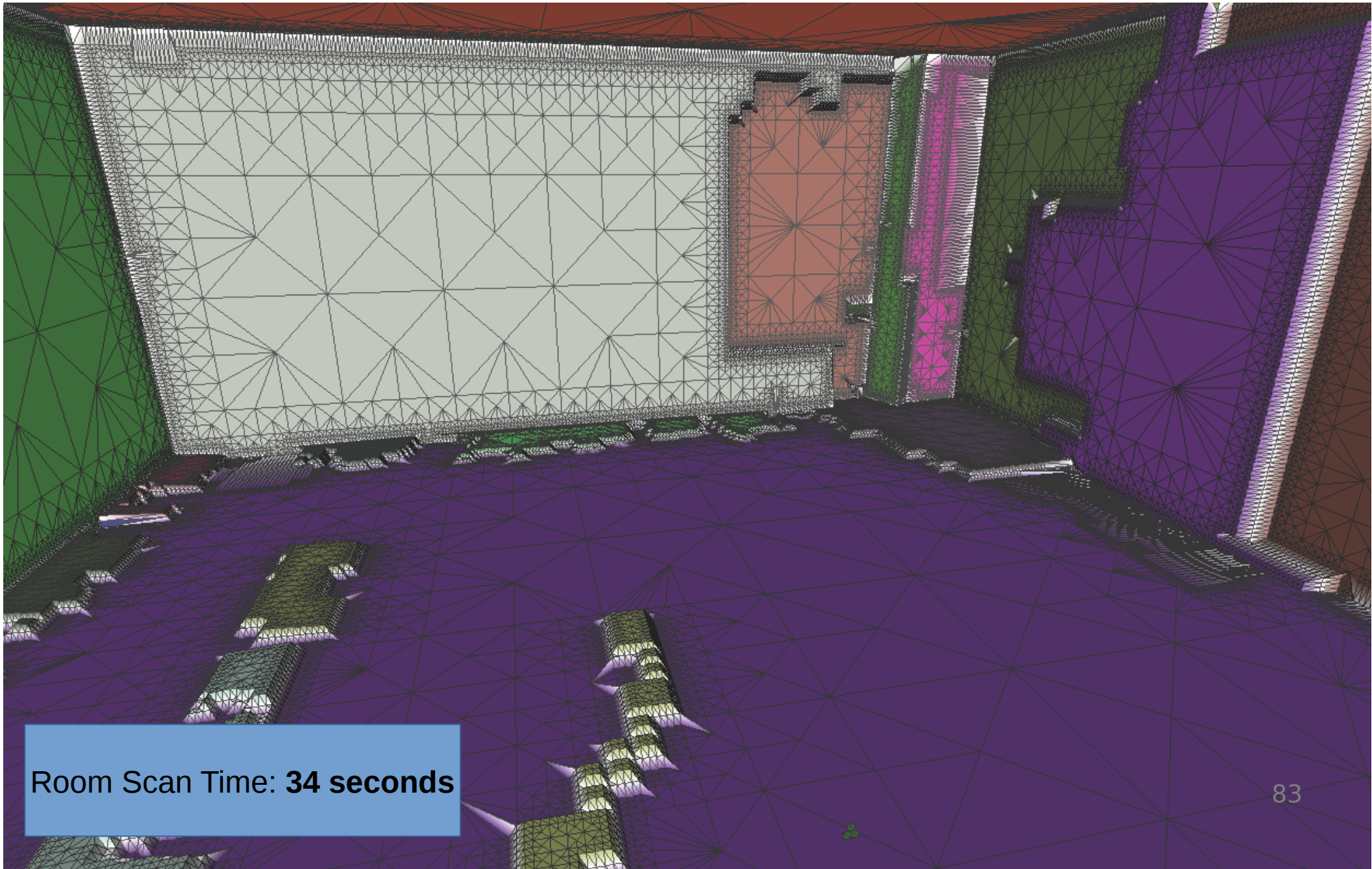
Final Mesh



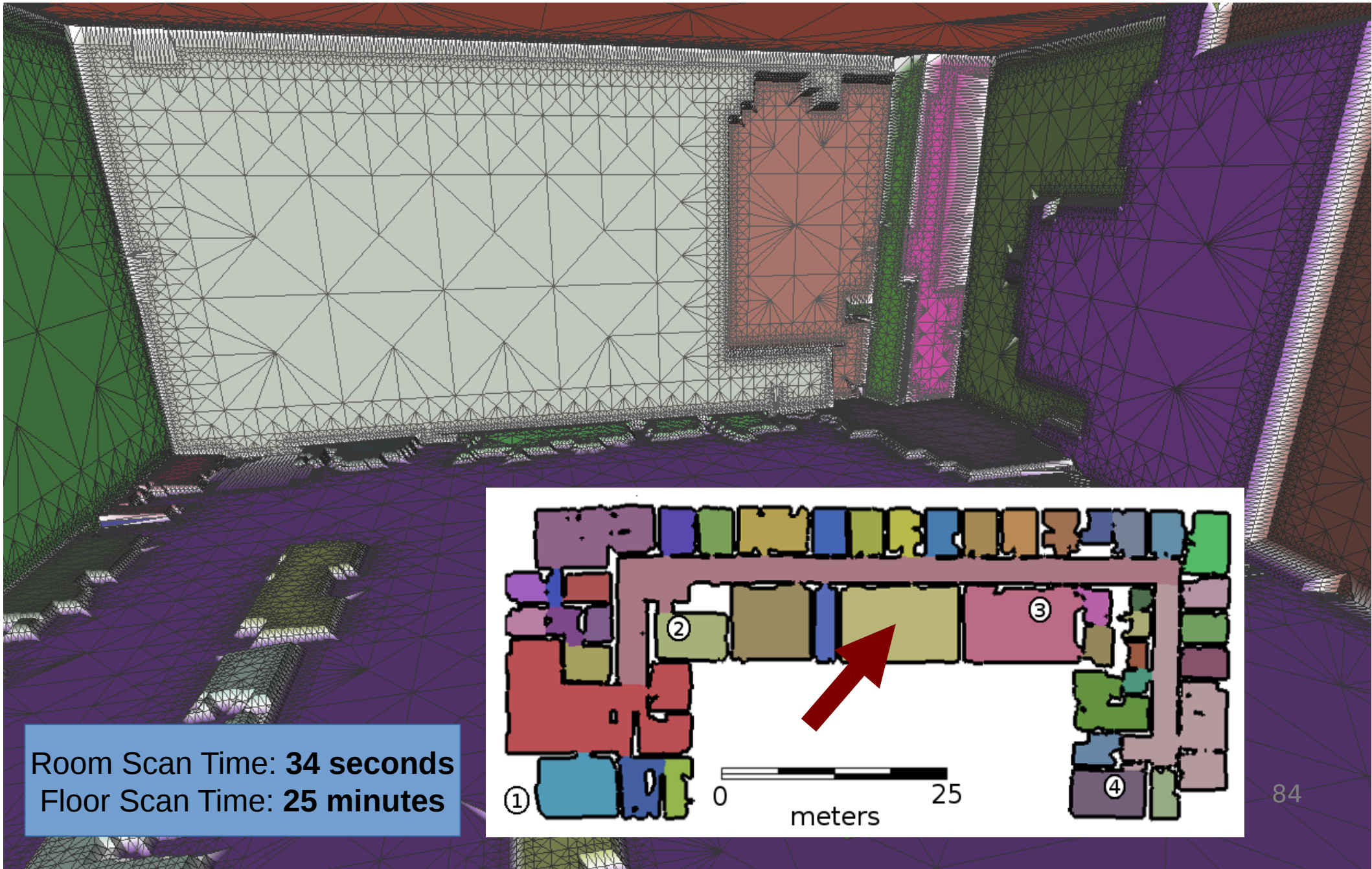
Final Mesh: Classroom



Final Mesh: Classroom

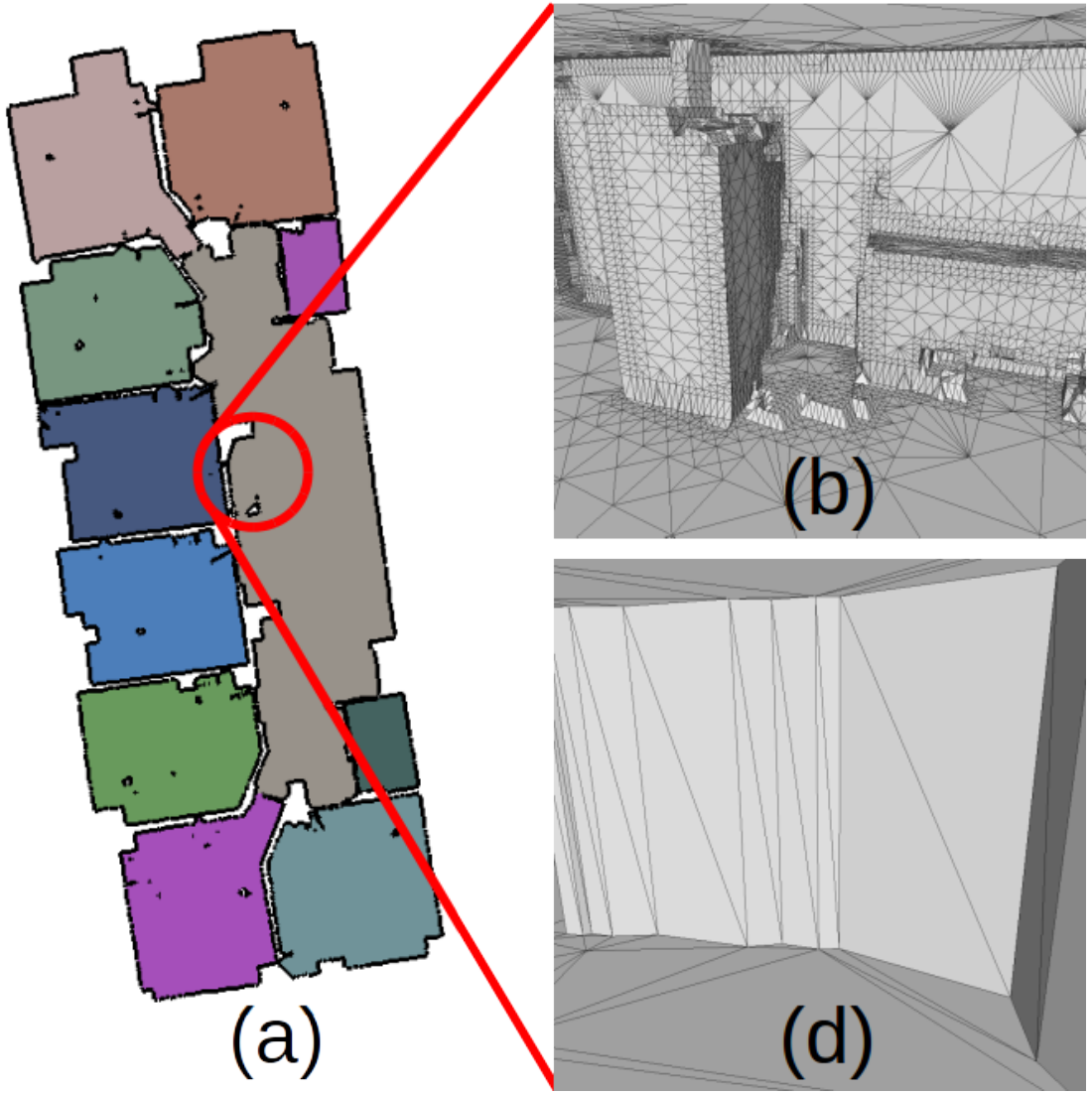


Final Mesh: Classroom



Conclusion

- Custom Hardware
- Modeling Techniques
  - 2D Floor Plans
  - 2.5D Simplified Models
  - 3D Complex Models
- Combining Modeling Techniques



Thank You