Deducing the Location of Glass Windows in 3D Indoor Environments

Mels Smit

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Mentor #2: Martijn Meijers
Mentor CGI: Robert Voûte
Delegate of BE: Lei Qu

TU Delft

CGI

In collaboration with:

Content

- Motivation
- Research Objective
- Theory
- Methodology
- Results
- Conclusion

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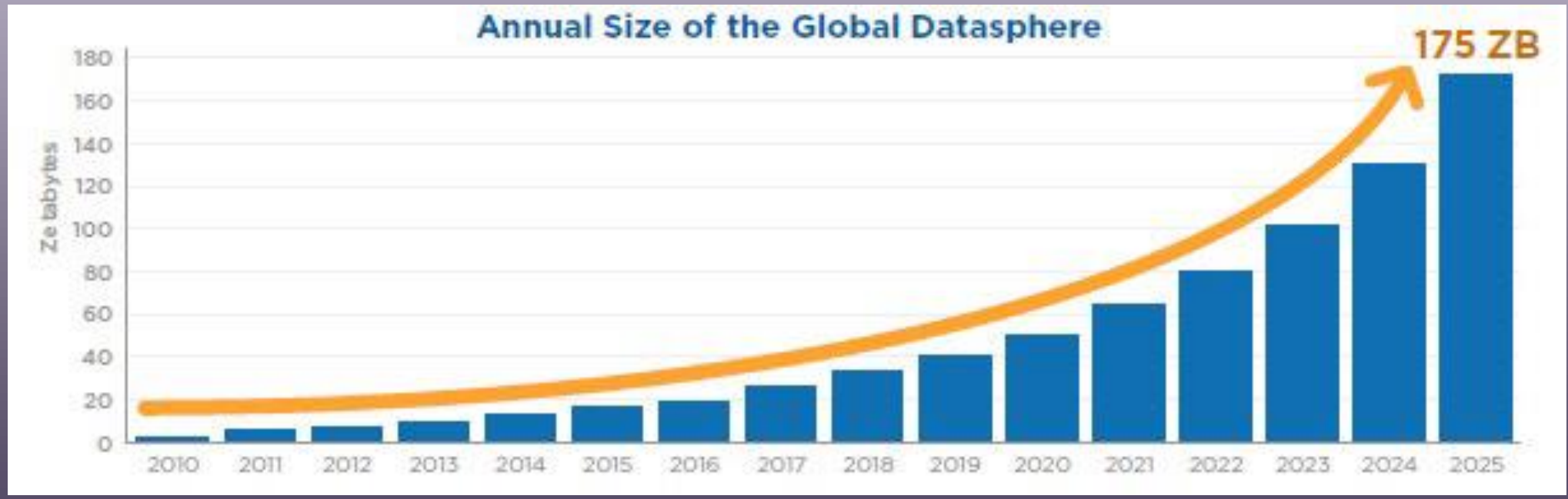
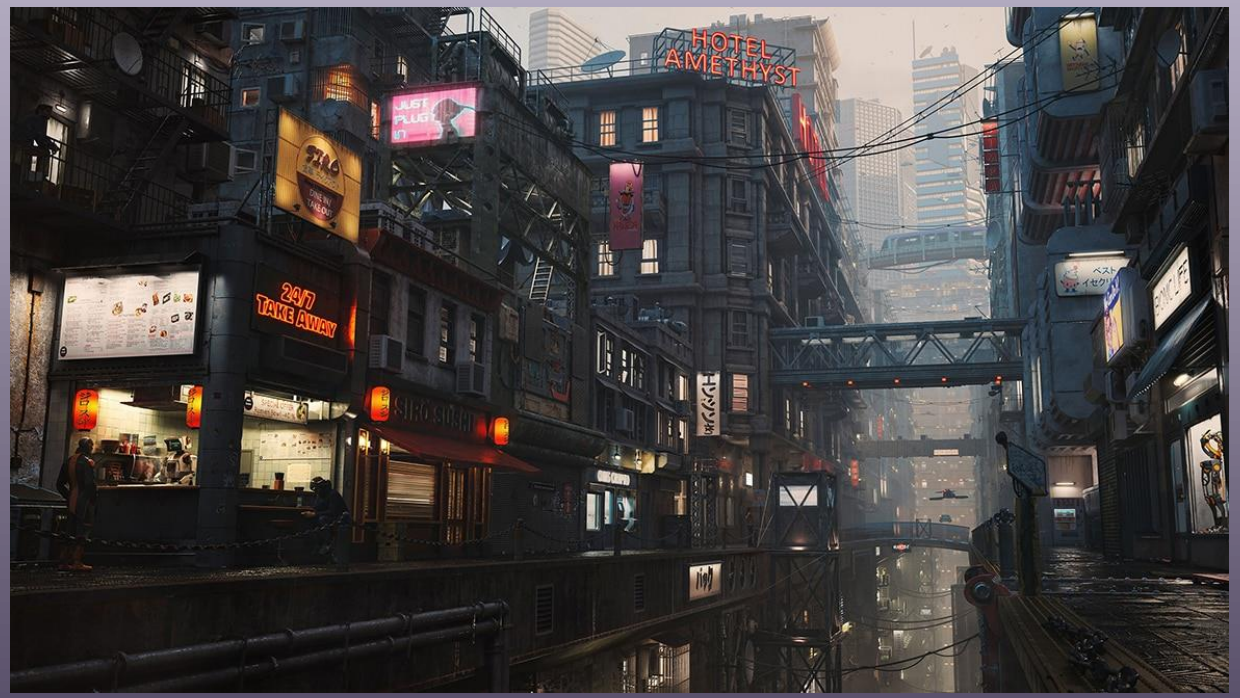
Increase of Data

- The Global Datasphere has increased drastically

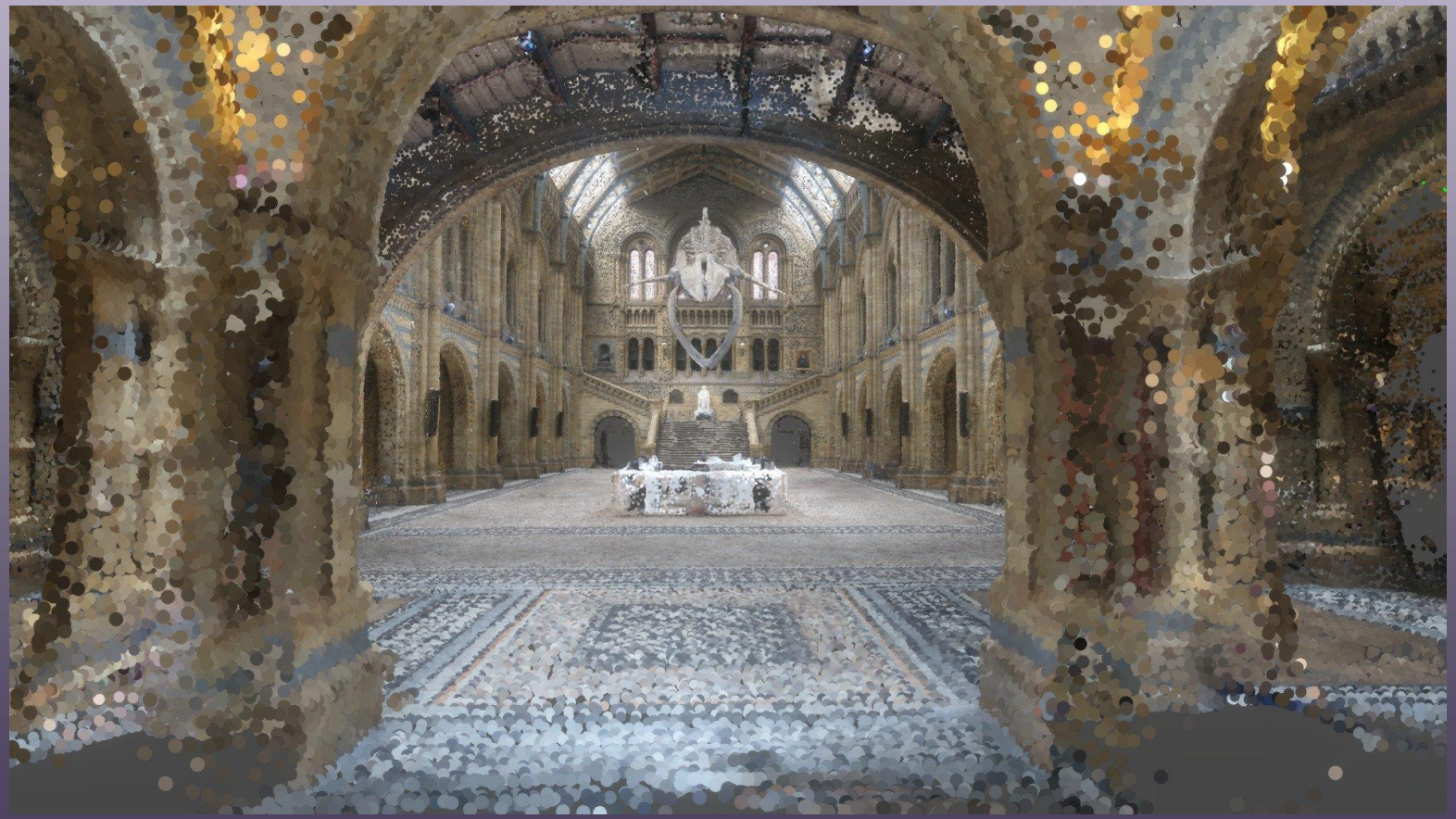


3D Environments



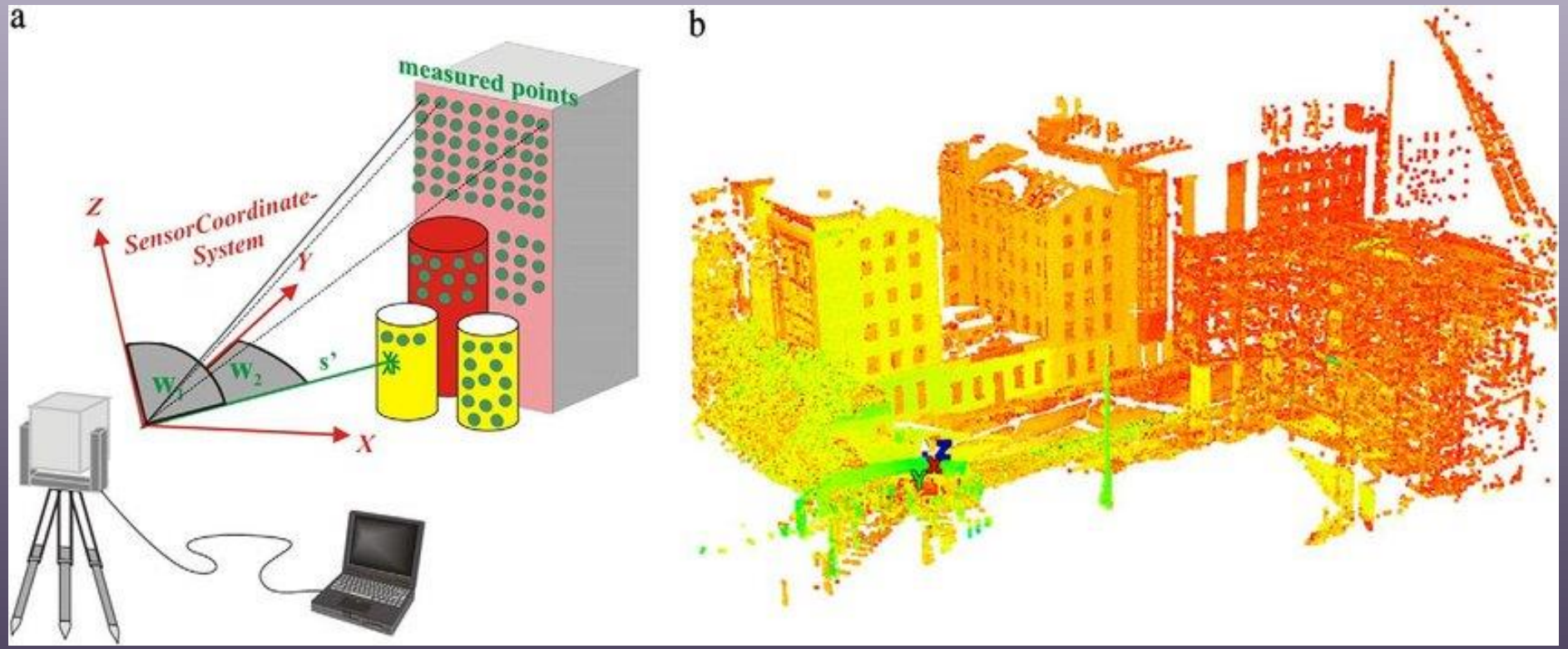
Point Cloud

- Dataset that represents an environment using (millions of) points.



LiDAR

- LiDAR scanning captures points using laser to represent e.g. buildings



Glass

- Problematic material for laser scanning.

- Reflective
- Transparent
- Still noticeable?

Problem Statement

- Prevent uncomfortable or potentially dangerous situations

- Add glass to the scene

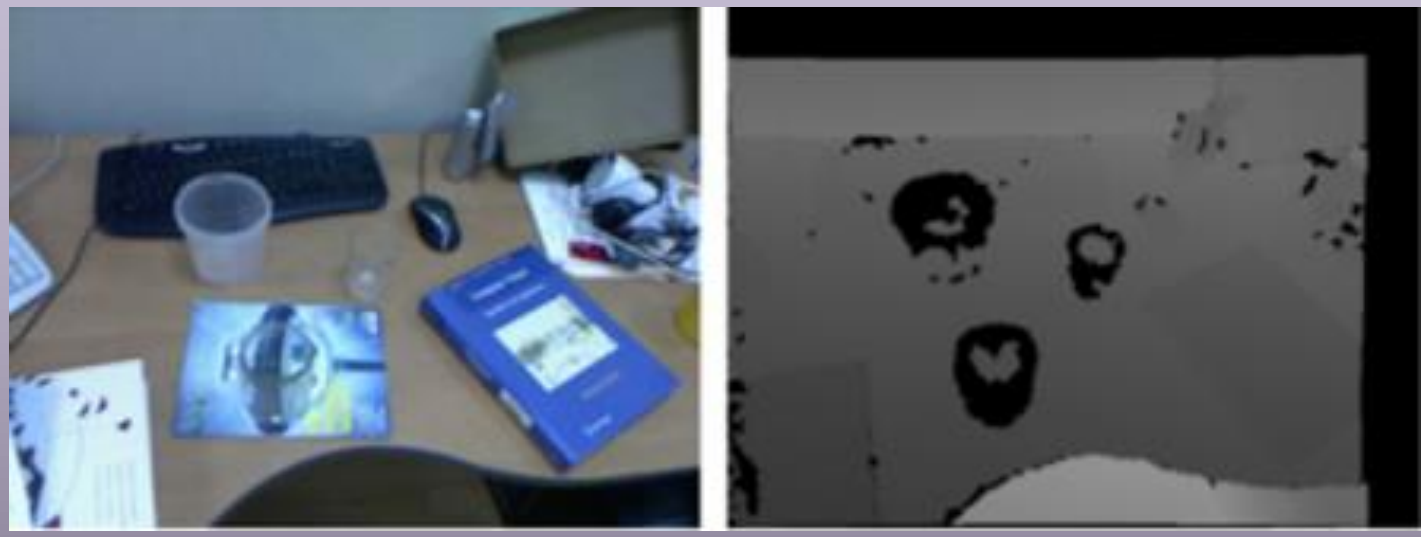
Related Work

- Physical Manipulation
  - Window foil

- Active Illumination
  - Structured light

Related Work

- Passive Methods
  - Depth properties

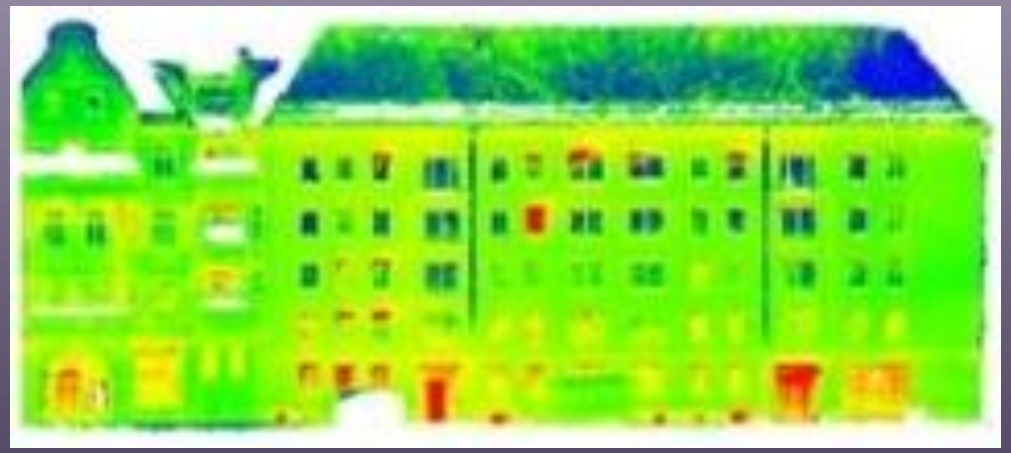


- Sensor Fusion
  - LiDAR + Sonar

Related Work

- Mirror detection
  - Robot + SLAM

- Temperature monitoring
  - Glass = heat loss



Downsides of other approaches

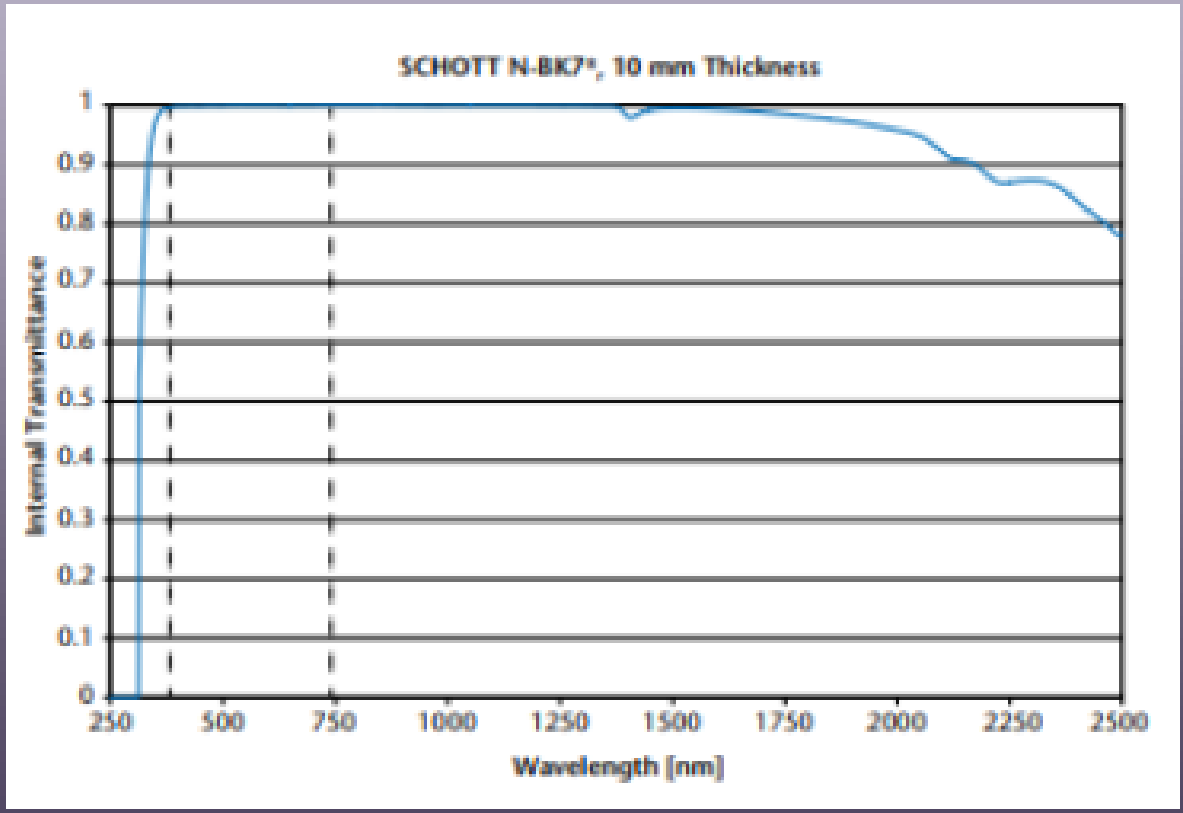
- **Different types of data**
  - Not always available
- **More expensive**
  - Different scanners
  - Time to prepare scene

Research Question

How can the location of glass be deduced using only information acquired from 3D point clouds and a reference position?

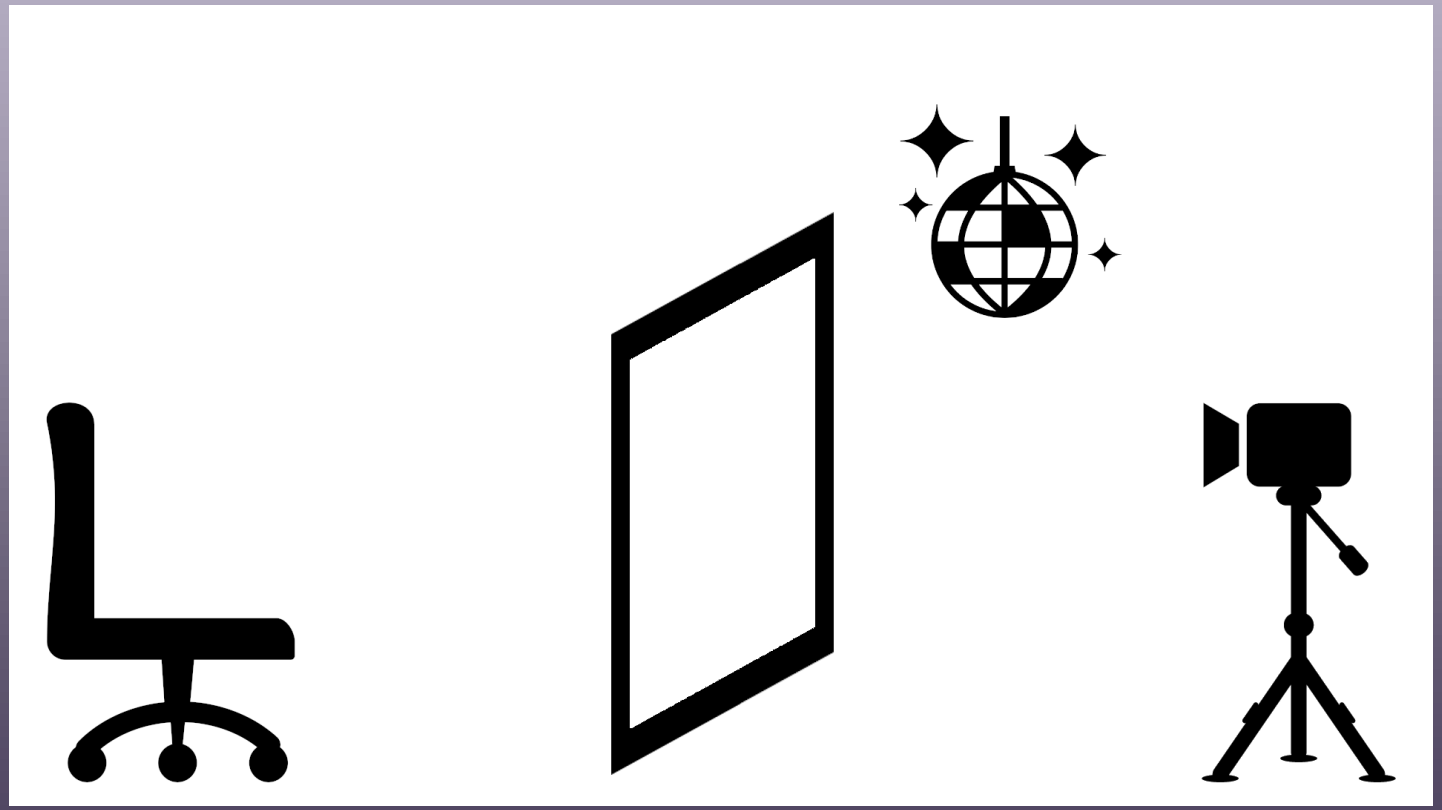
Why can glass not be captured properly?

- Laser with wavelength of ≈ 900 nm



Interaction of Laser with Glass

- Possibility 1: Transmission



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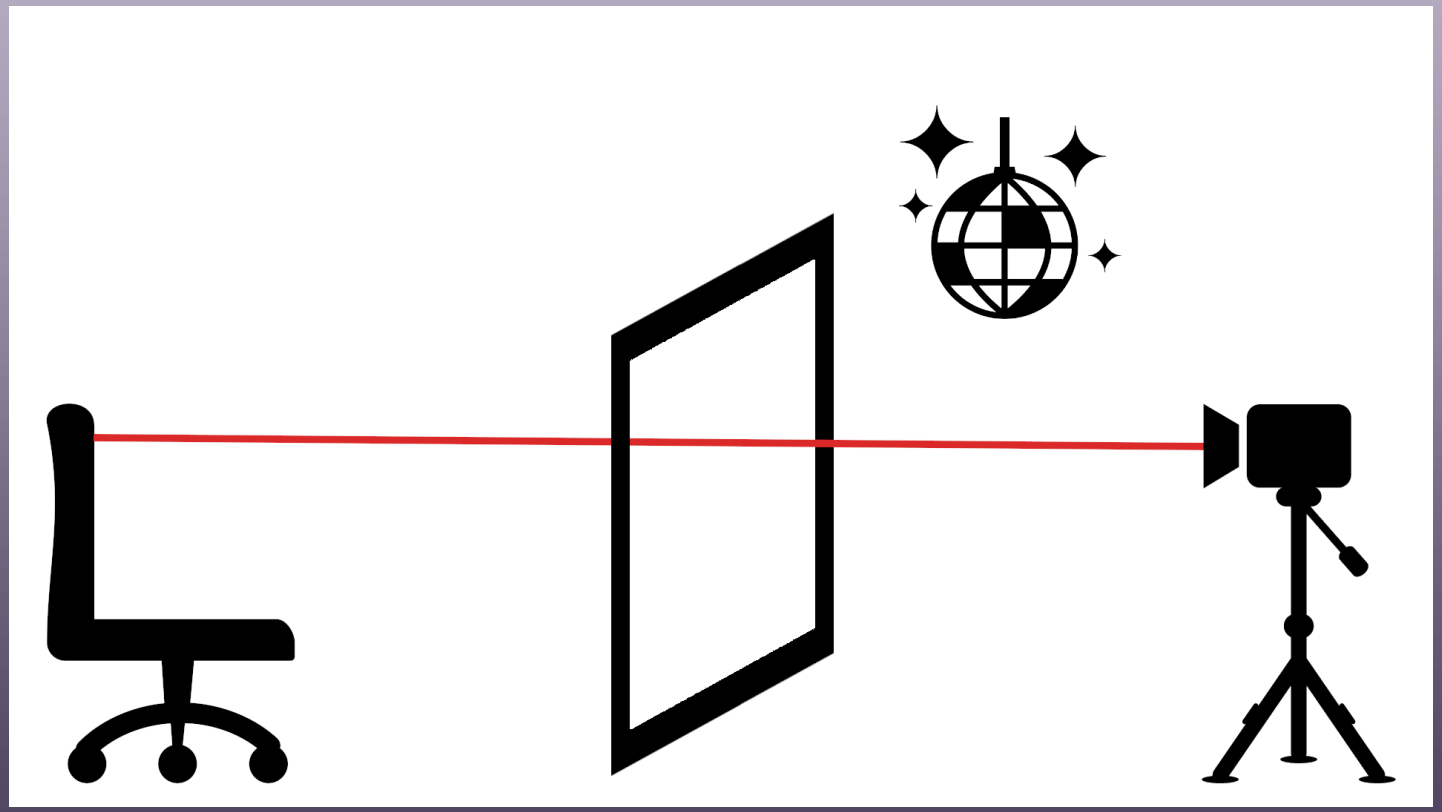

Interaction of Laser with Glass

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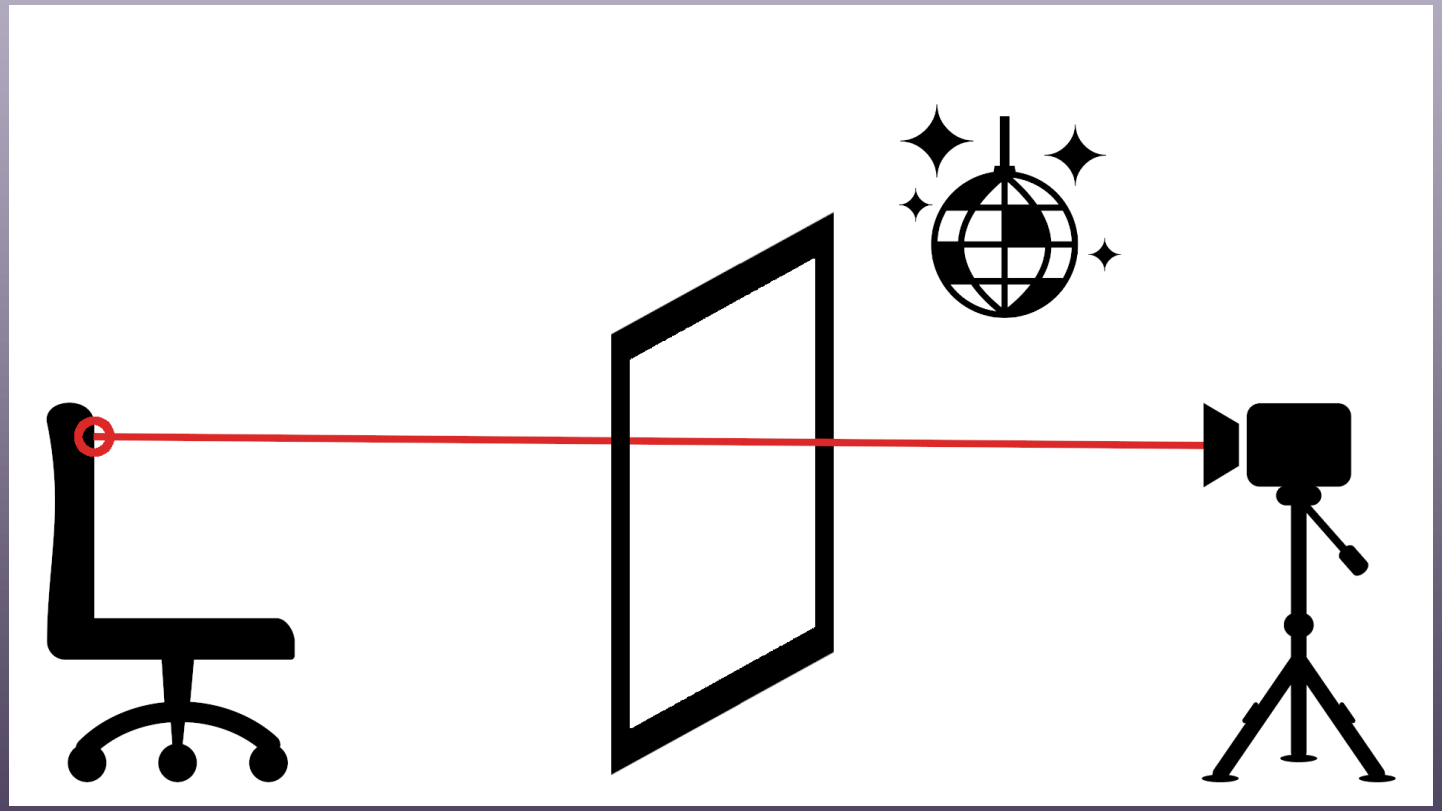
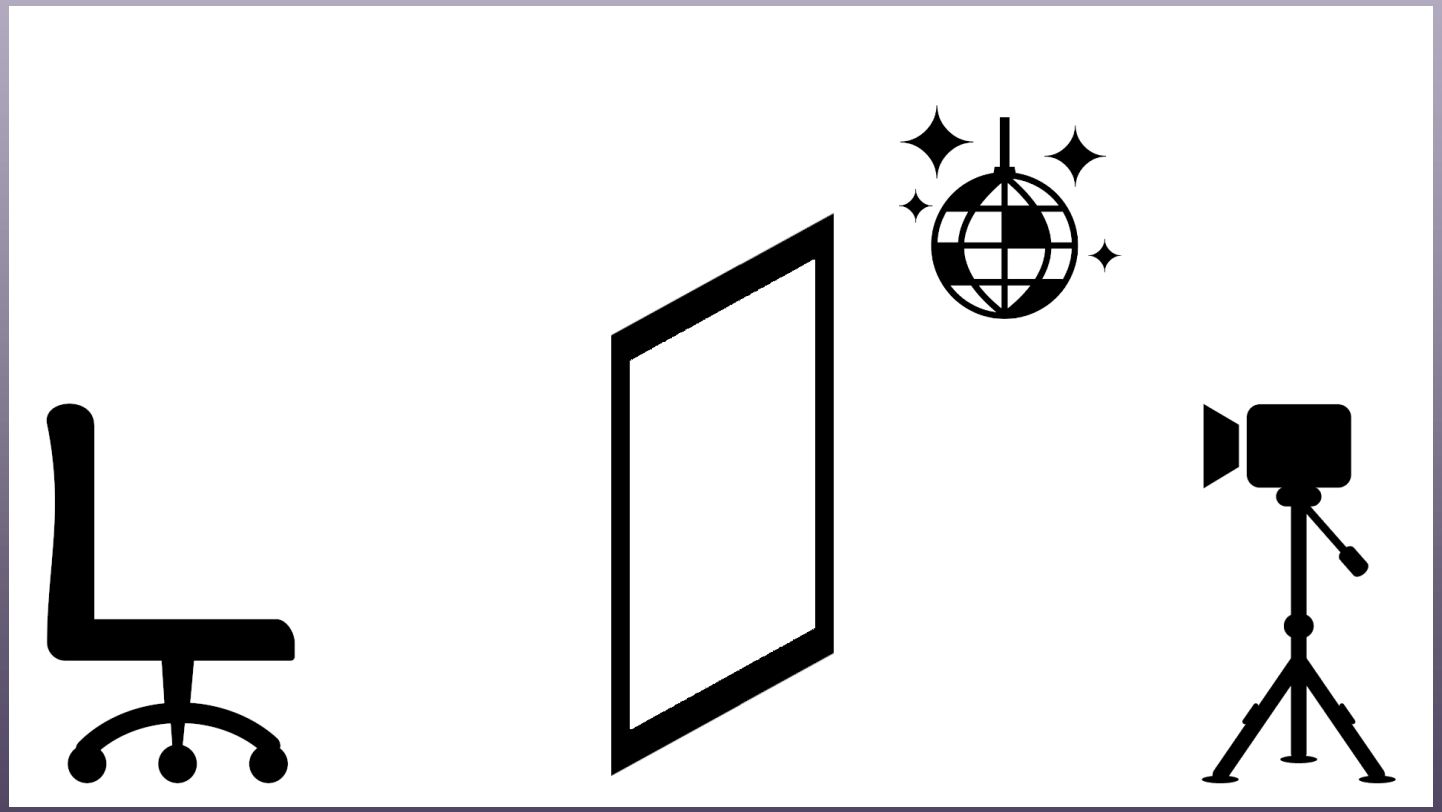


Interaction of Laser with Glass

- Possibility 2: Reflection



Interaction of Laser with Glass

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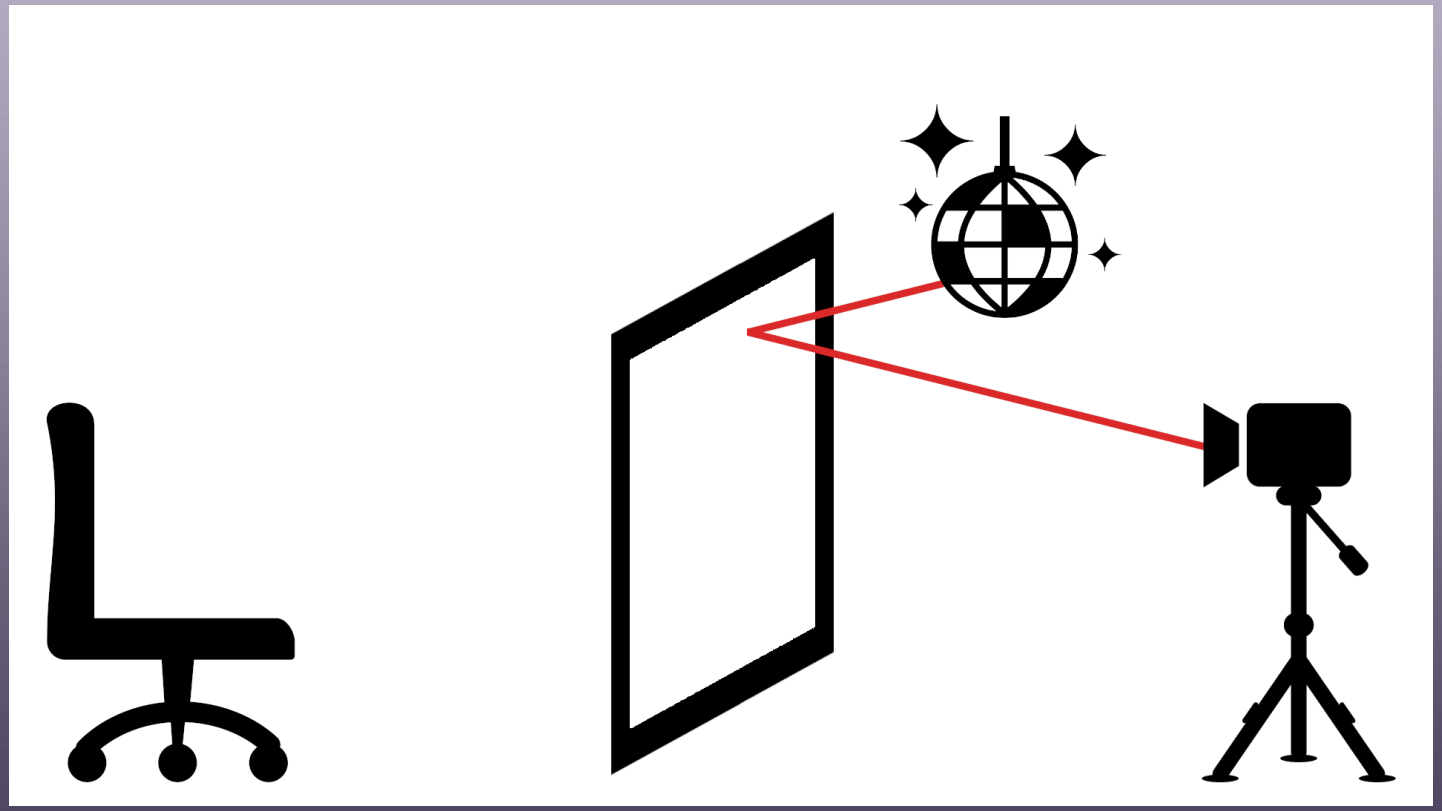

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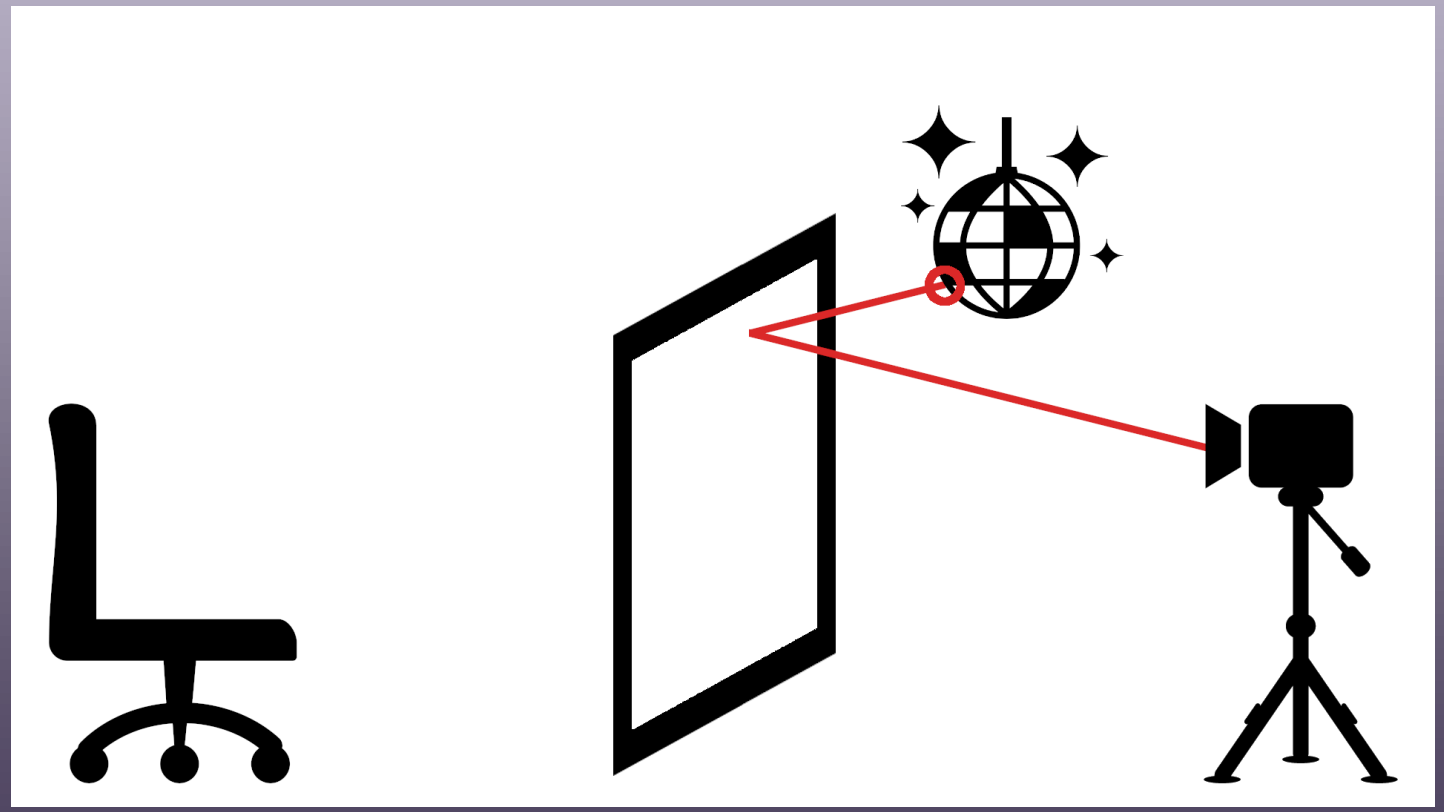

Interaction of Laser with Glass

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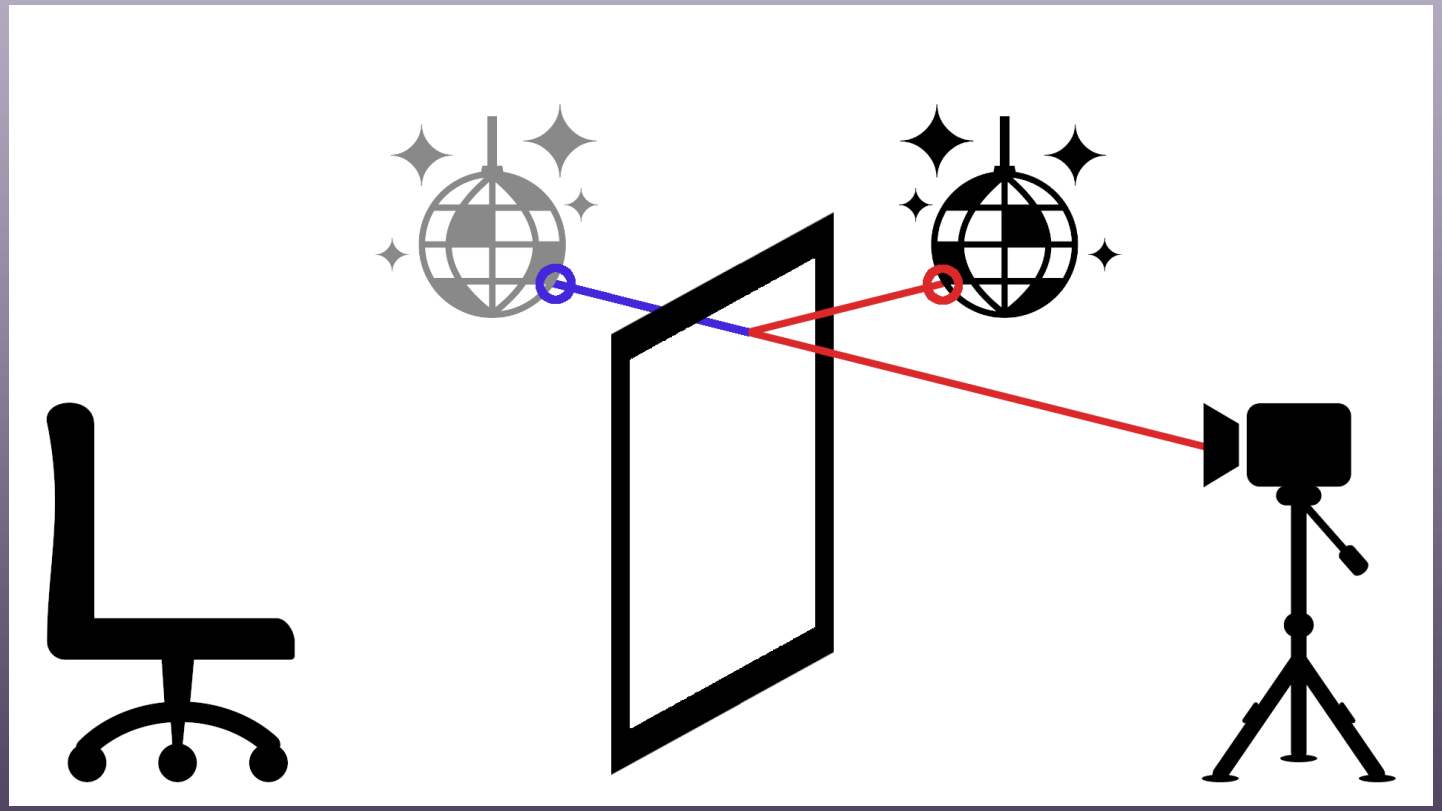
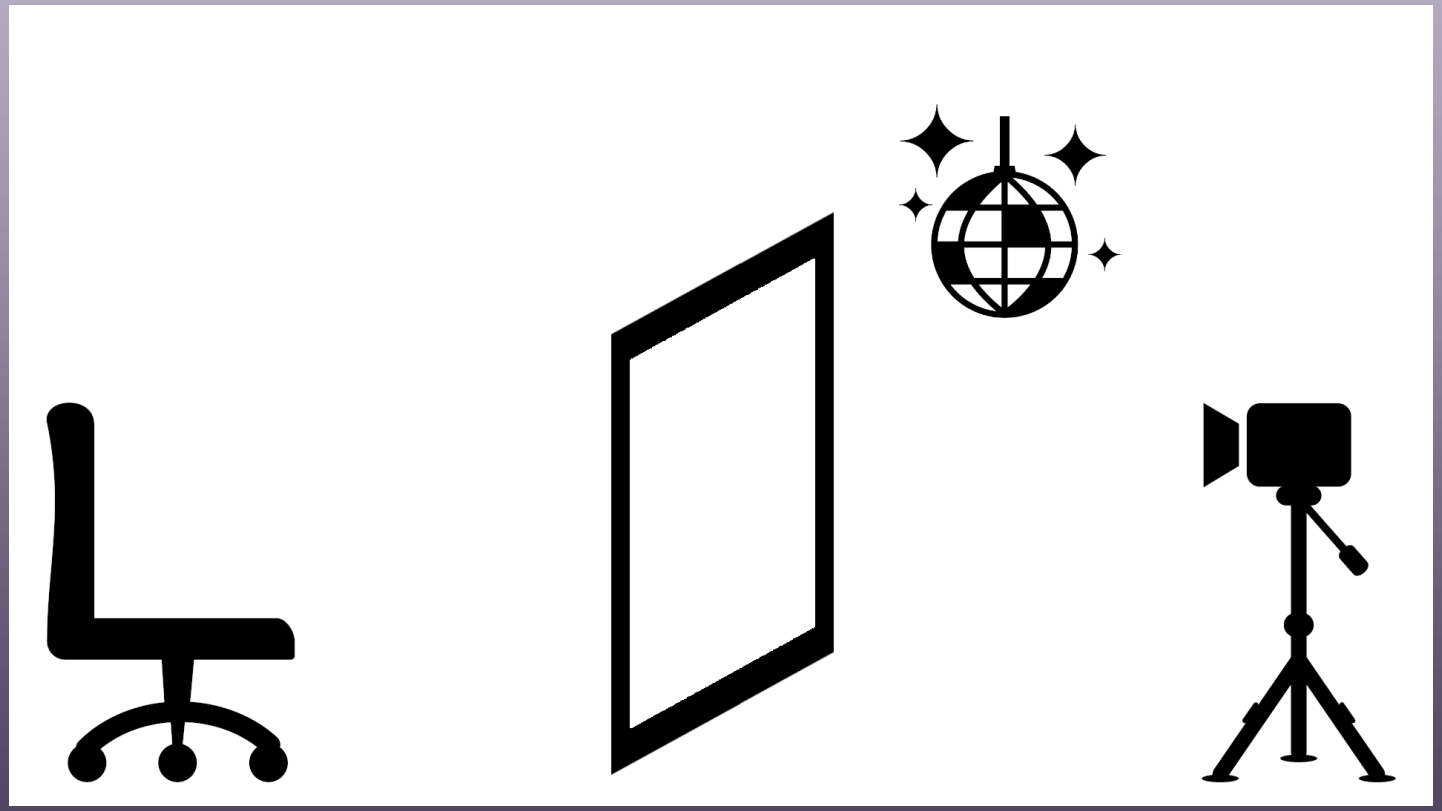


Example of possibility 2 in the data

Interaction of Laser with Glass

- Possibility 3: Direct reflection or absorption



Interaction of Laser with Glass

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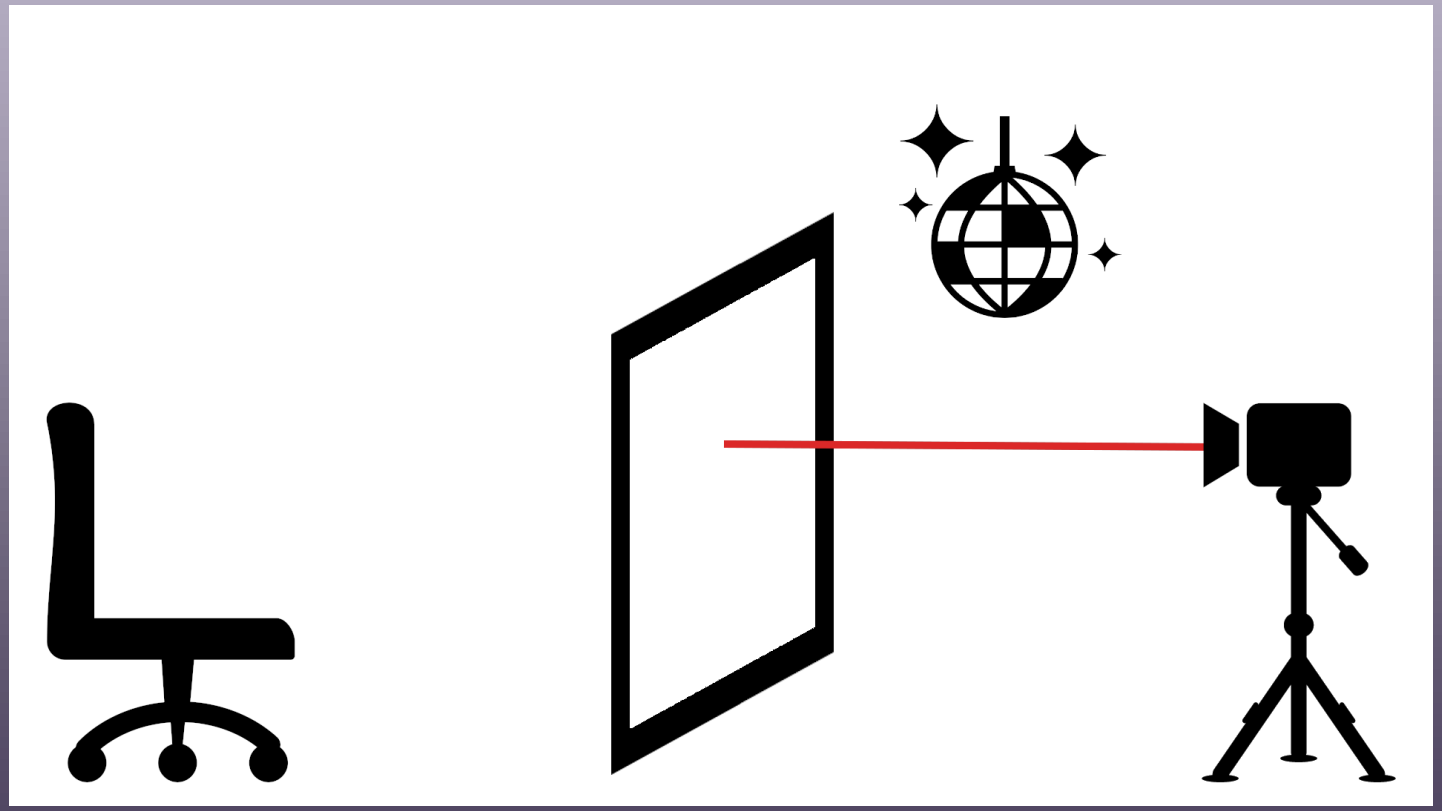

Interaction of Laser with Glass

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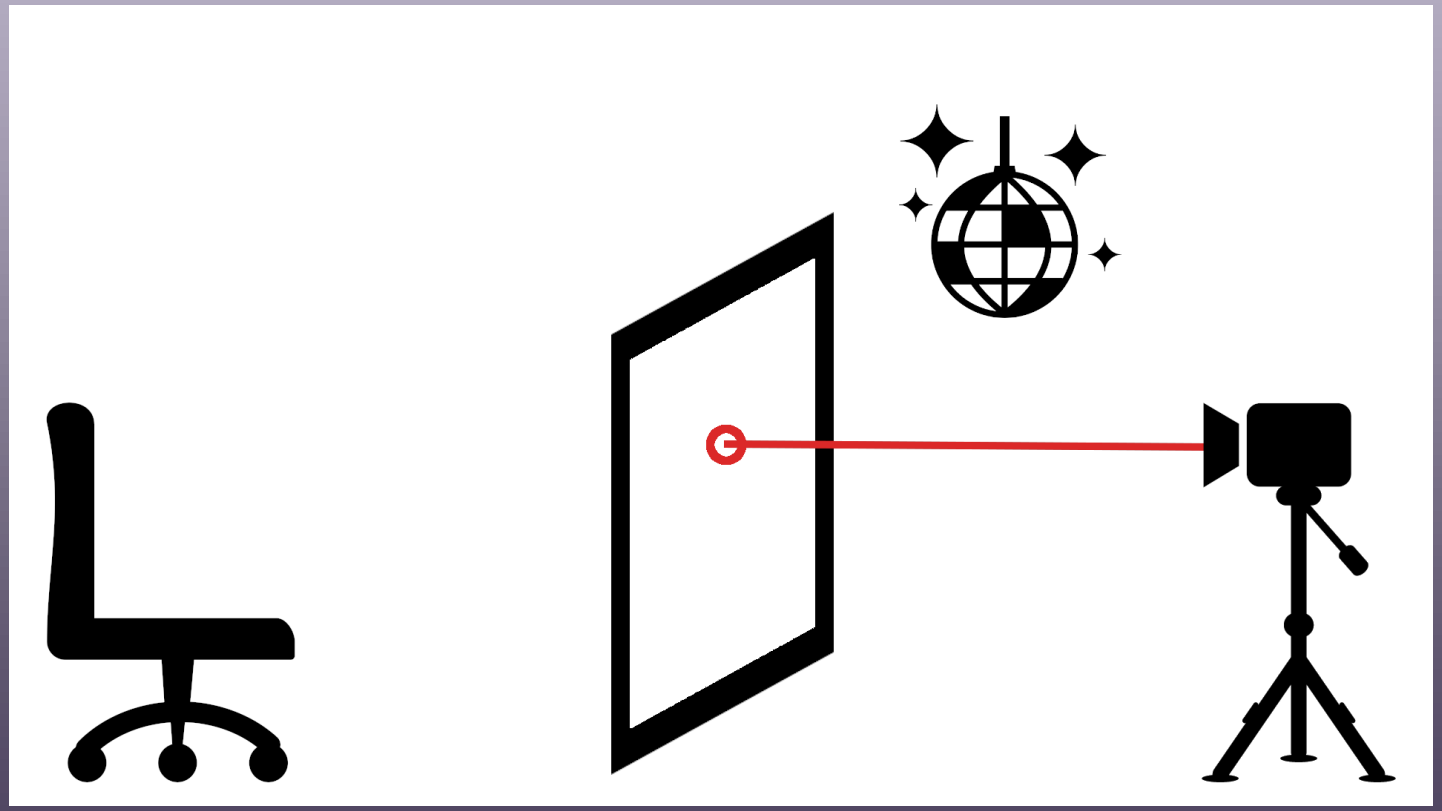
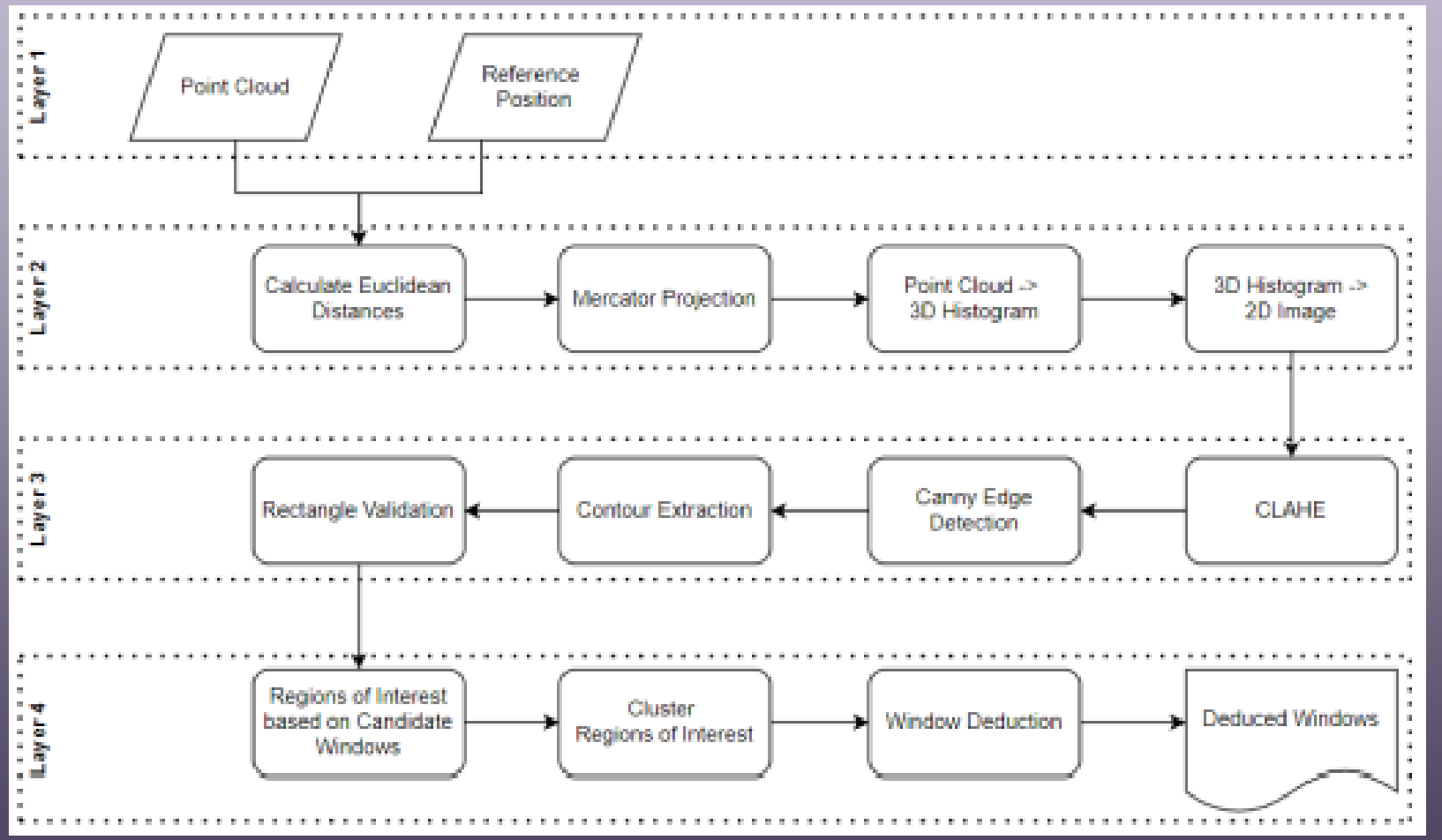
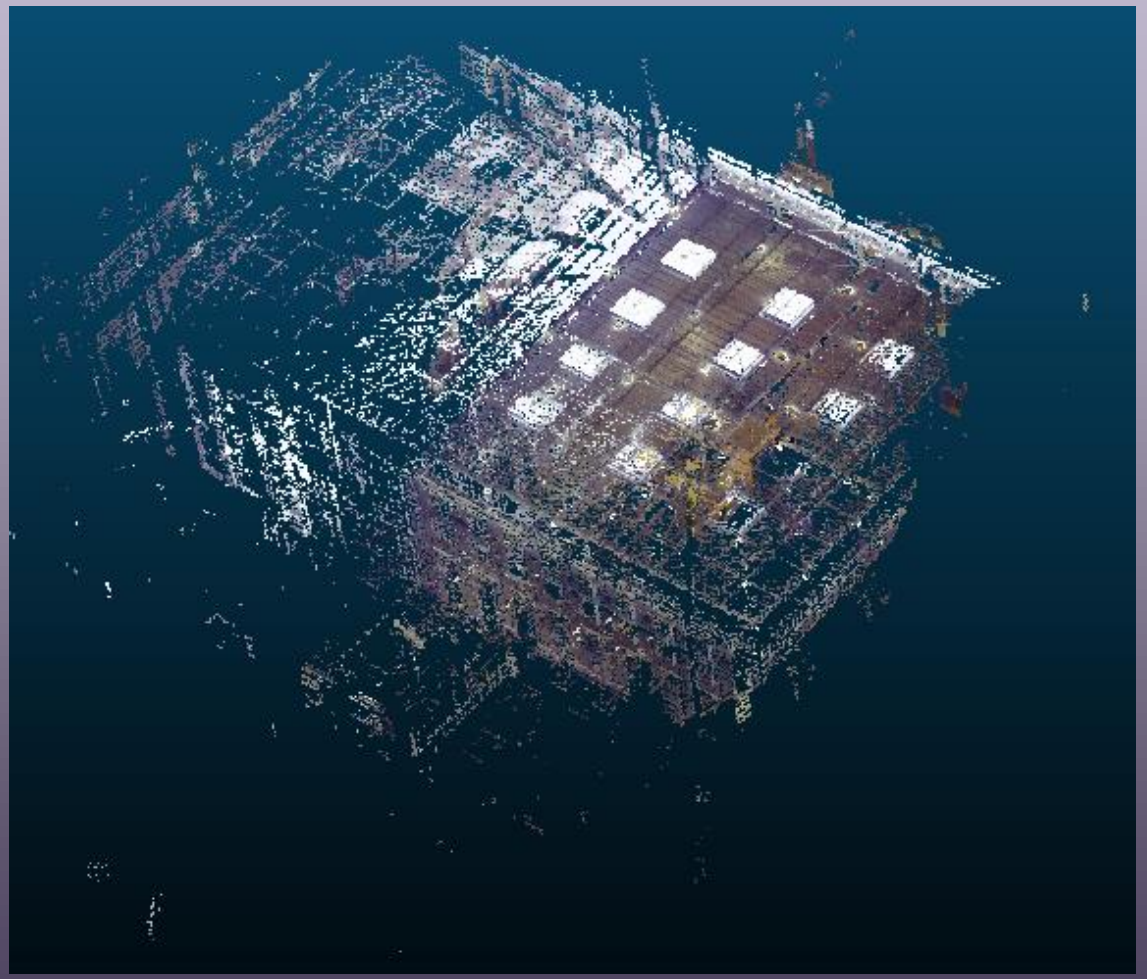


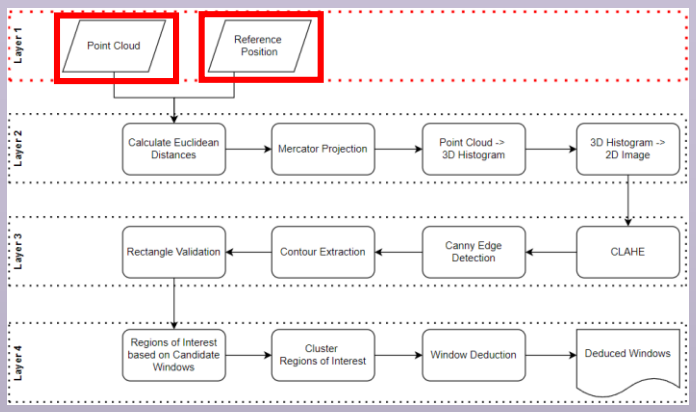
Example of possibility 3 in the data

Overview Methodology



Input data




Layer 1
Point Cloud
Reference Position
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Calculate Euclidean Distances
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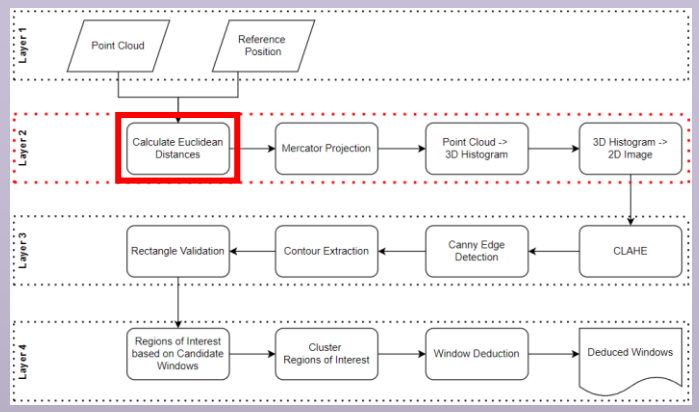
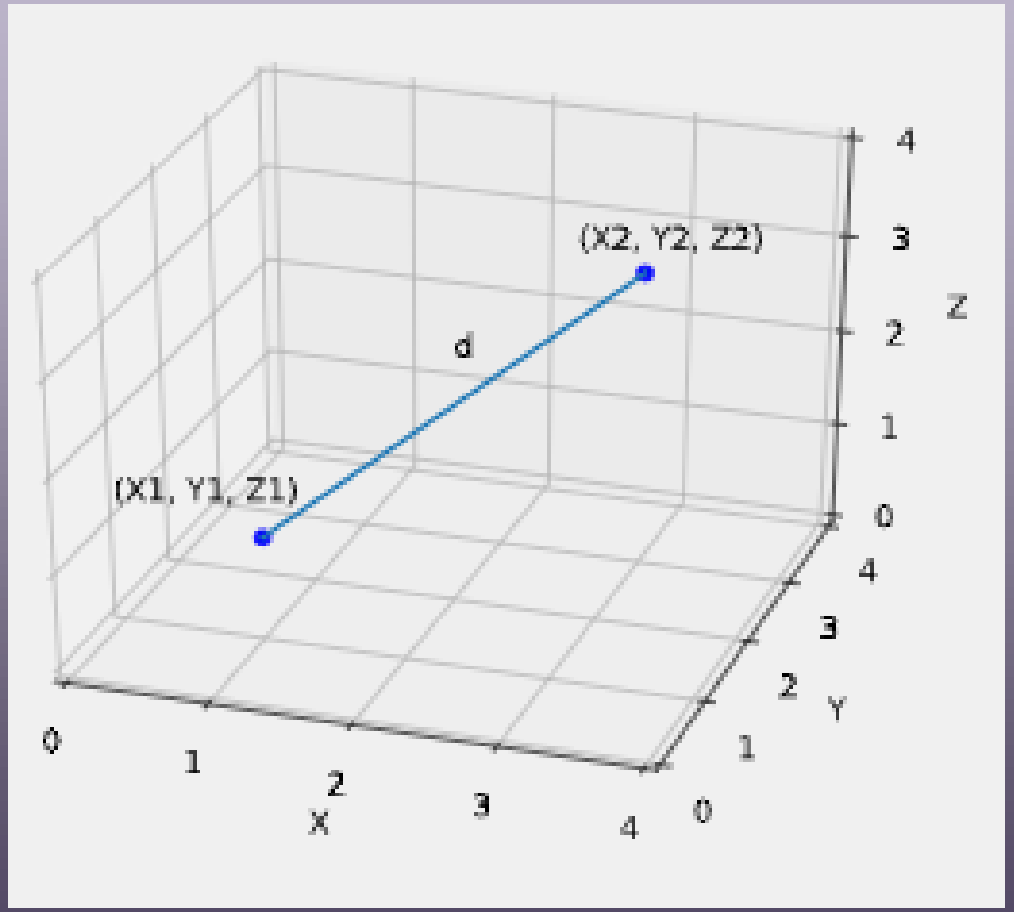
Deduced Windows

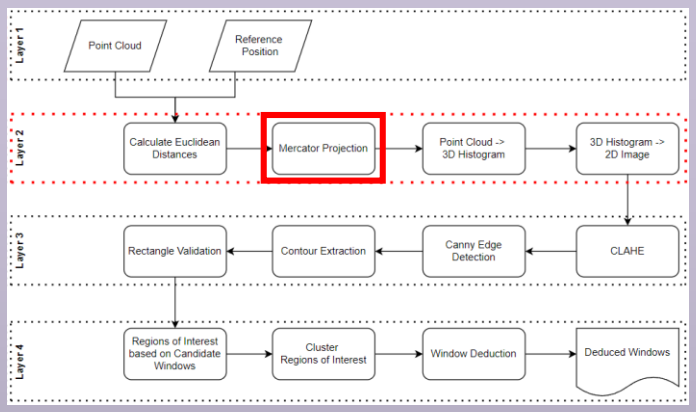

1

Calculate Euclidean Distances

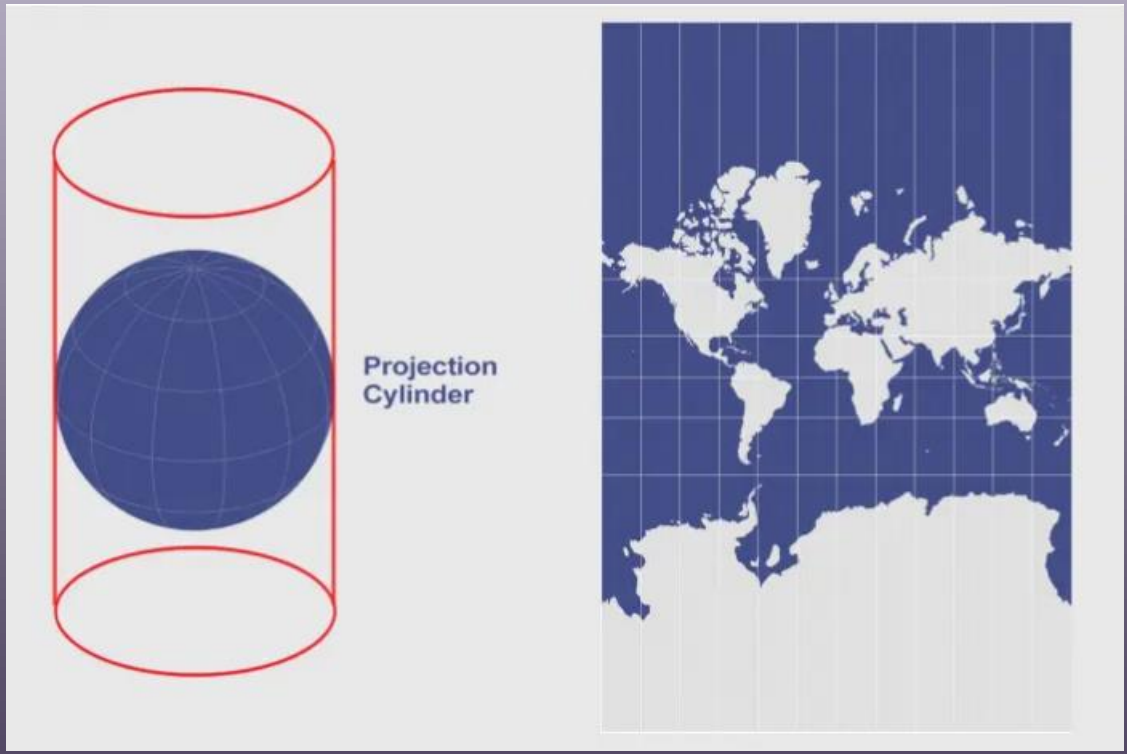


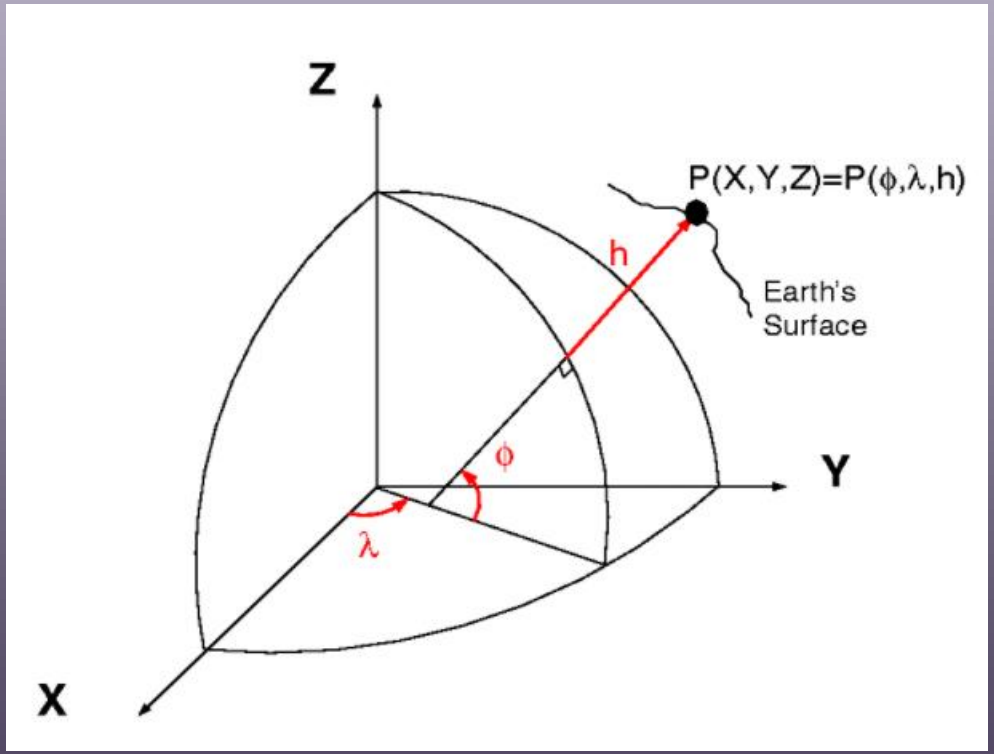


Mercator Projection

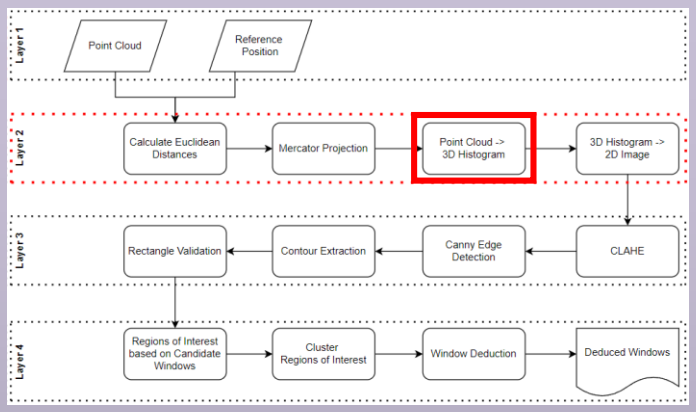


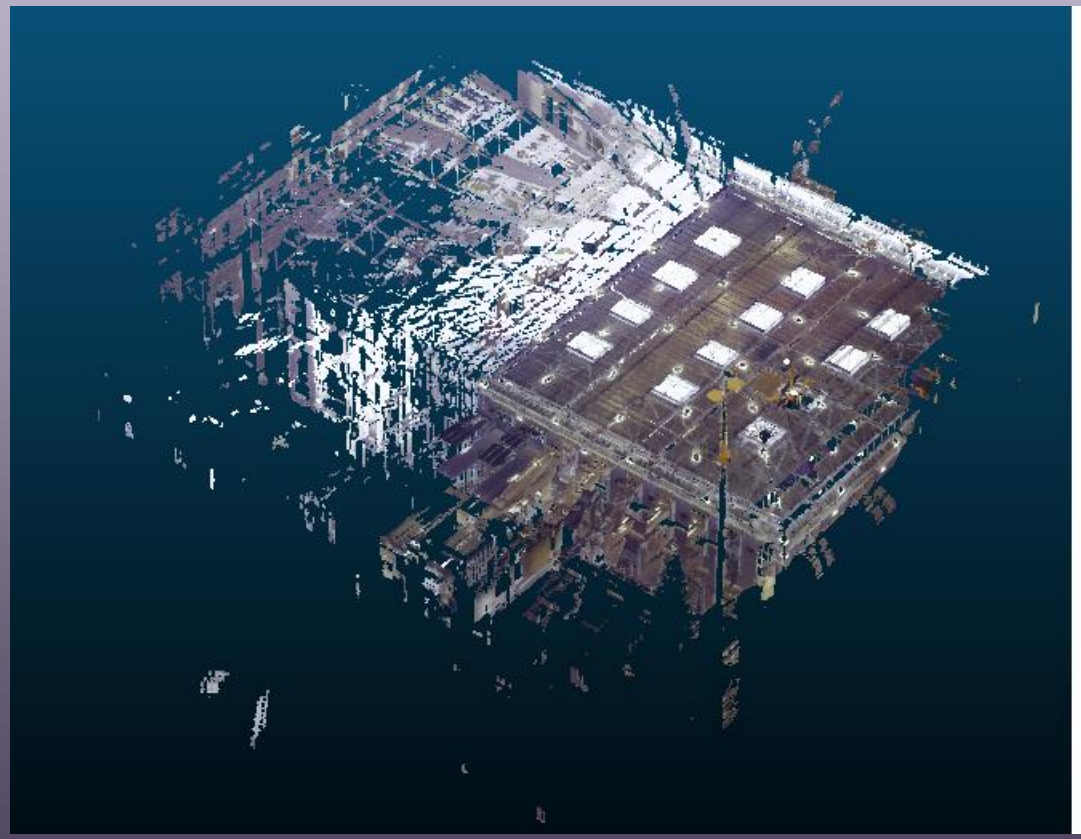
- Reference point = Projection Origin

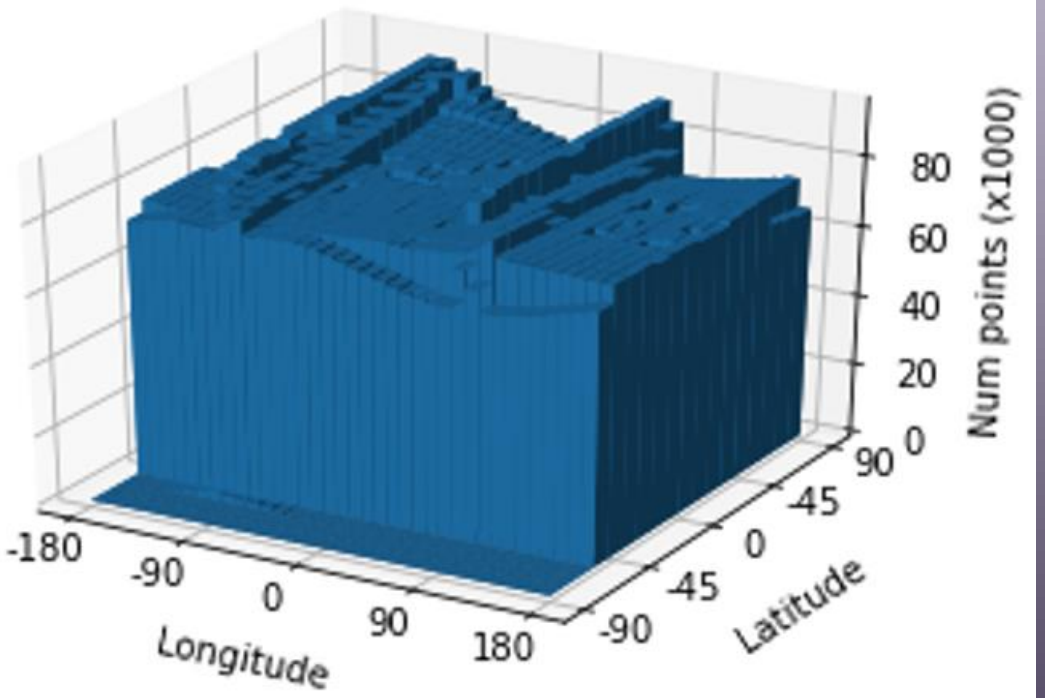




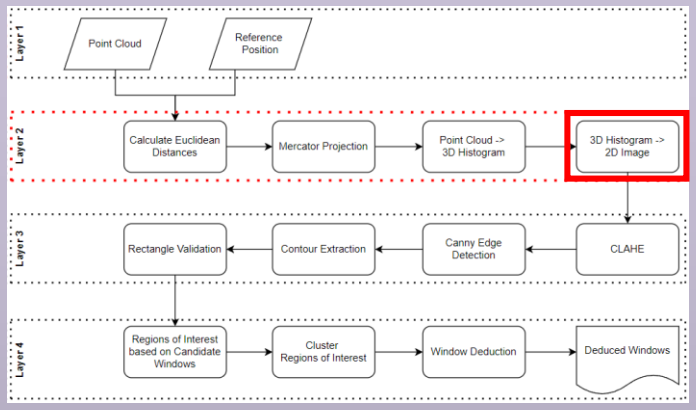
Point Cloud → 3D Histogram

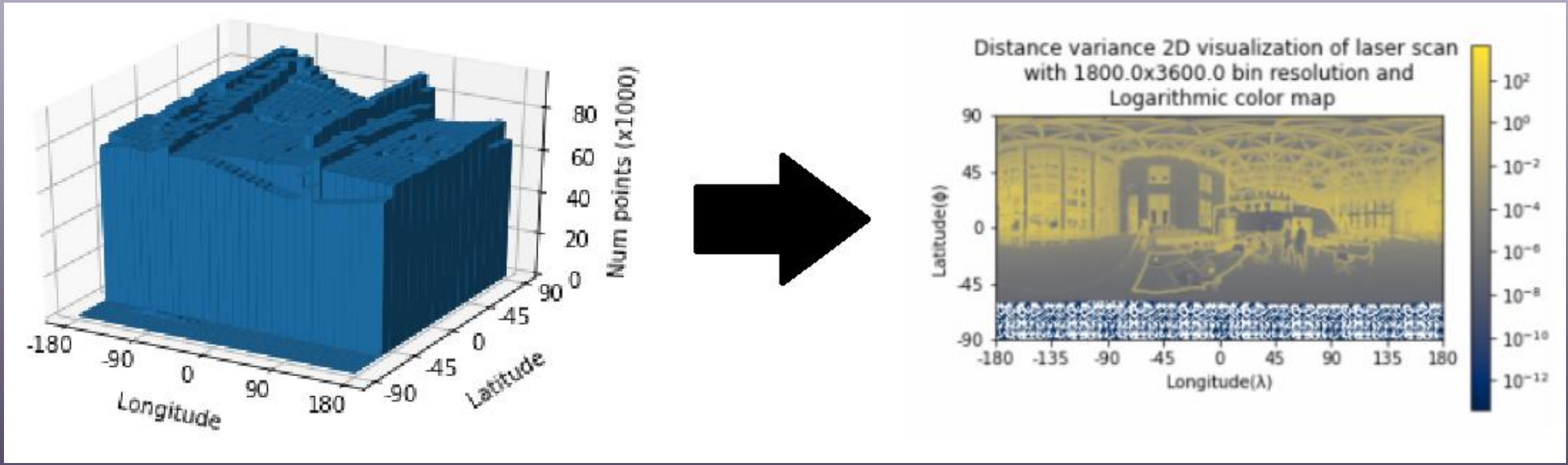




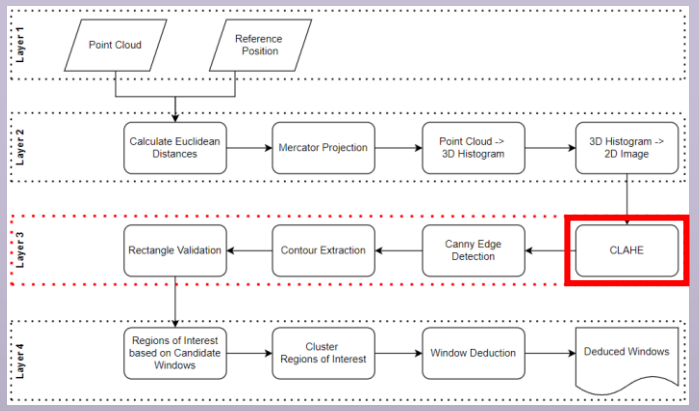


3D Histogram → 2D Image

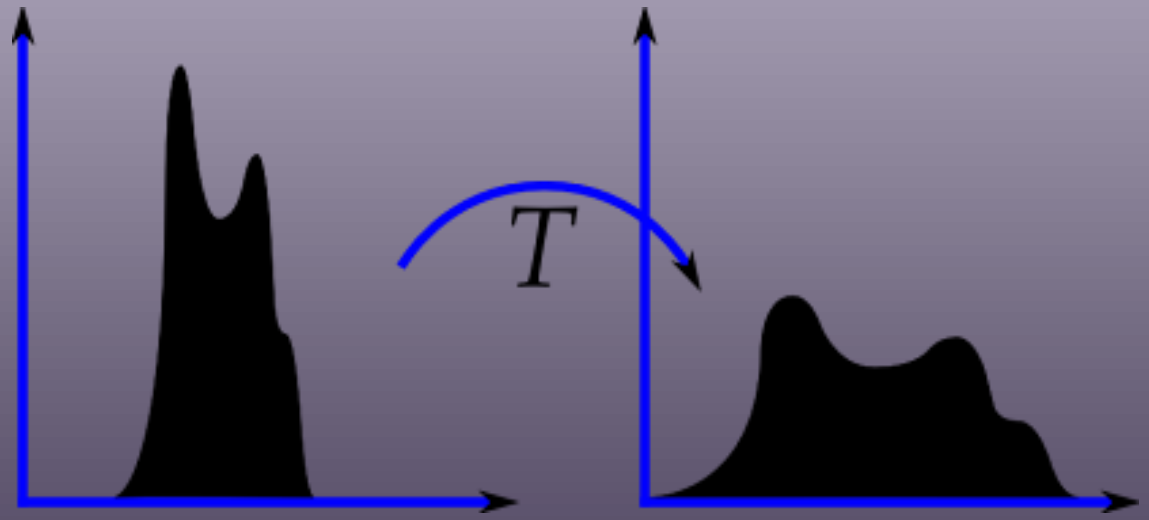




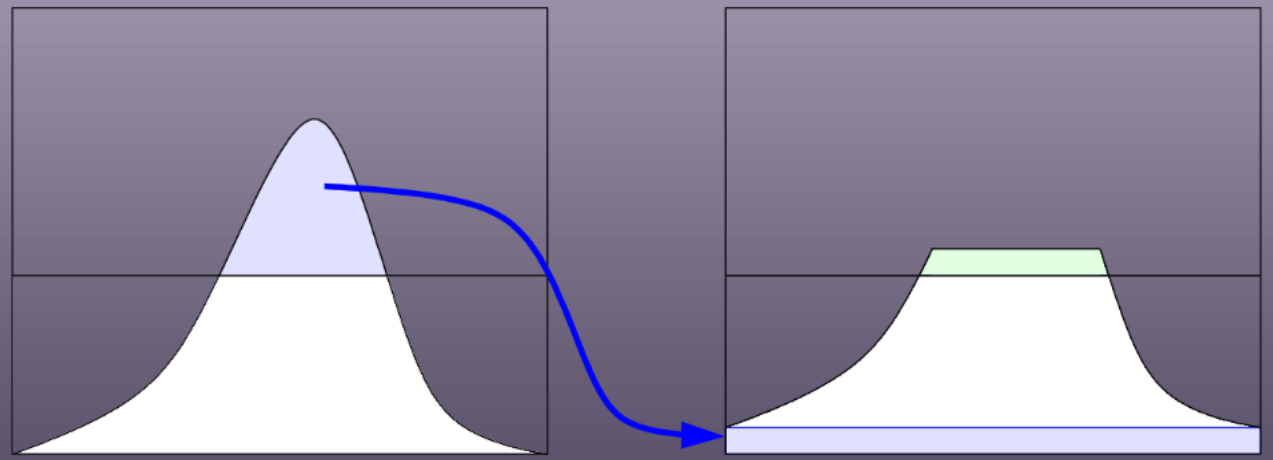
CLAHE



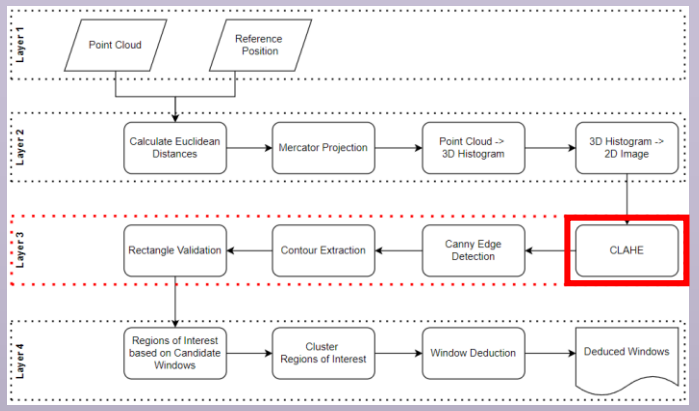
- Histogram Equalization



- Contrast Limitation



CLAHE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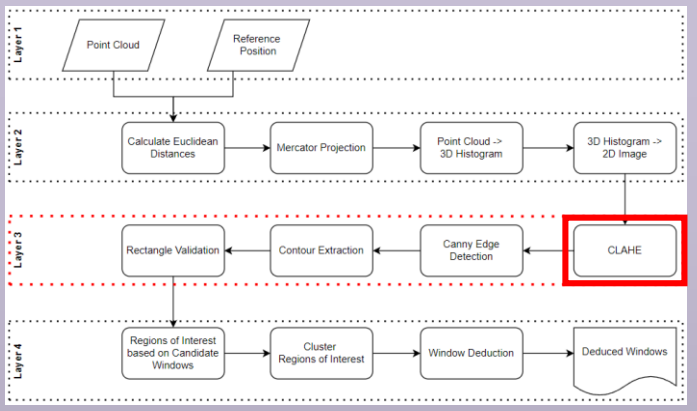
Deduced Windows

CLAHE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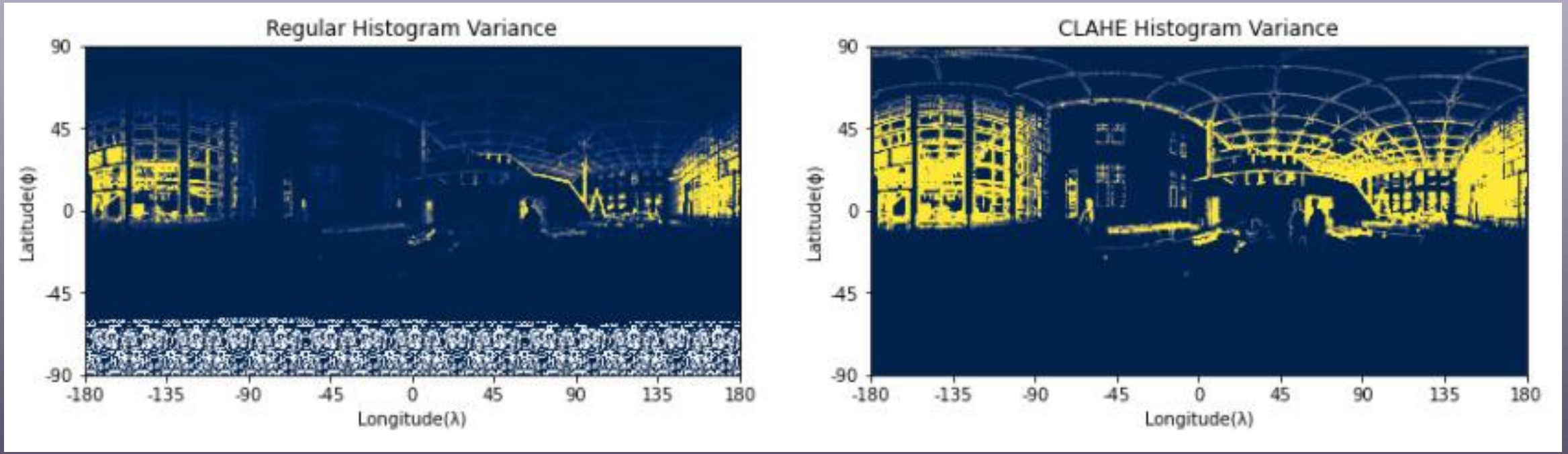
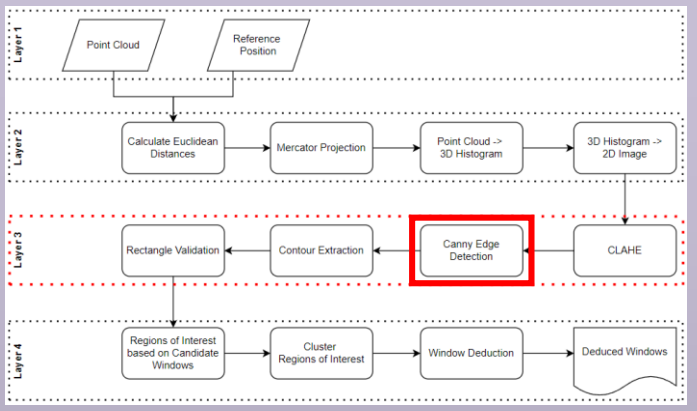

Regular Histogram Variance
Latitude(ϕ)
90
45
0
-45
-90
-180
-135
-90
-45
0
45
90
135
180
Longitude(λ)
CLAHE Histogram Variance
Latitude(ϕ)
90
45
0
-45
-90
-180
-135
-90
-45
0
45
90
135
180
Longitude(λ)

Canny Edge Detection



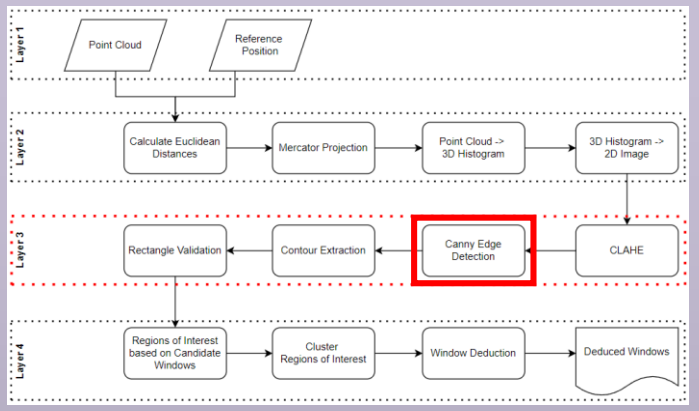
-1	0	1
-2	0	2
-1	0	1

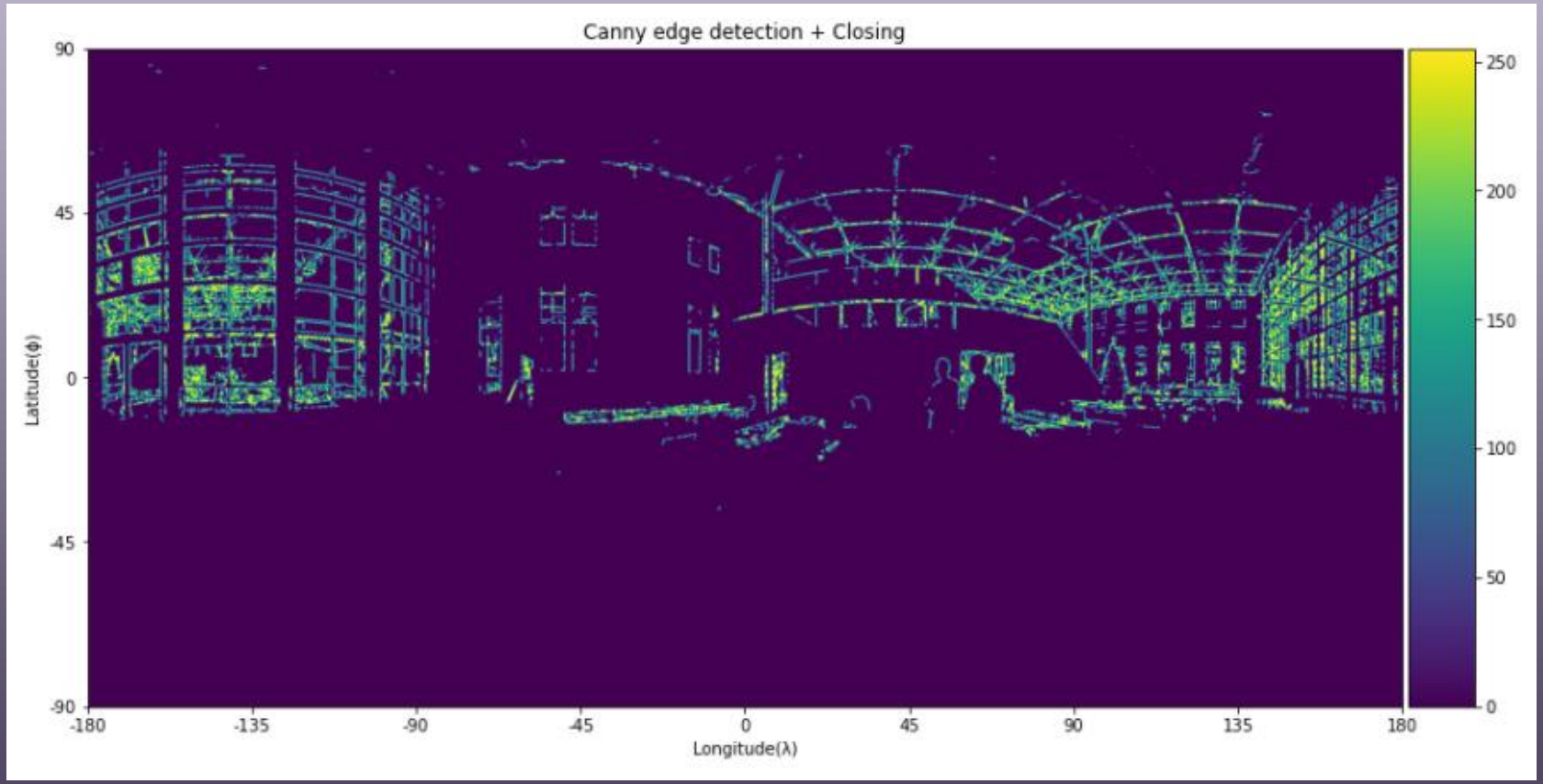
Sobel X

1	2	1
0	0	0
-1	-2	-1

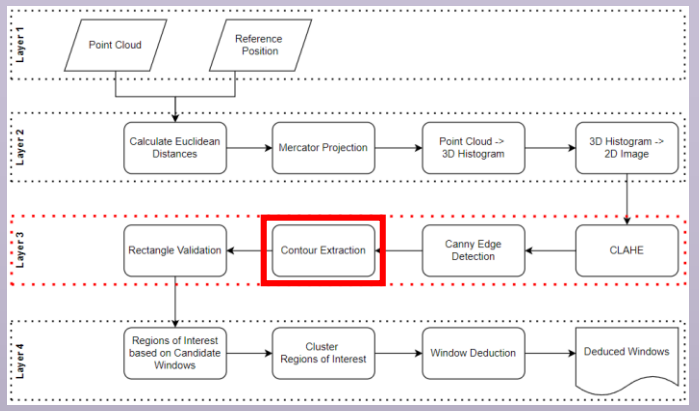
Sobel Y

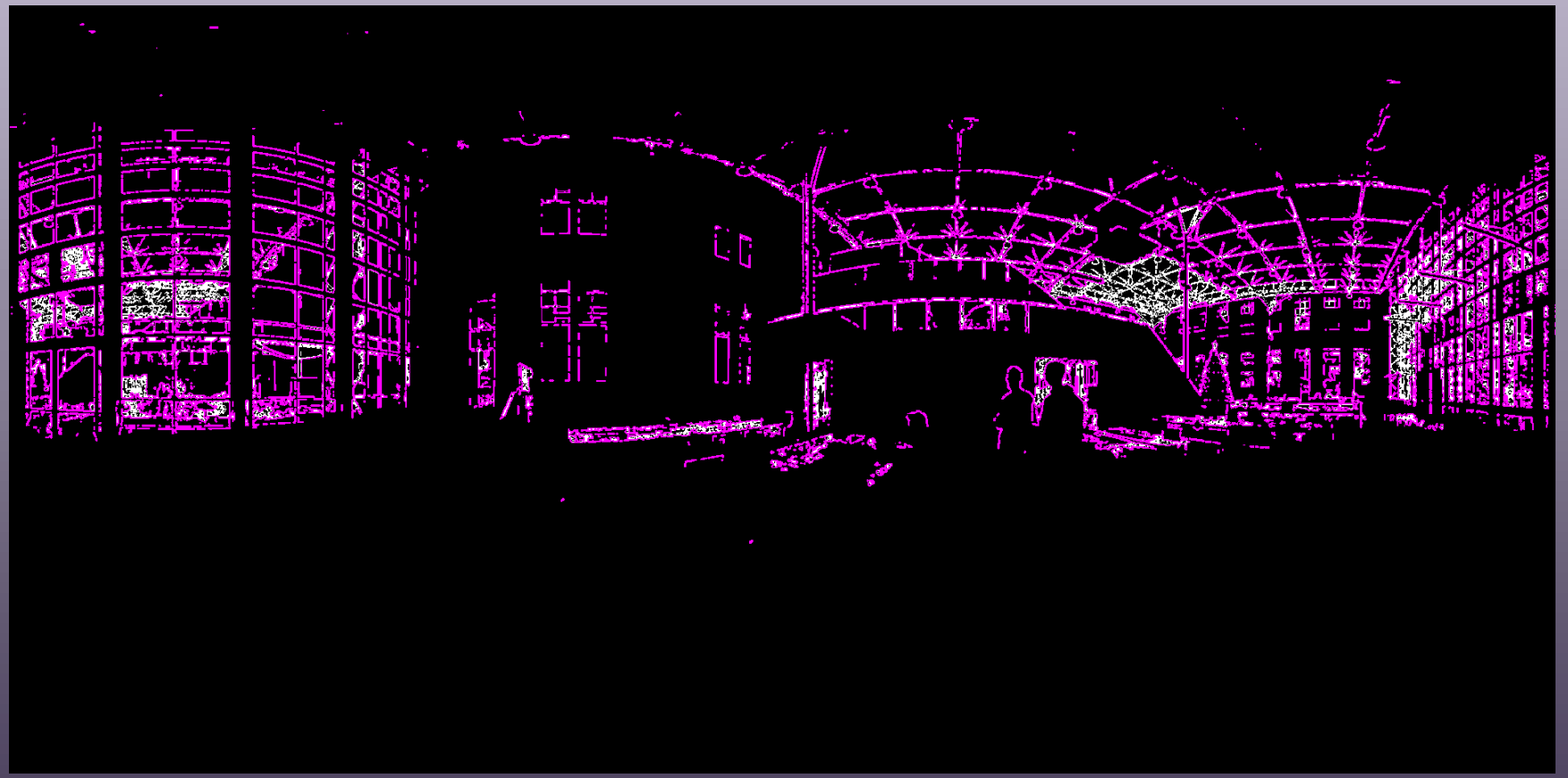
Canny Edge Detection



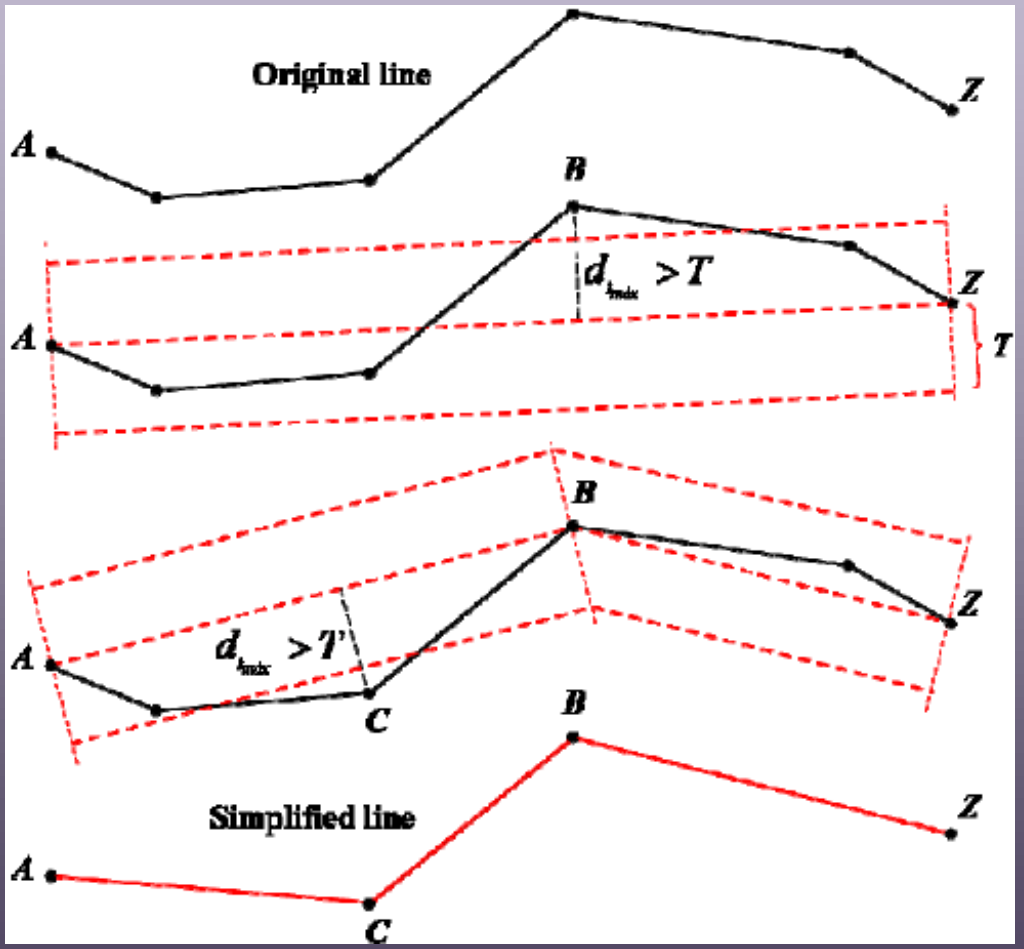


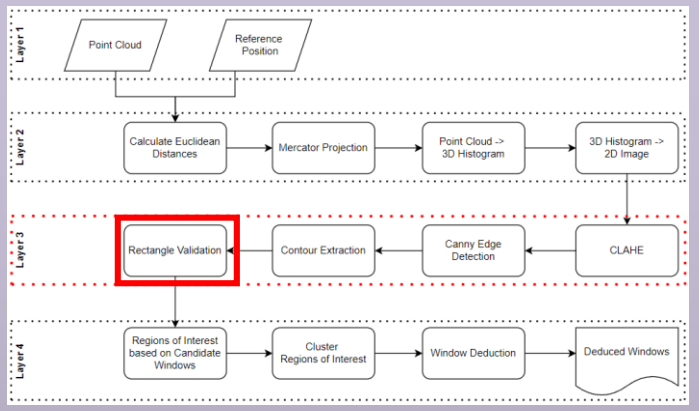
Contour Extraction





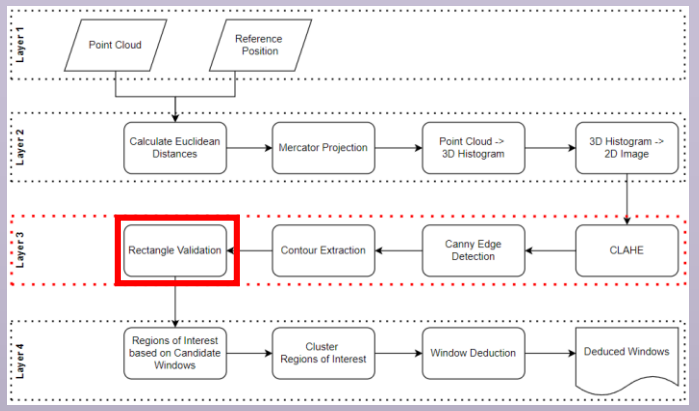
Rectangle Validation





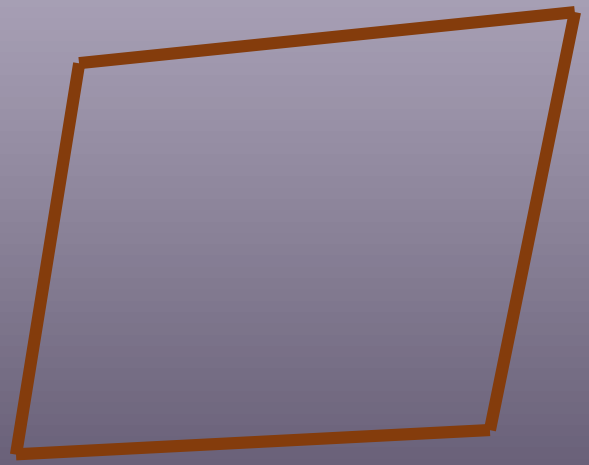
- Contour simplification
  - Douglas-Peucker algorithm
  - 4 points as corners

Rectangle Validation

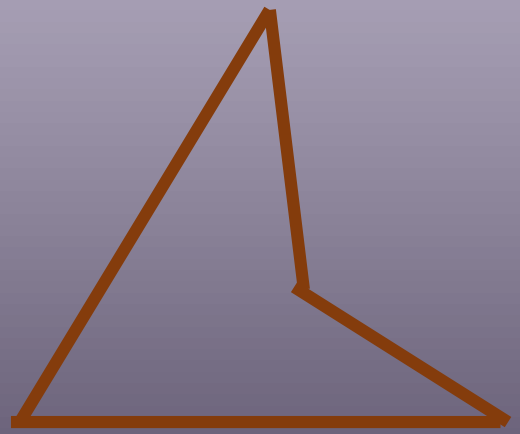


What is considered a window?

- 4 corners 90° ± Error Margin

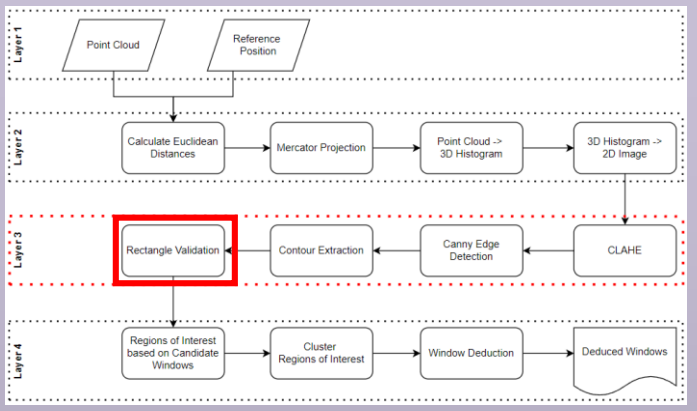


Valid

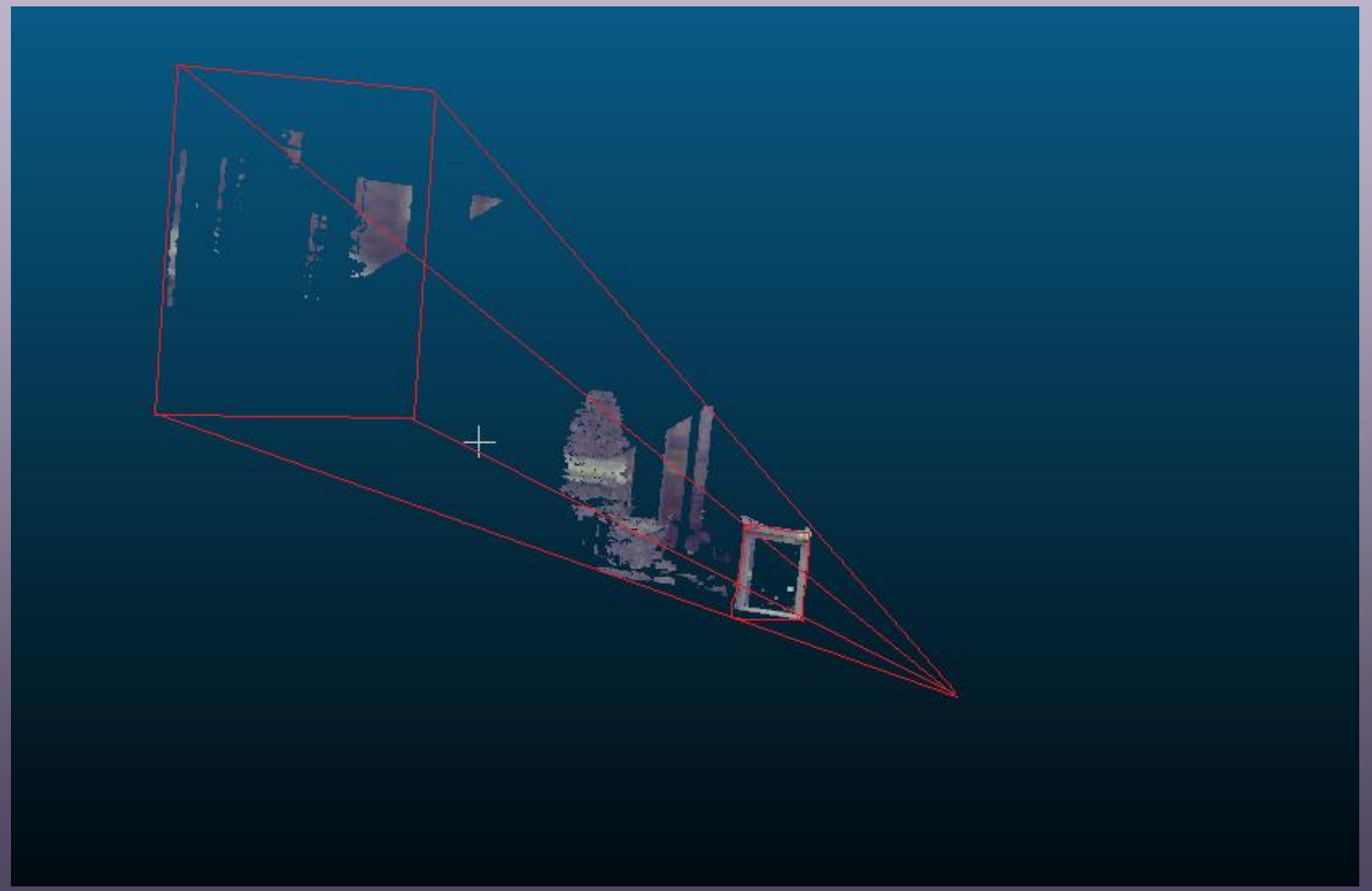


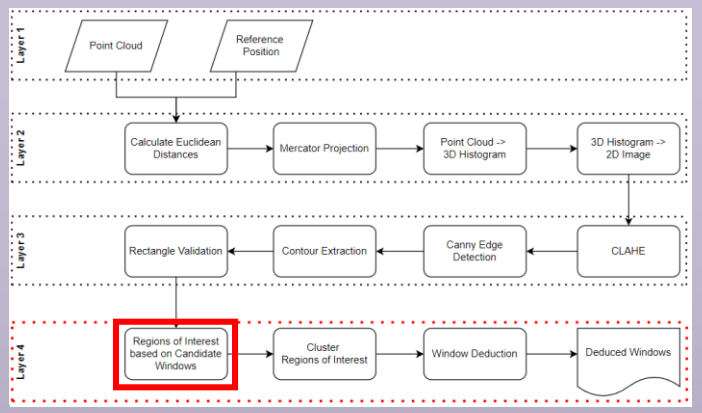
Invalid

Rectangle Validation



Get Regions of Interest based on Candidate Windows

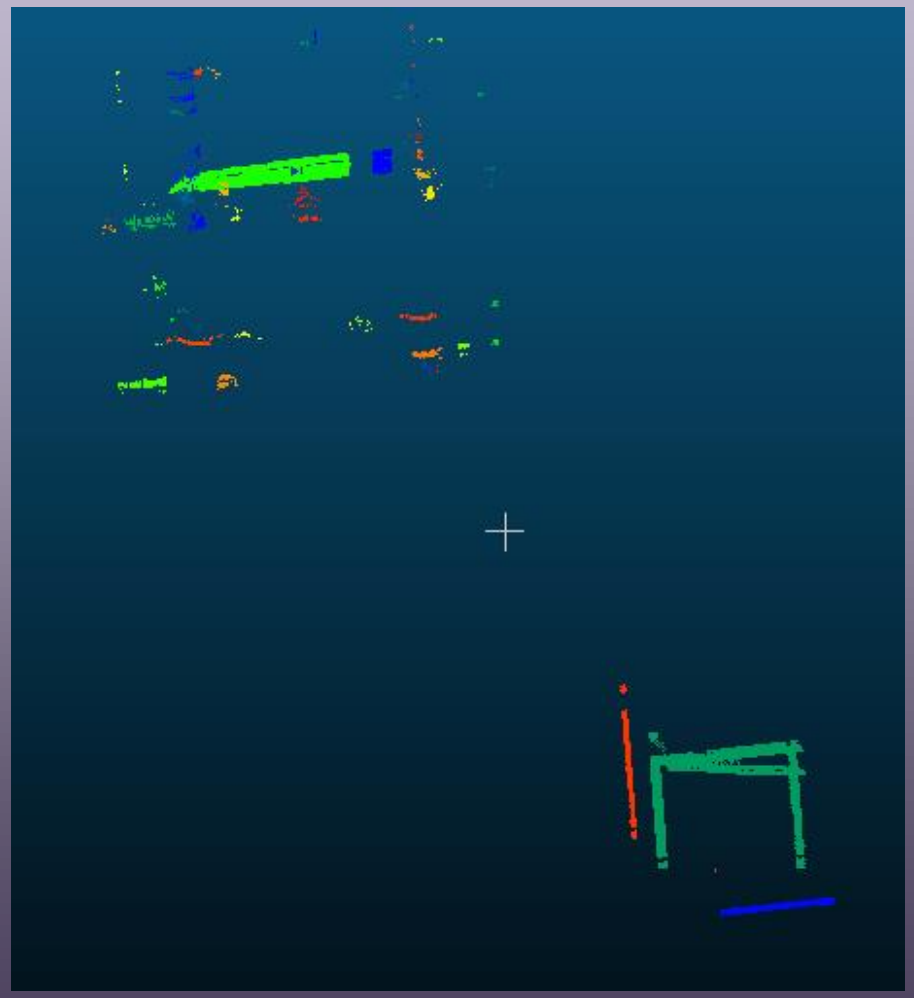


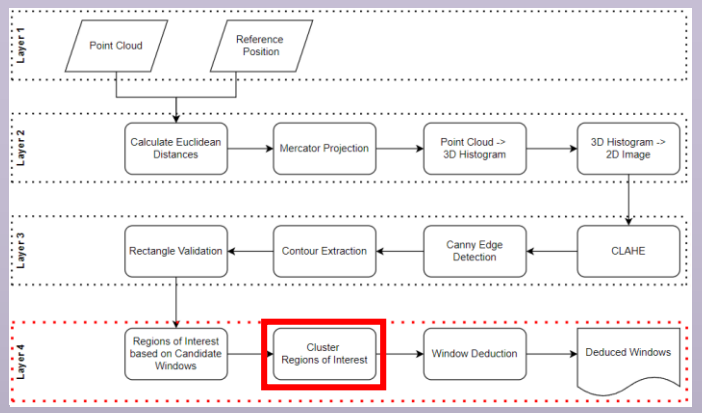


- Pyramid-shaped region of interest in LiDAR point cloud with reference point as the origin/tip

Cluster the Regions on Interest

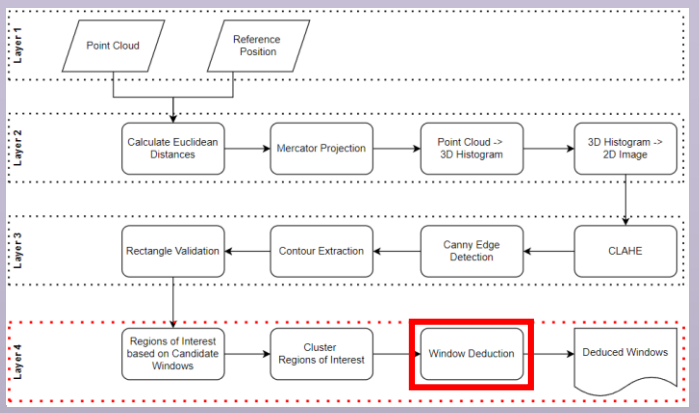
- Density-Based Clustering
- Takes gaps in space into account

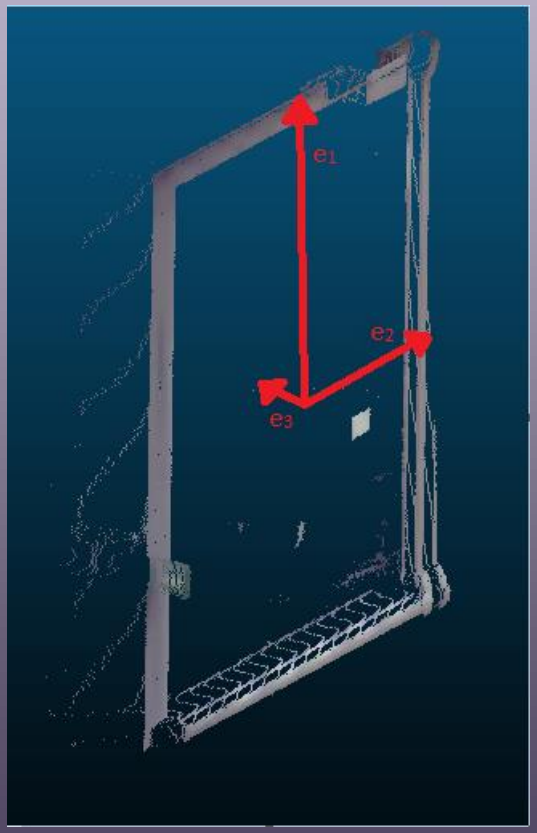




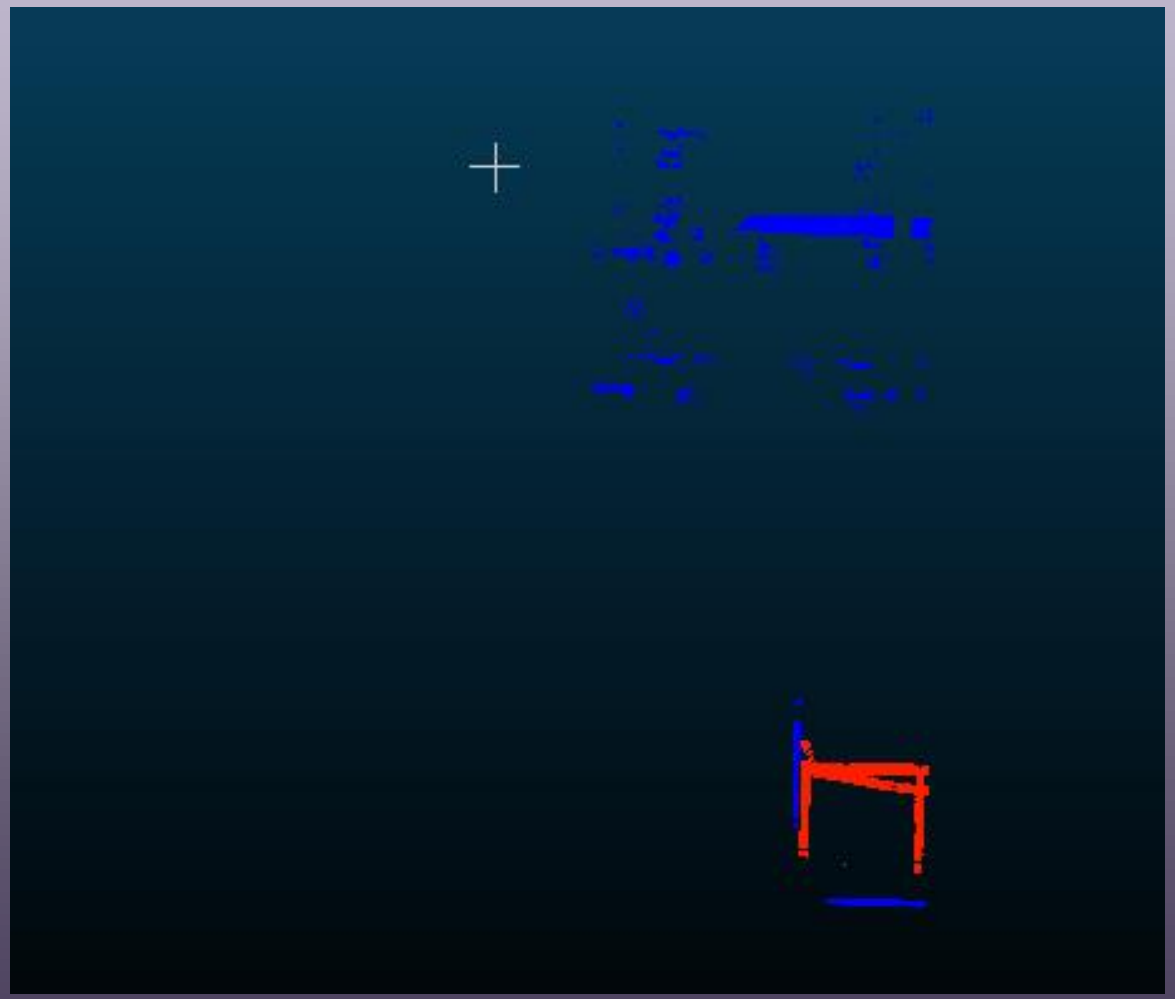
Window Deduction

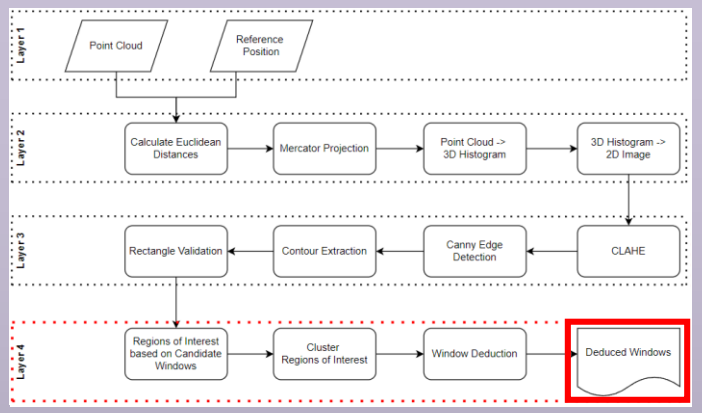
- Principal Component Analysis
- 3 eigenvalues and 3 eigenvectors per cluster
- Calculate geometrical features:
  - Linearity
  - Planarity
  - Sphericity
  - Verticality
  - Change of Curvature
- Highest weighted average





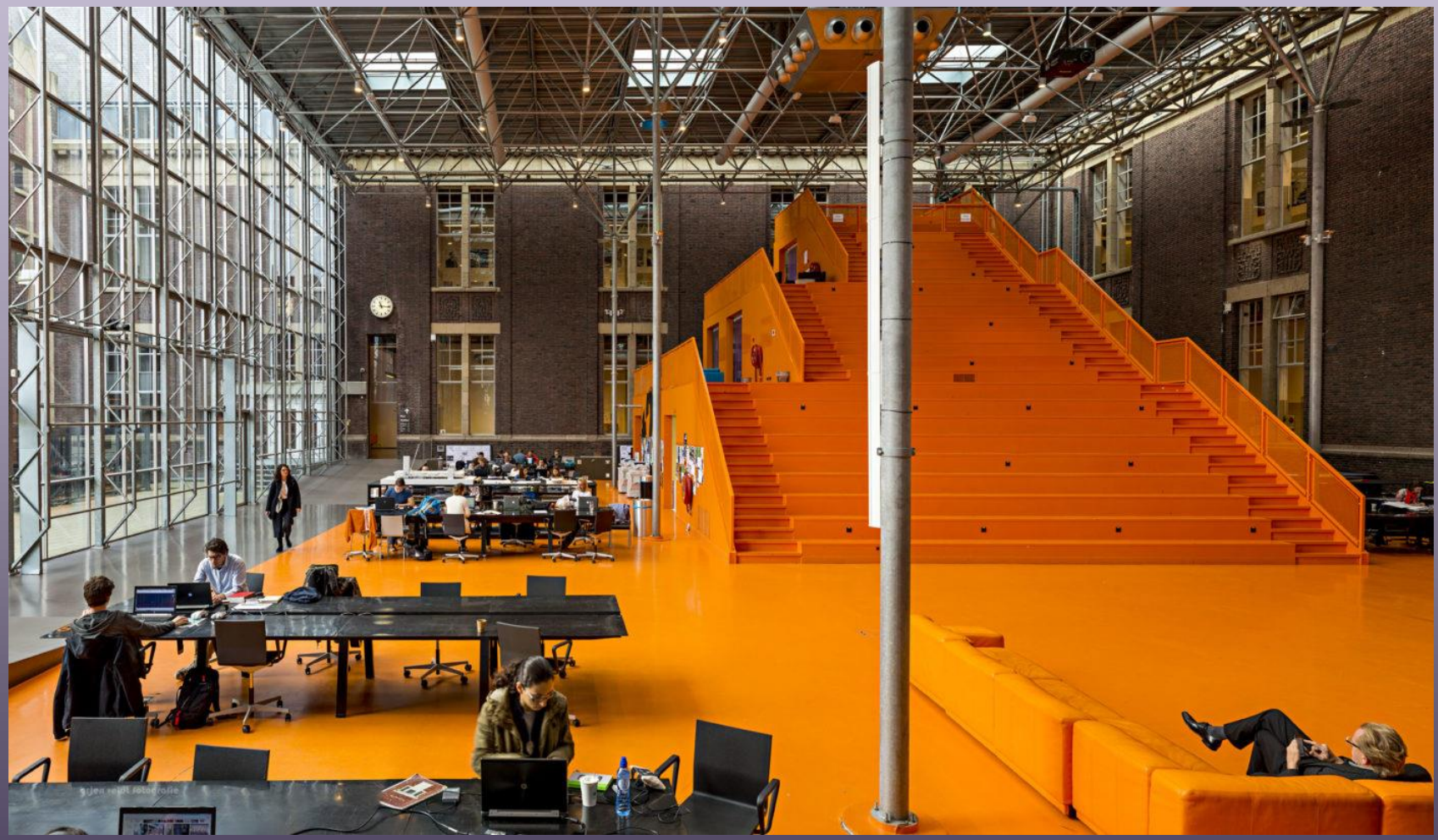
Deduced Windows



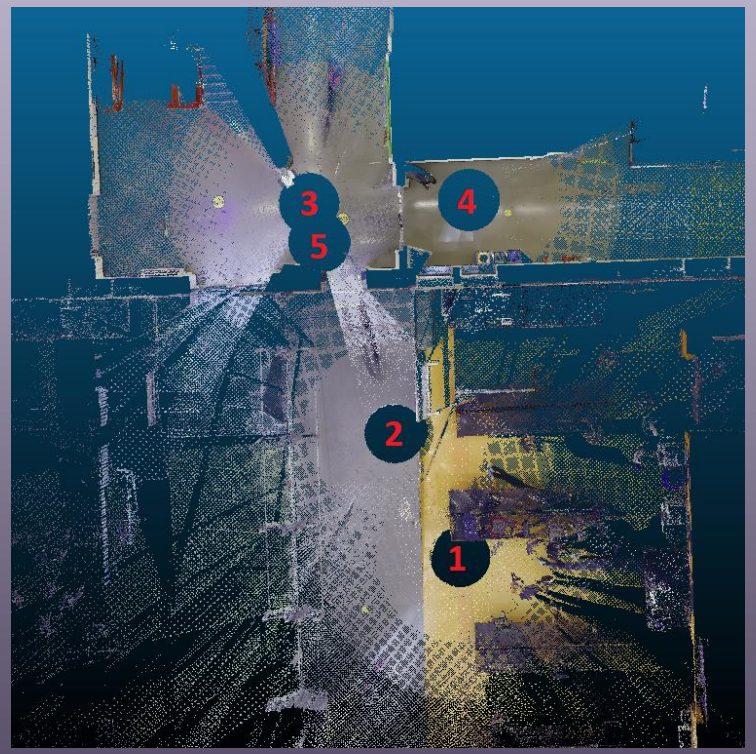


Location

- Orange Hall
  - Wall of windows
  - Indoor windows
  - Open doors
  - Metal beams



Scan locations



Scene 1

Scene 2

Scene 3

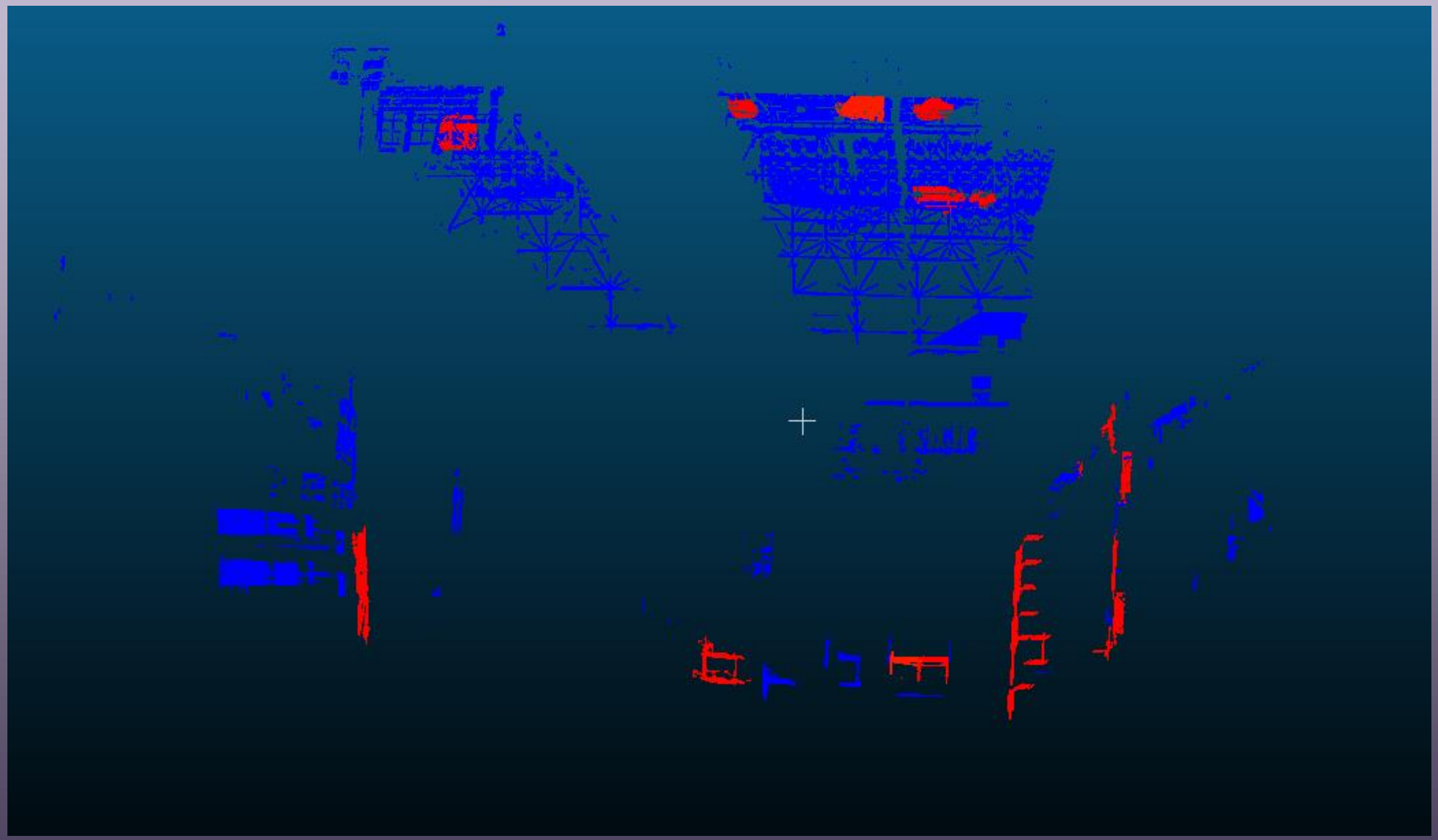
Scene 4

Scene 5

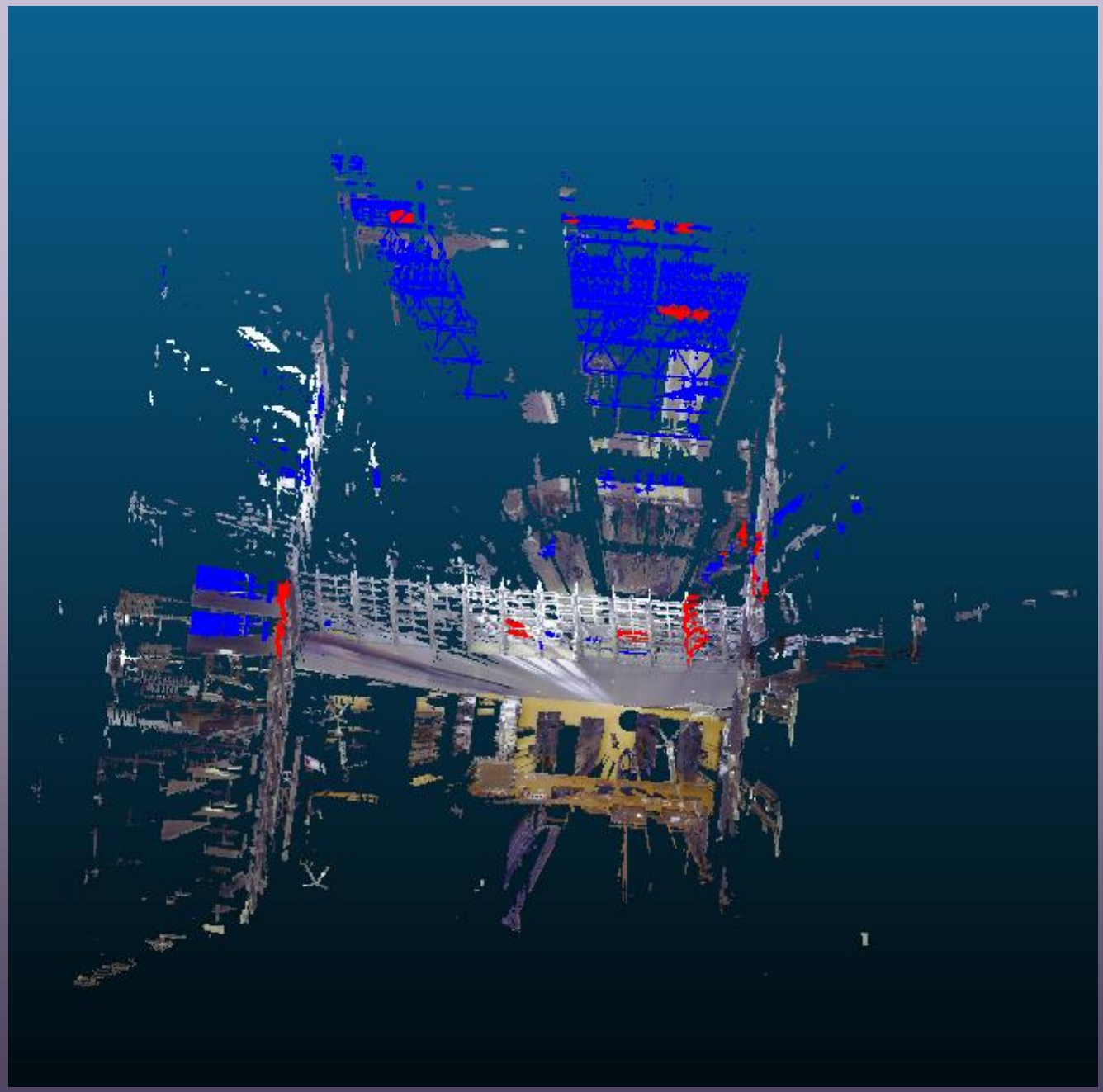
Location

- Leica RTC360
- Terrestrial Laser Scanner
- Range from 0.5 to 130 meter
- Up to 2 million points per second
- About 41 million point per scene

Results

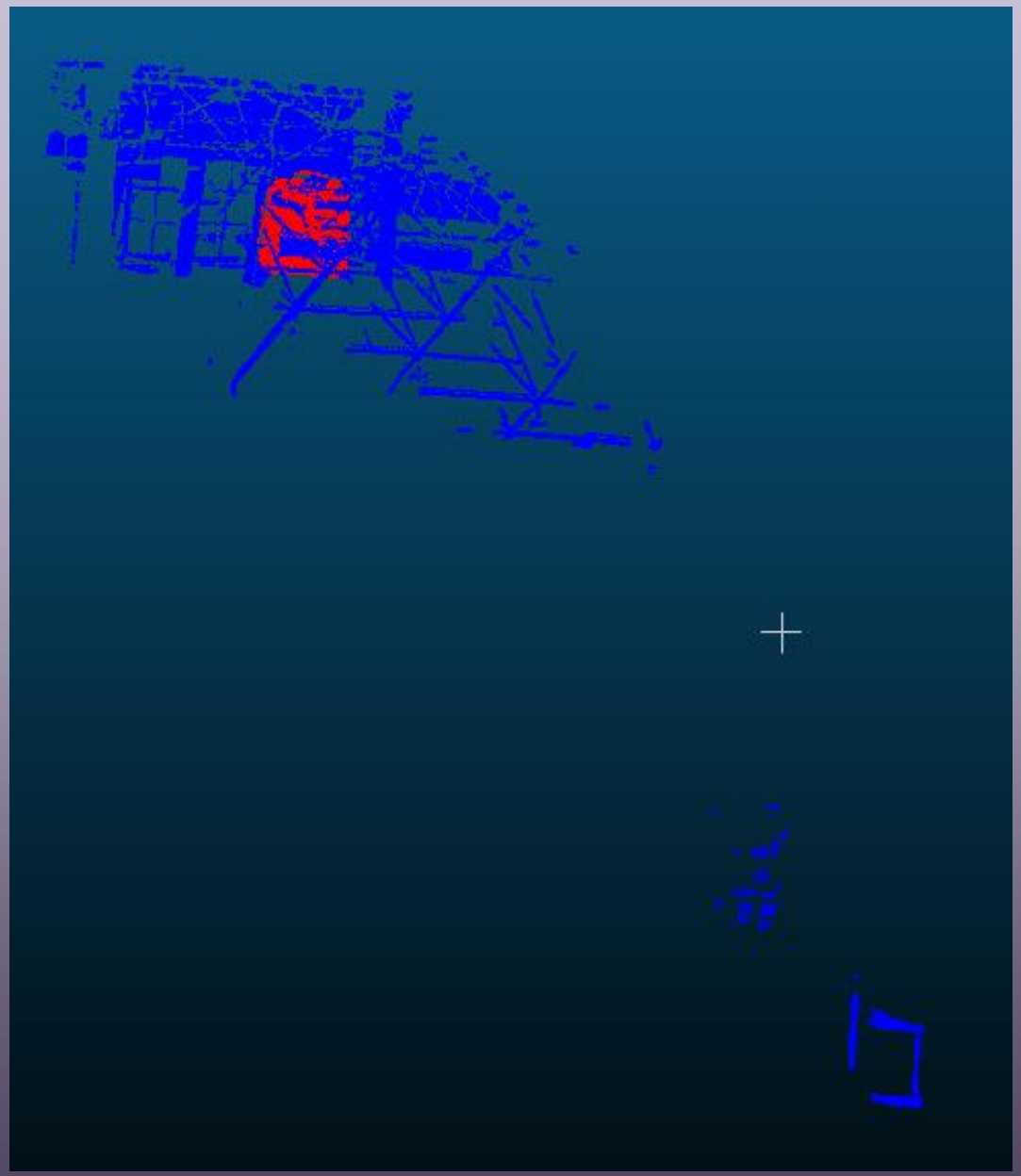


Results



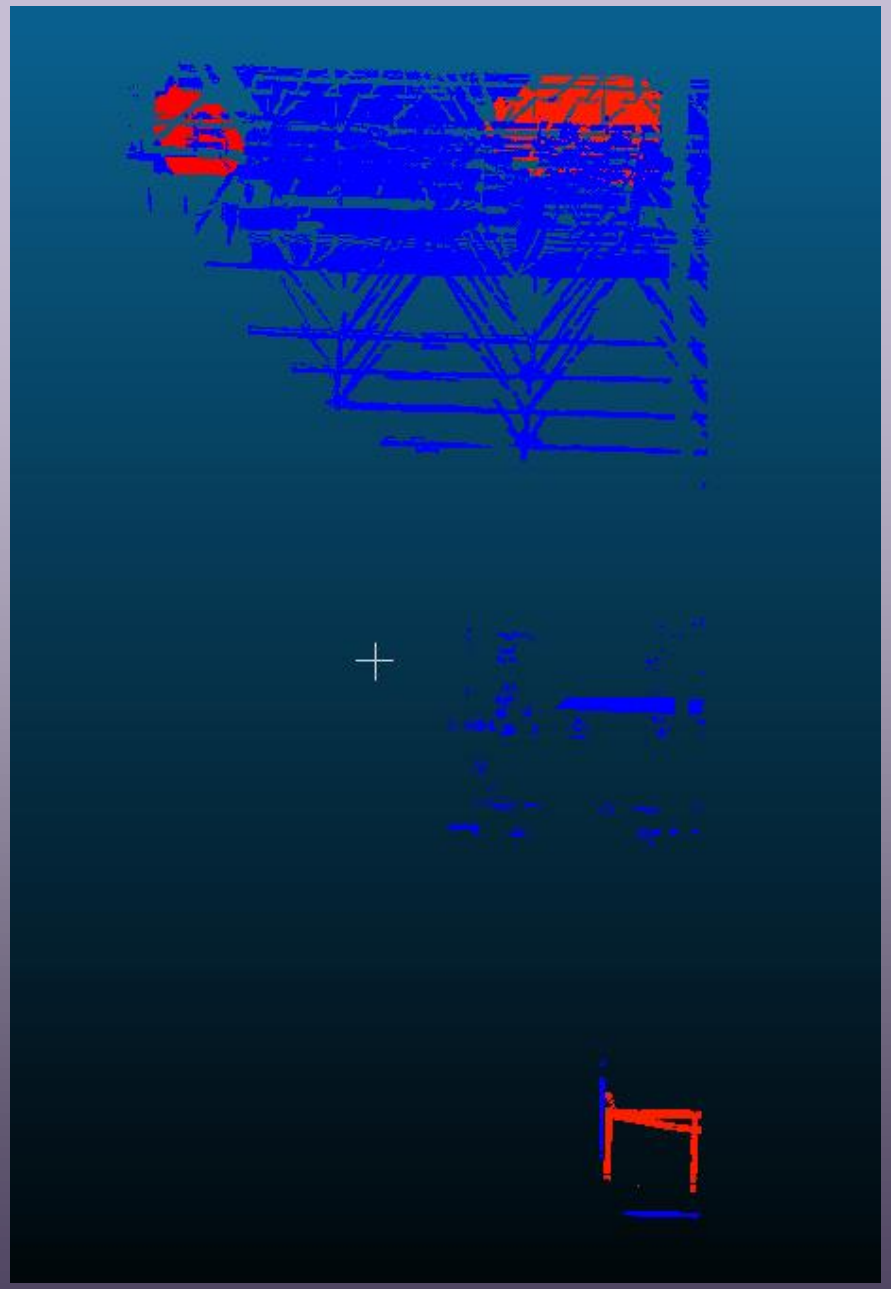
Undetected window

- Intended window not found
  - Low scores on Linearity and Planarity
  - Rectangular cluster detected in the back



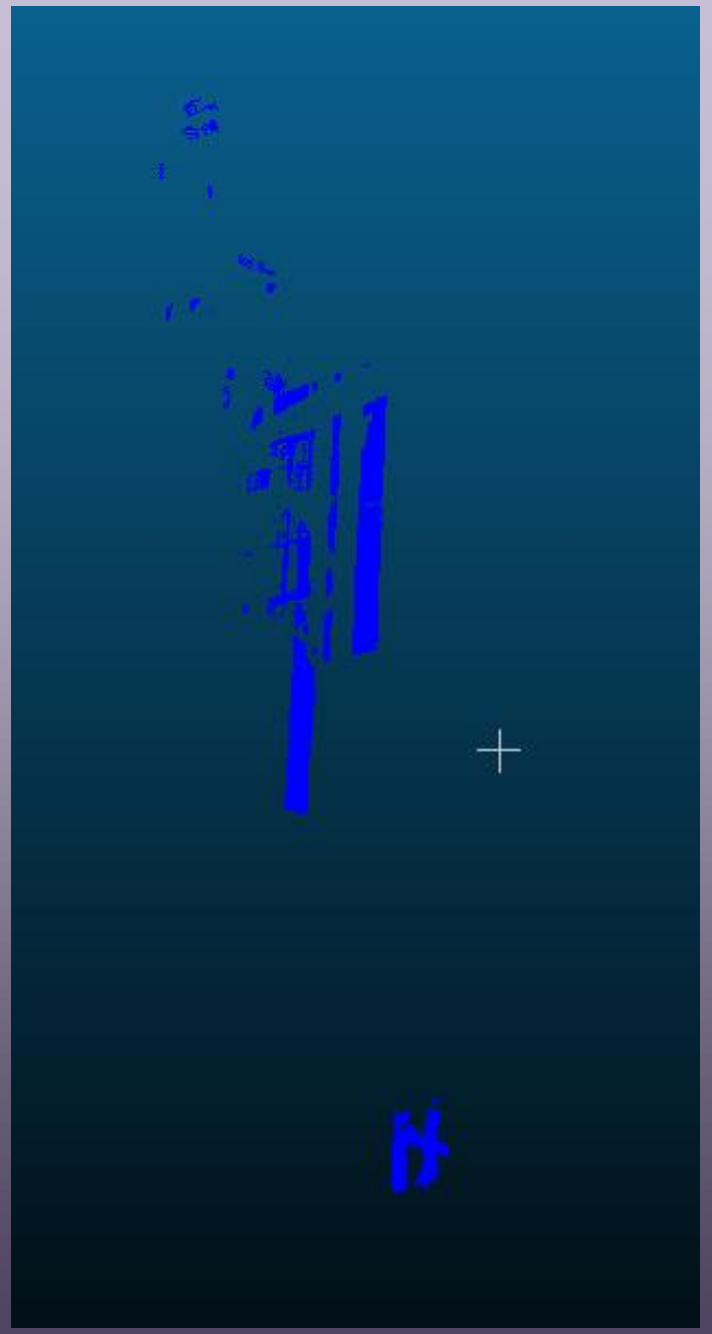
Too many results

- Rectangular structures in the back are also found.



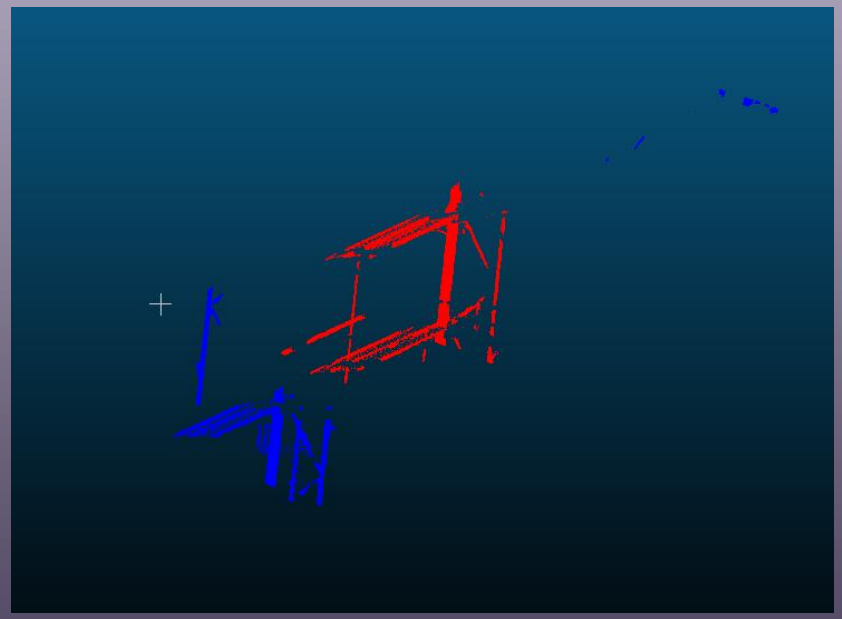
Nothing found in region

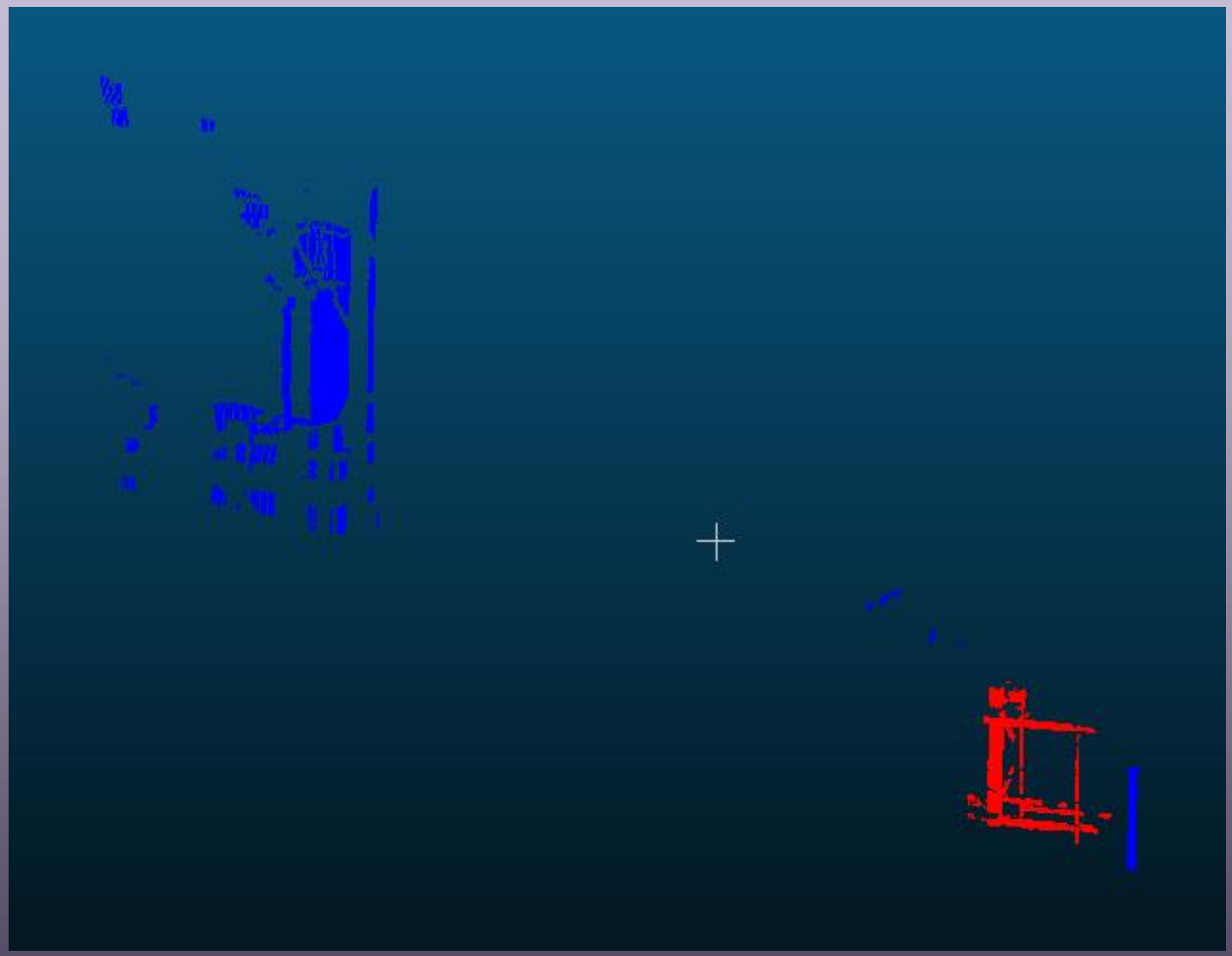
- Properly labeled to not include a result
  - Means invalid candidate window



Too large results

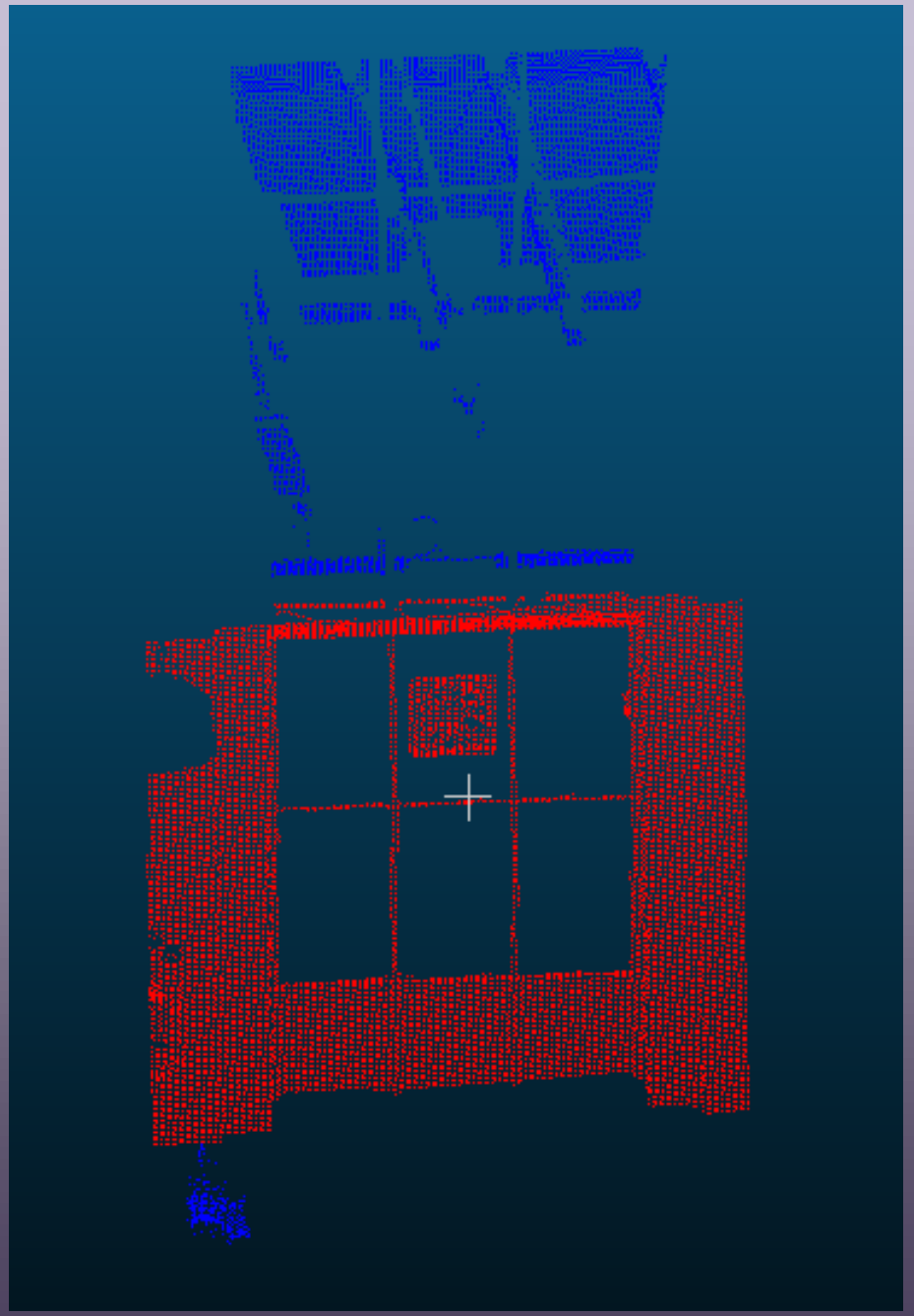
- Correct window indication
  - Beam behind it is also detected





Too large results

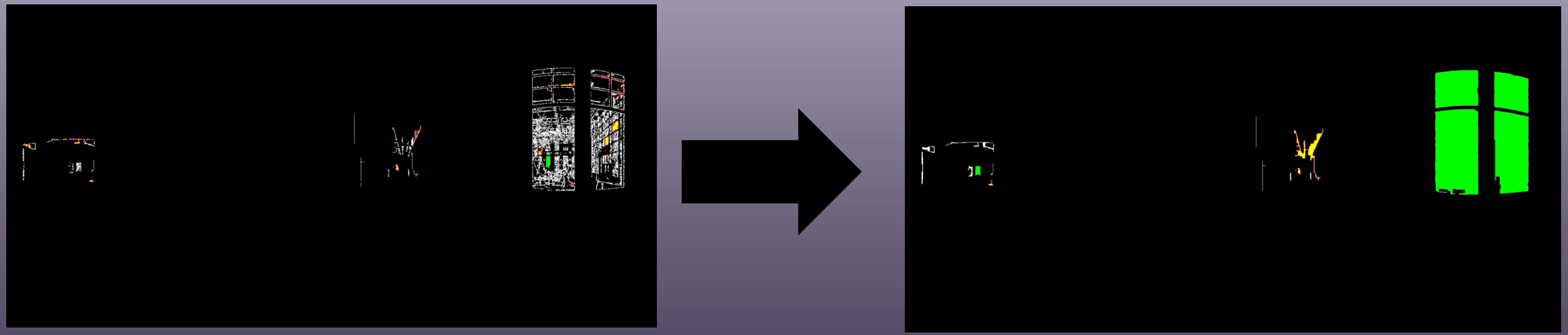
- Initial candidate window was too large
  - Still correct but with extra data around it



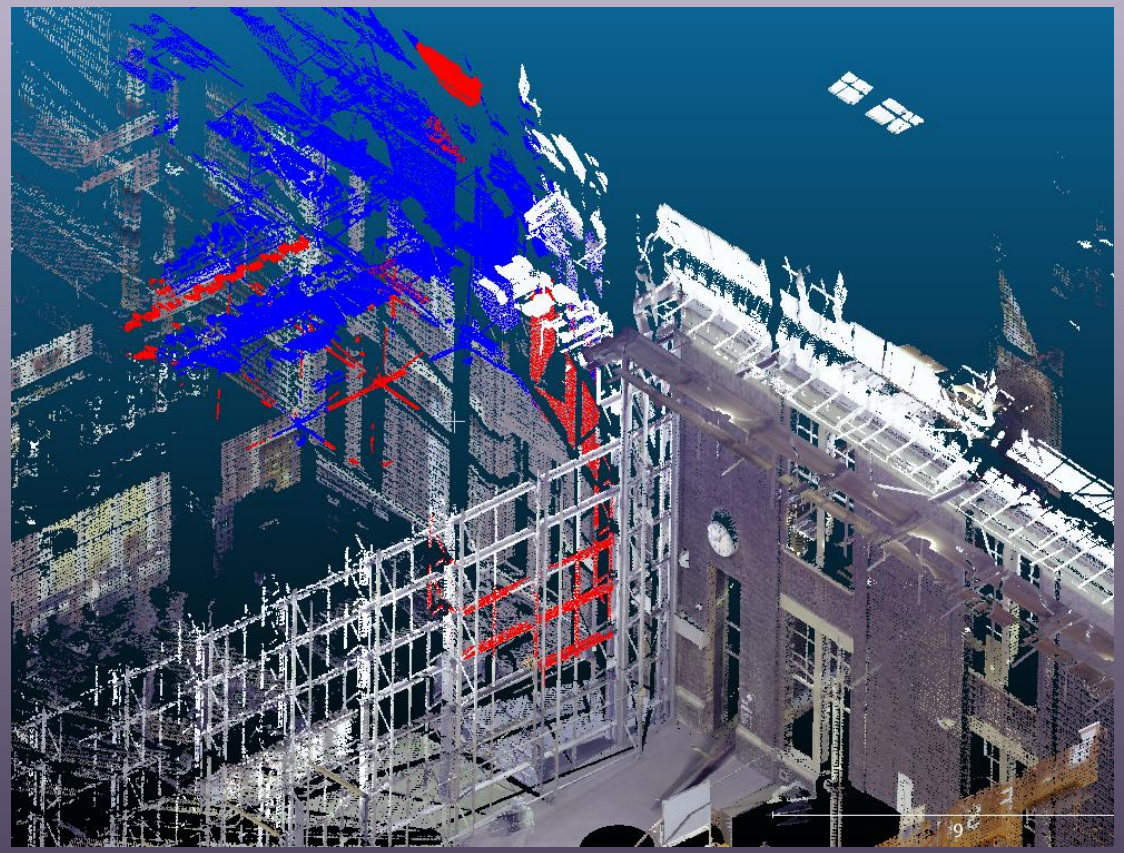
Problems other scenes

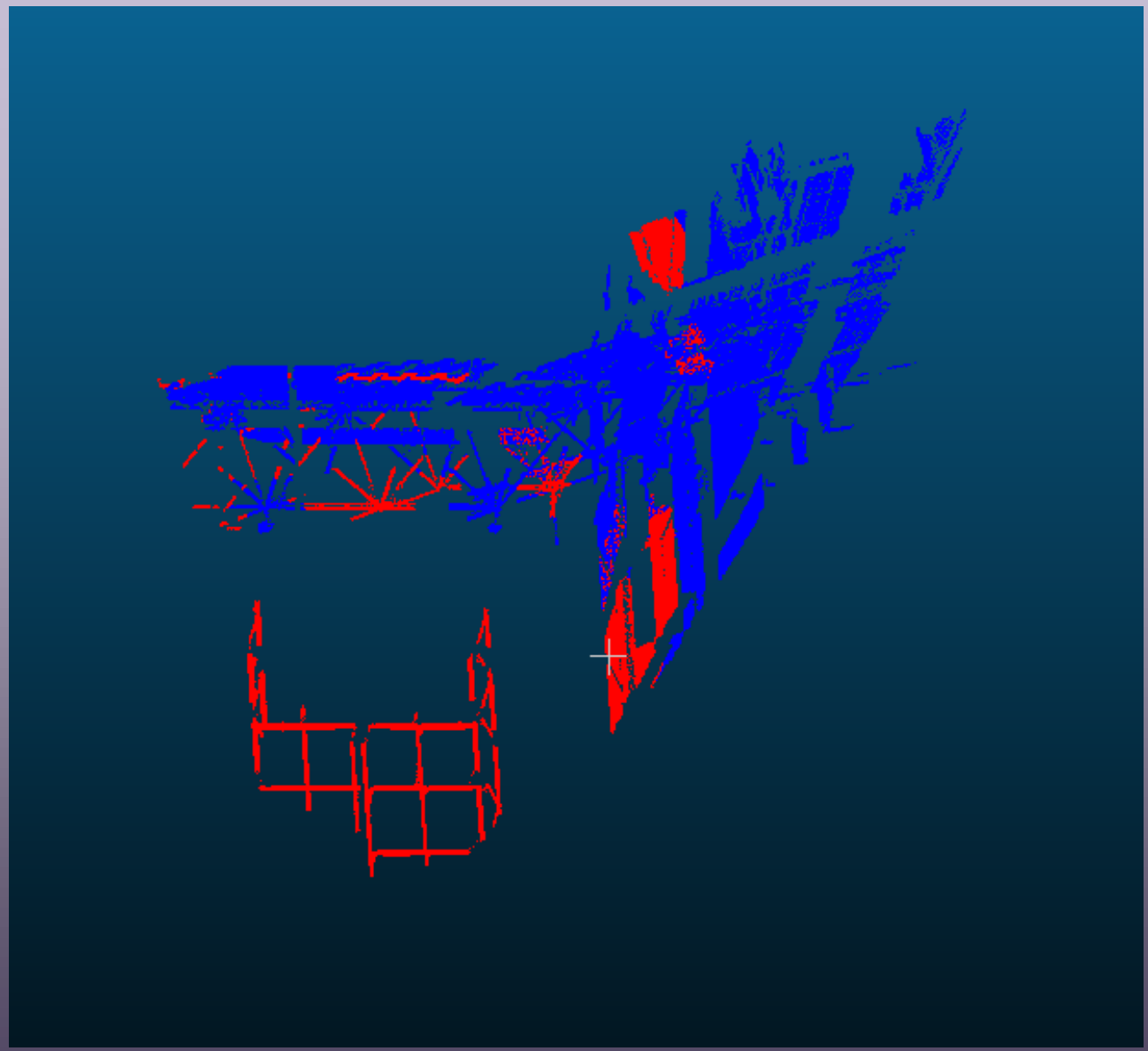
Workaround

- Enlarging the closing kernel
  - Initially 3x3 kernel now 13x13 kernel
  - Lowers details in scenes, but increases simplicity and reach

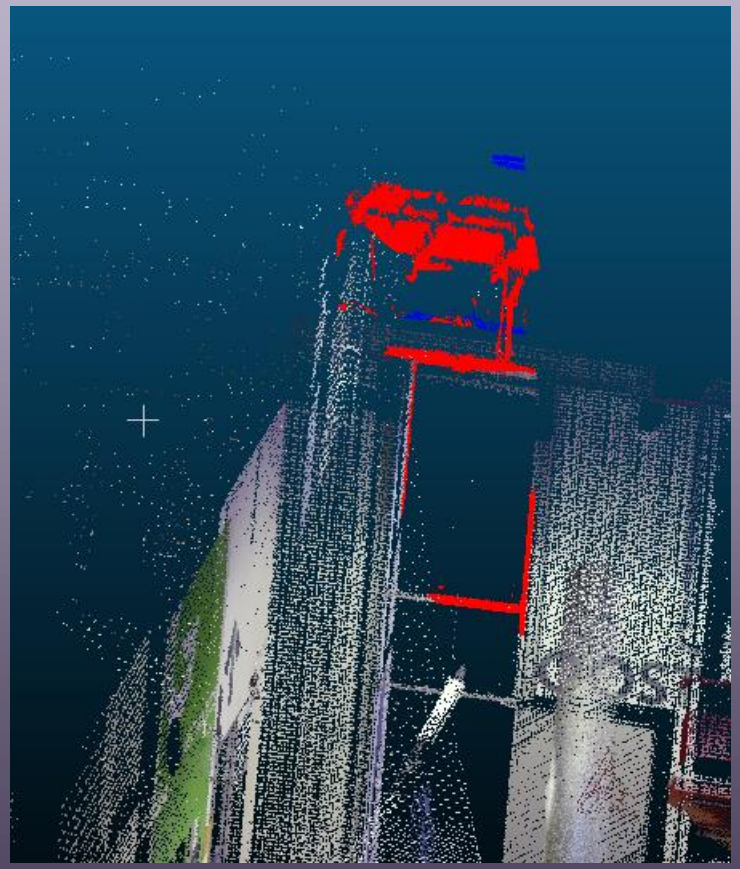


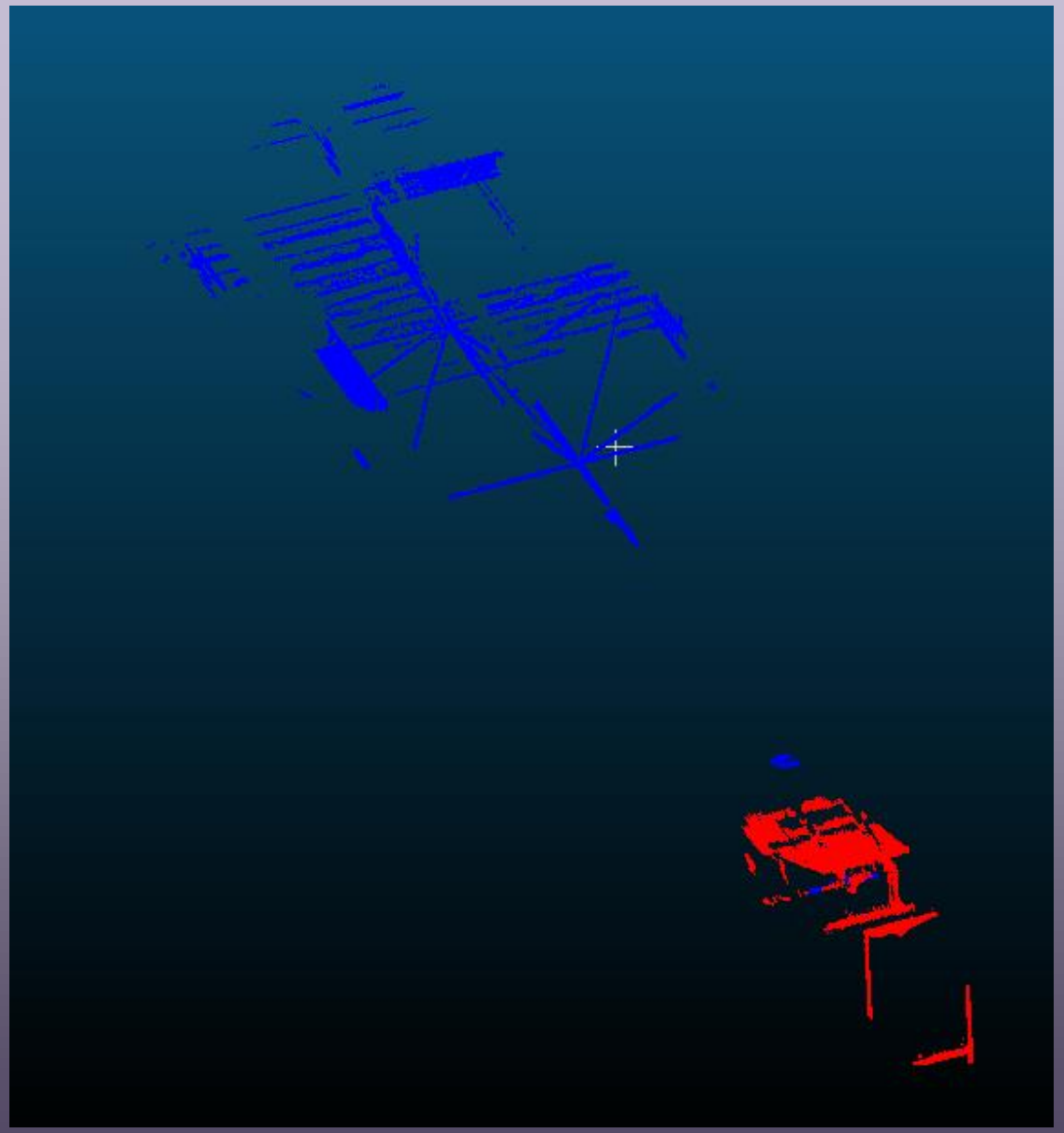
Results Scene 2





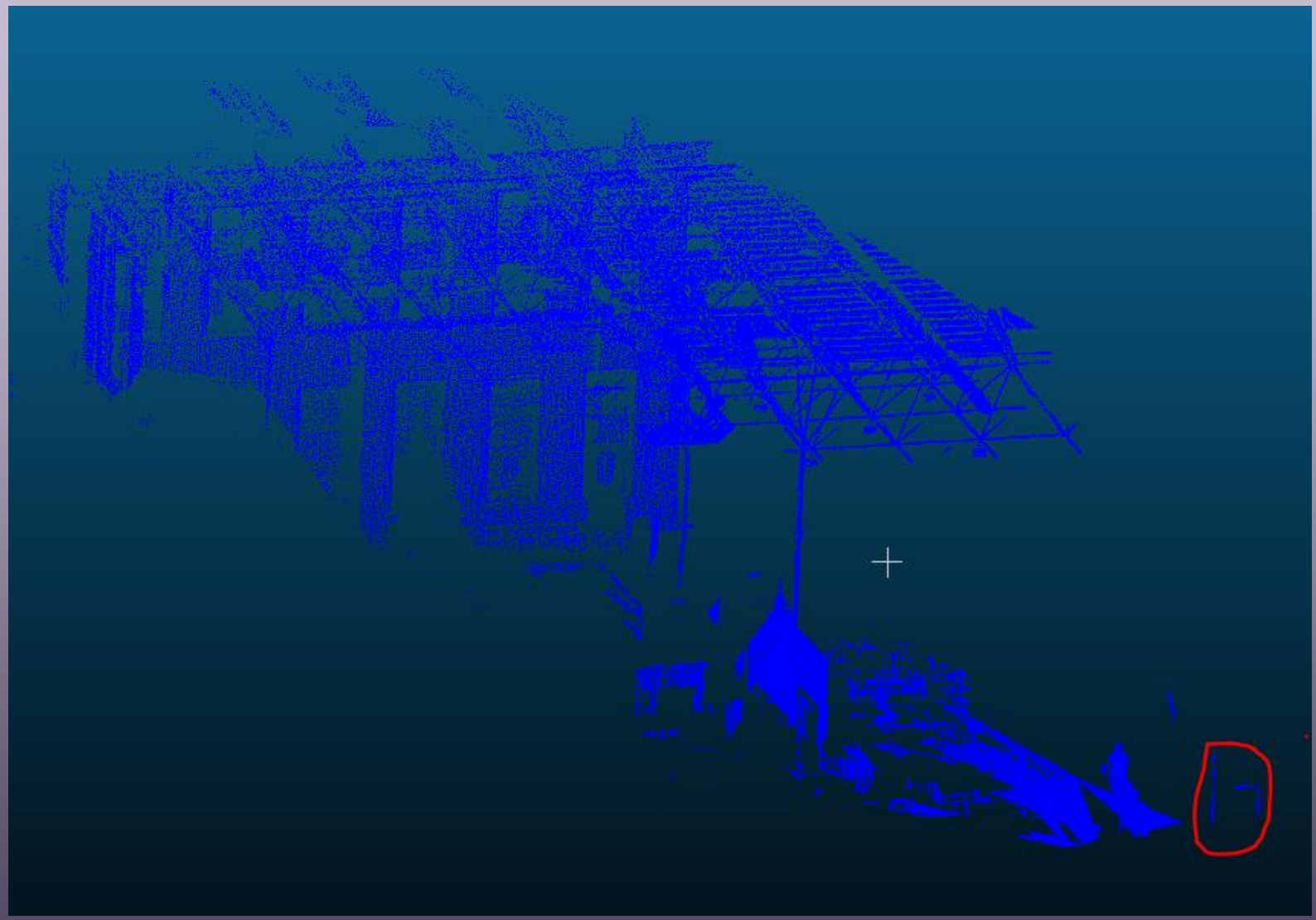
Results Scene 3



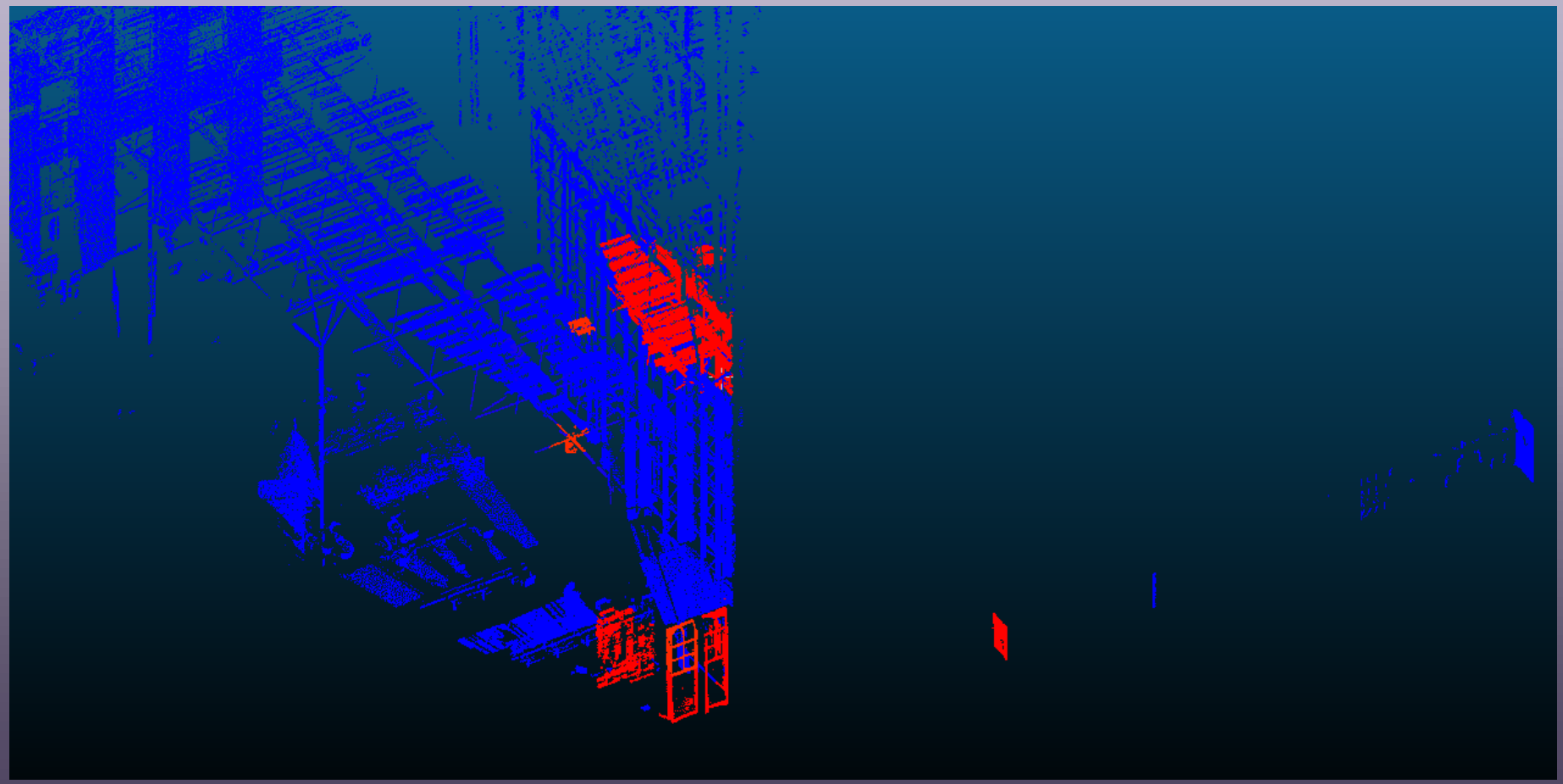


Results Scene 5

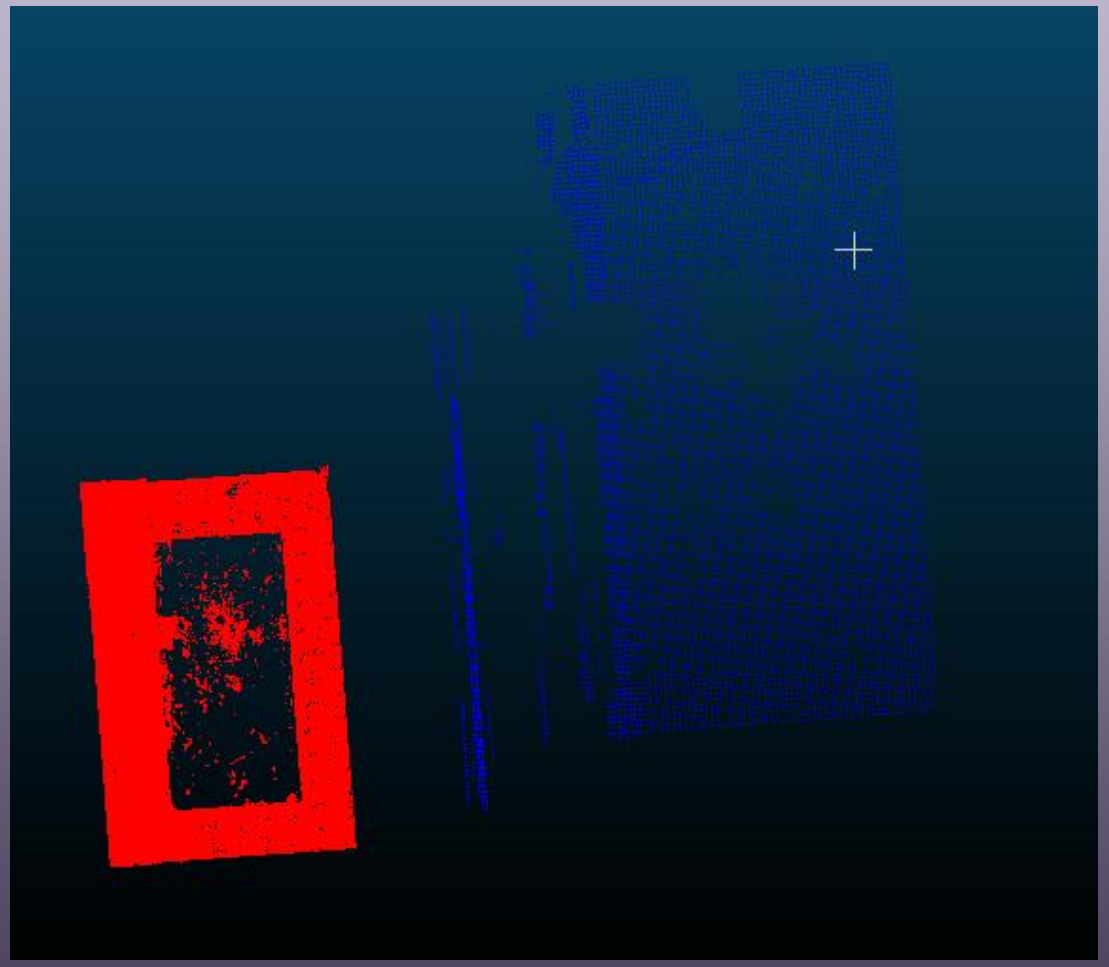
- No windows in this scene is correct
- Mistaken contour was part of the door frame

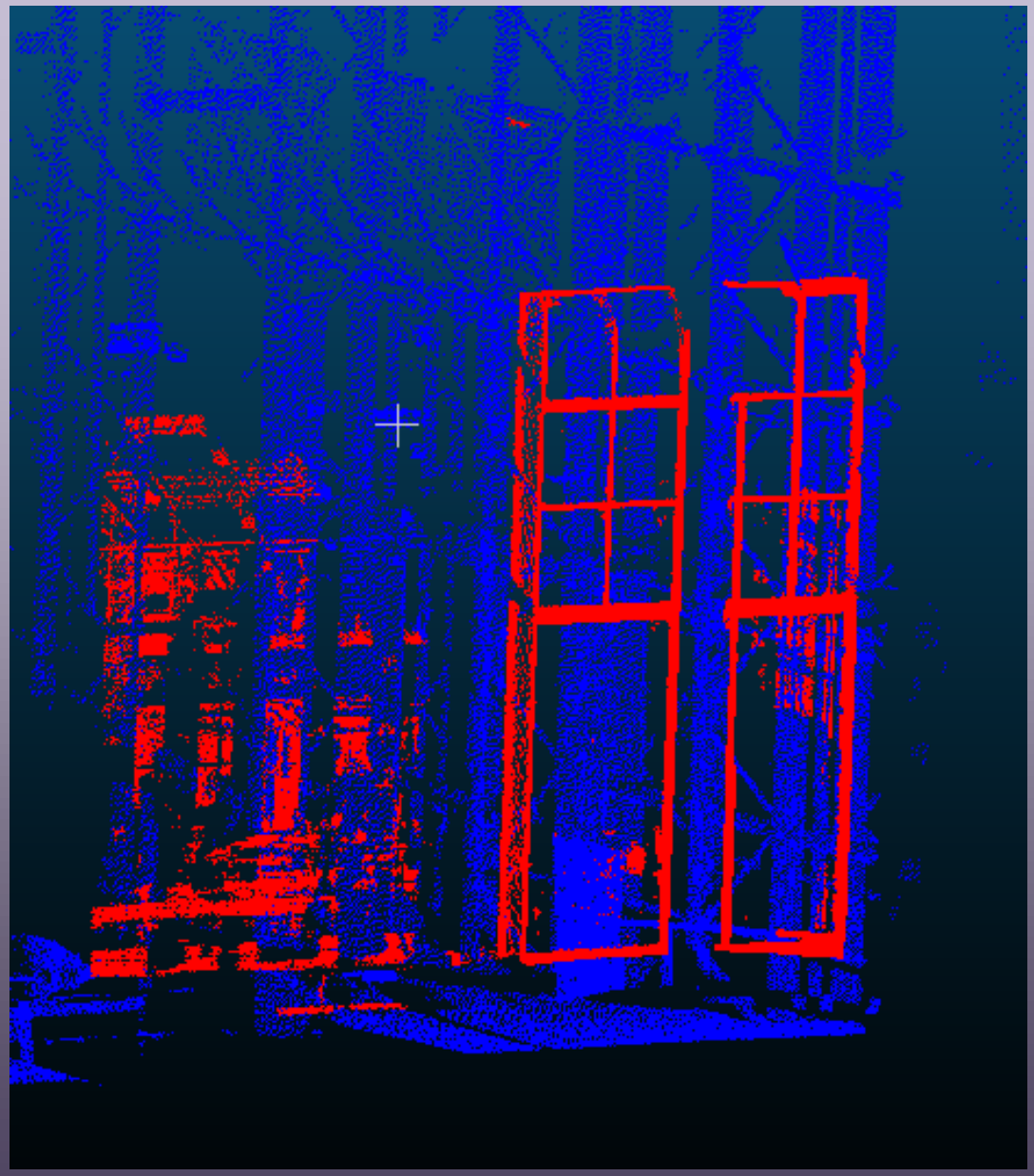


Results Scene 4



Results Scene 4





Conclusion

How can the location of glass be deduced using only information acquired from 3D point clouds and a reference position?

Conclusion

- Mixed Results
  - Difficult testing scene
- Possibility for deduction is shown!
- But…
  - Similar objects get recognized
    - Rectangular clusters
    - Beams
  - Issue with separating object

Future work

- Usage of different data to enhance the point cloud
  - Different datatypes to help with logic of deducing the location of glass
- Further investigation of point neighbourhoods
  - Once windows have been found more can be said on point classification
- Combination of multiple scans
  - Iteratively improve results by enhancing and validating them from other angles
- Deep Learning
  - Help find proper contours or clusters

Questions?

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- Slide 5 left: https://www.autodesk.com/solutions/3d-environment-modeling-workflow
- Slide 5 right: https://www.arkance-systems.be/be/what-is-a-digital-twin/
- Slide 6: https://sketchfab.com/3d-models/point-cloud-demo-natural-history-museum-london-05940cf8ceaa44b4852bb6f04537cb97
- Slide 7: Mohamed Saleh Sedek in **3D Range Sensors Capture, Transform and Modeling of Defects**
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