Semantic annotation of urban scenes: Skyline and window detection

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Experiment

Experiment

Did you see?

- building

Did you see?

- building
- tree

Did you see?

- building
- tree
- bicycle

Did you see?

- building
- tree
- bicycle
- street lamb

Did you see?

- building
- tree
- bicycle
- street lamb
- blue car

Did you see?

- building
- tree
- bicycle
- street lamb
- blue car
- red car

Did you see?

- building
- tree
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- blue car
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- brand of the car?

Experiment

Q

- Why are we so good at depth recognition/object detection?

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- Why are we so good at depth recognition/object detection?
- How can we apply this to a computer system?

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- How can we apply this to a computer system?
  - *Computer Vision*

Outline

Human perception

- Why are we so good at depth recognition/object detection?

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- Depth cues

Human perception

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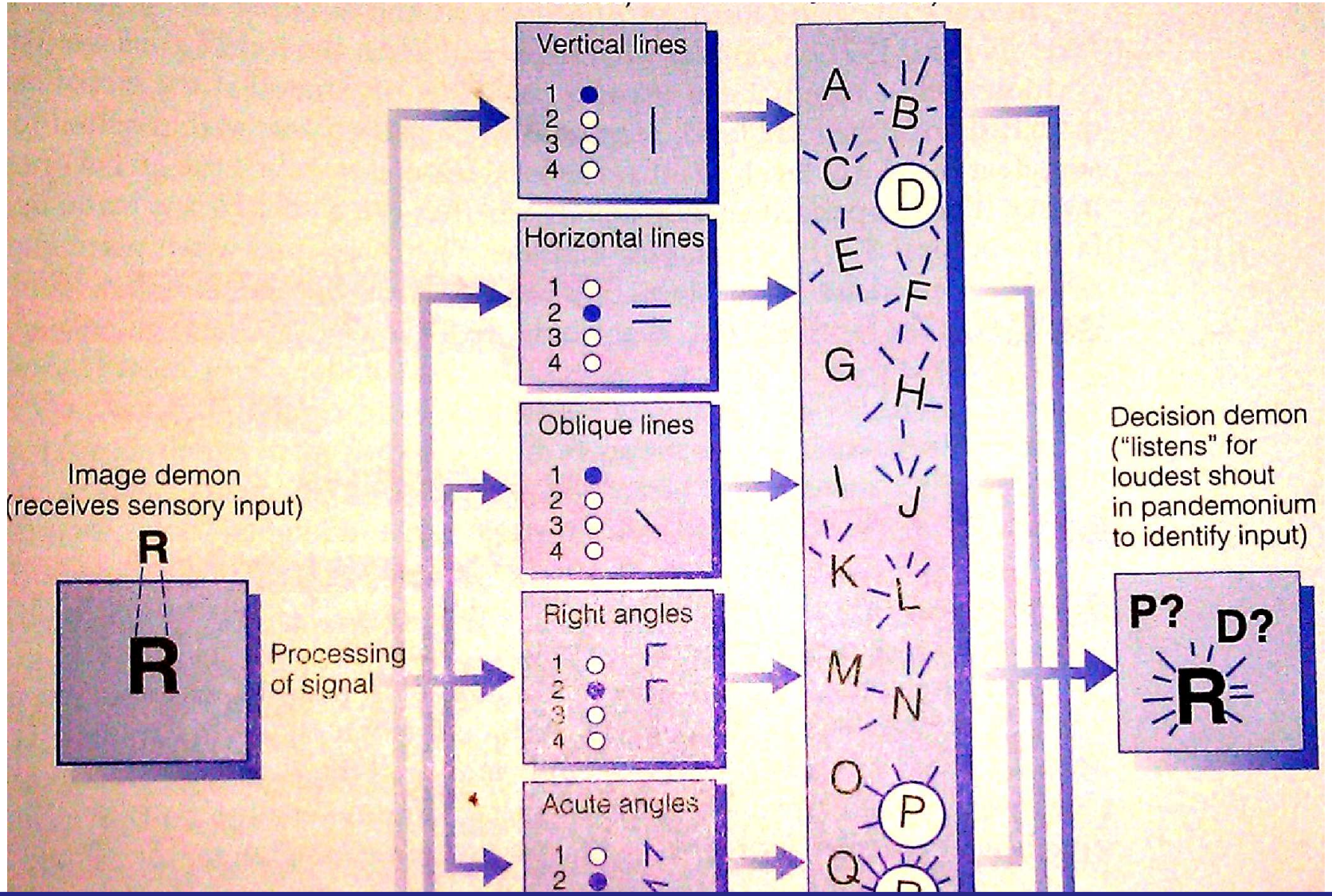
- Binocular disparity

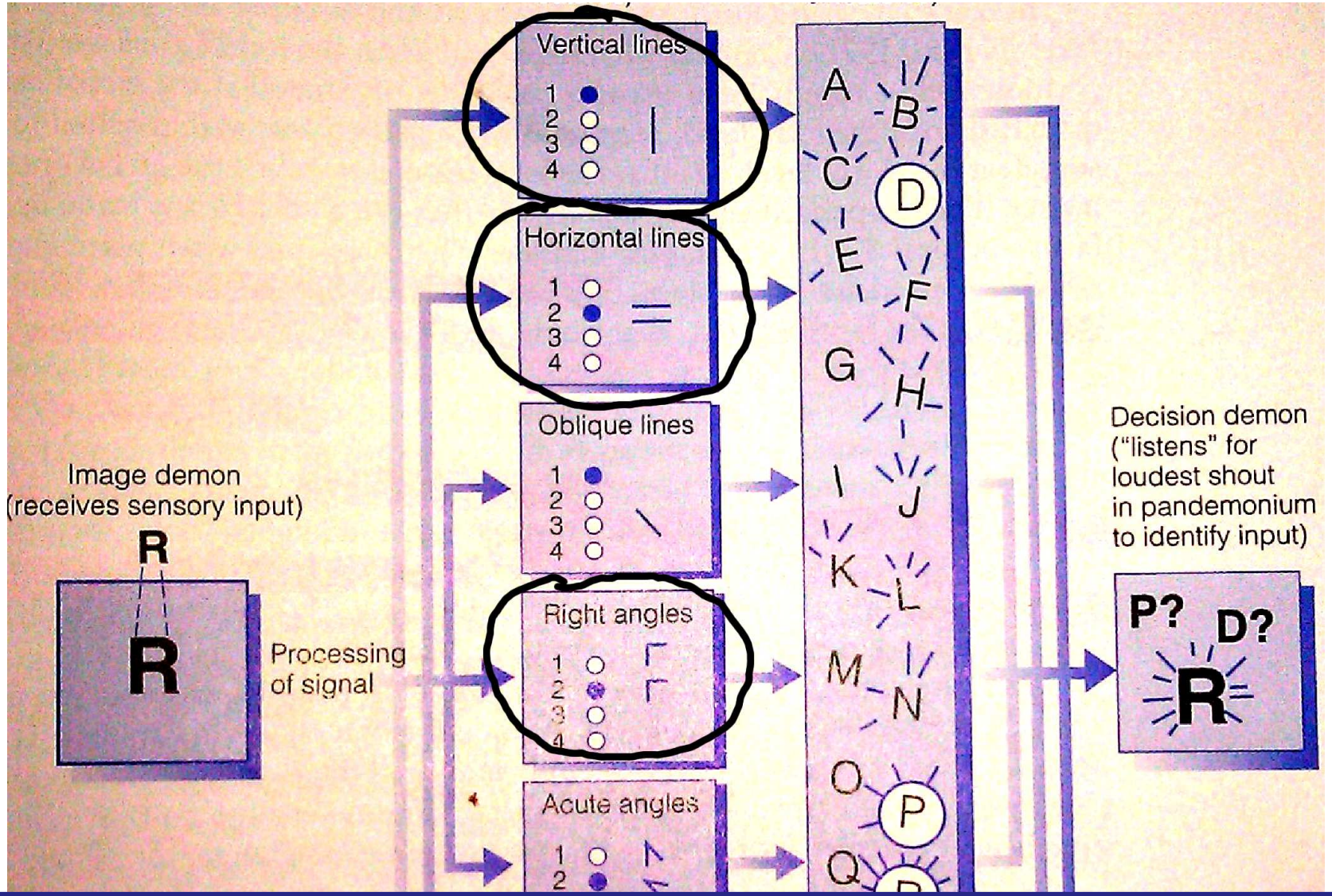
Human perception

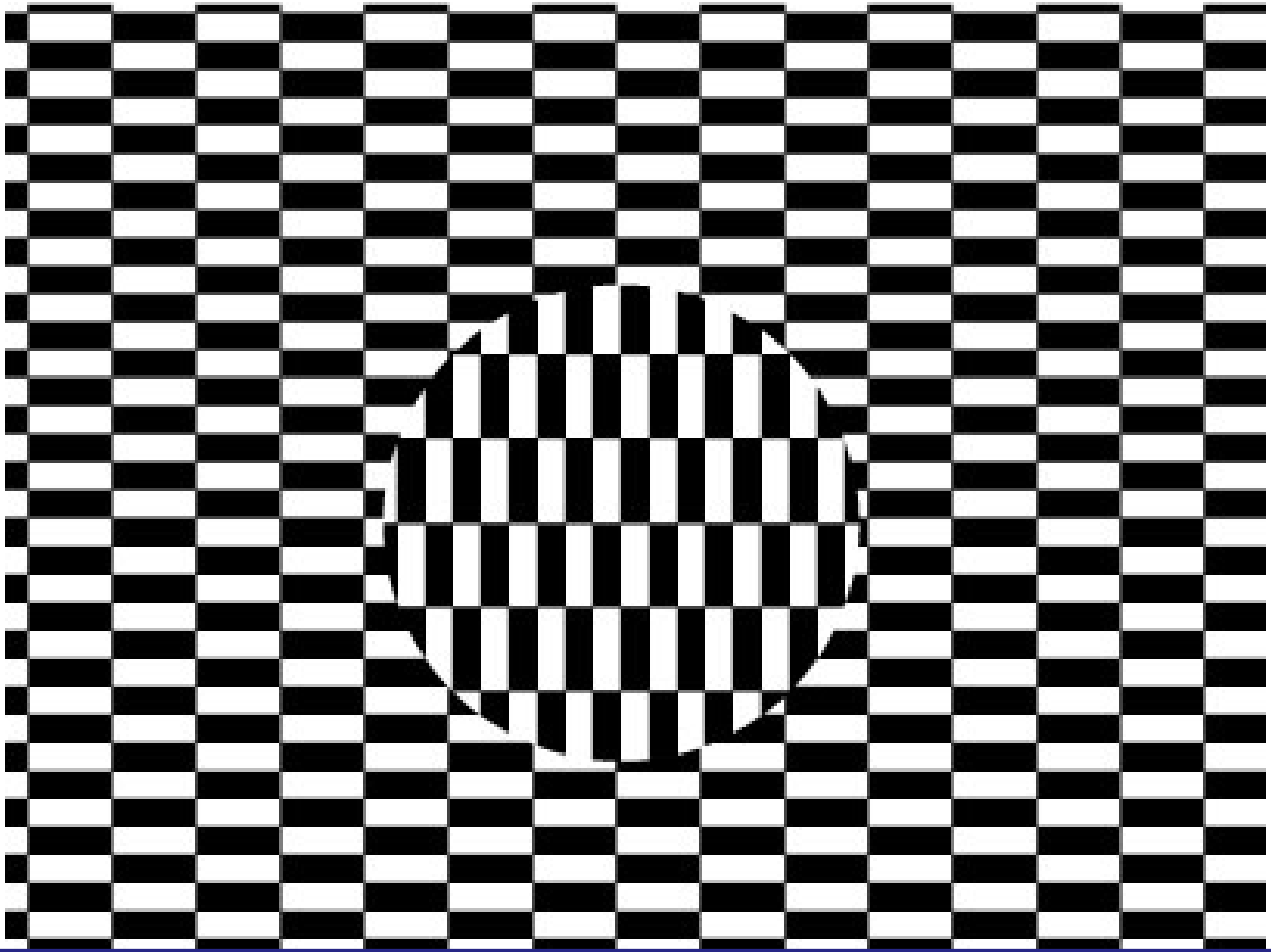
- Why are we so good at depth recognition/object detection?
- Depth cues
- Binocular disparity
- Classify objects: feature detection

Classify objects by feature detection



Classify objects by feature detection





Where is my research about?

- Annotation of urban scenes

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  - Skyline detection

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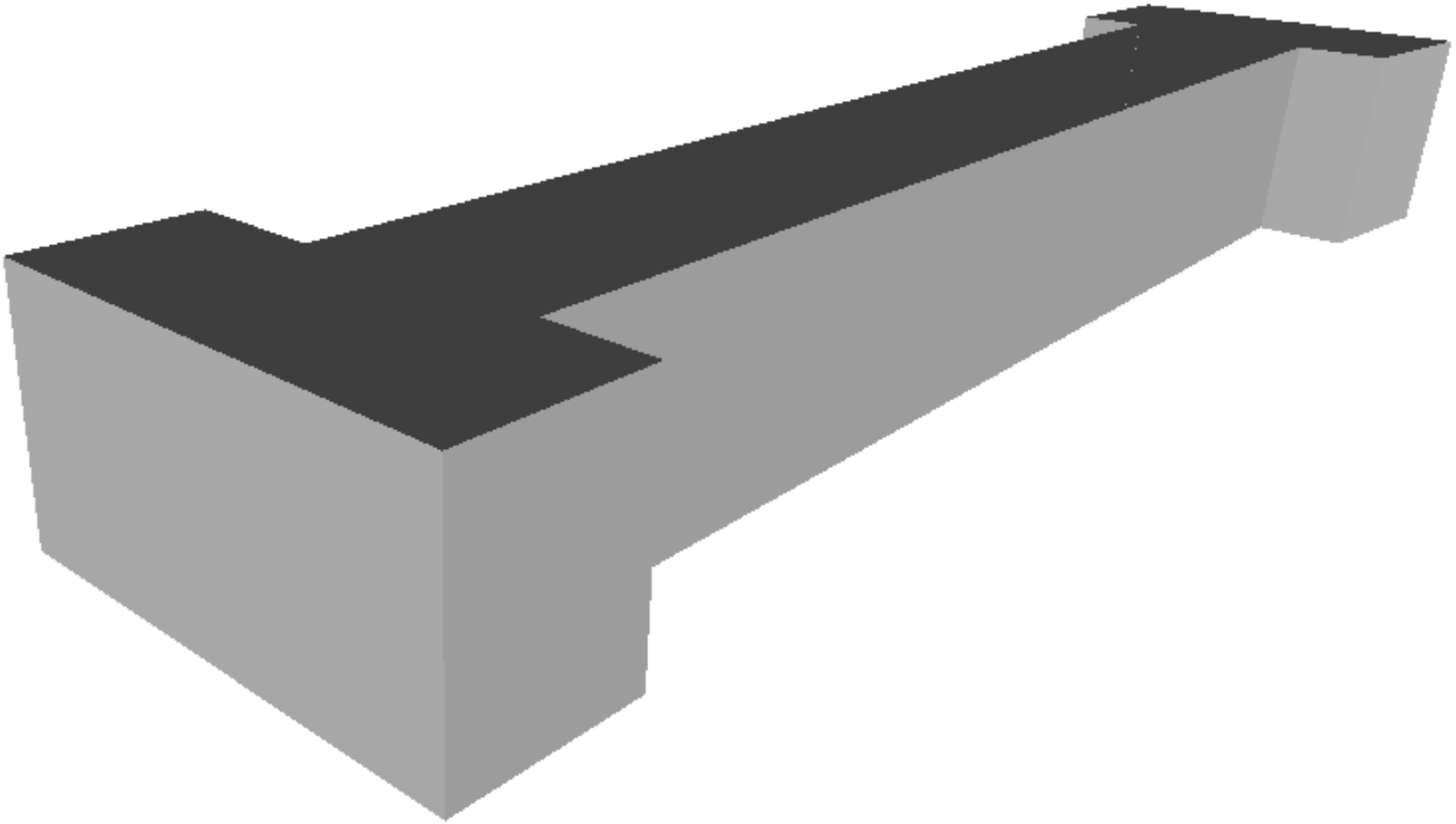
  - 3D building reconstruction

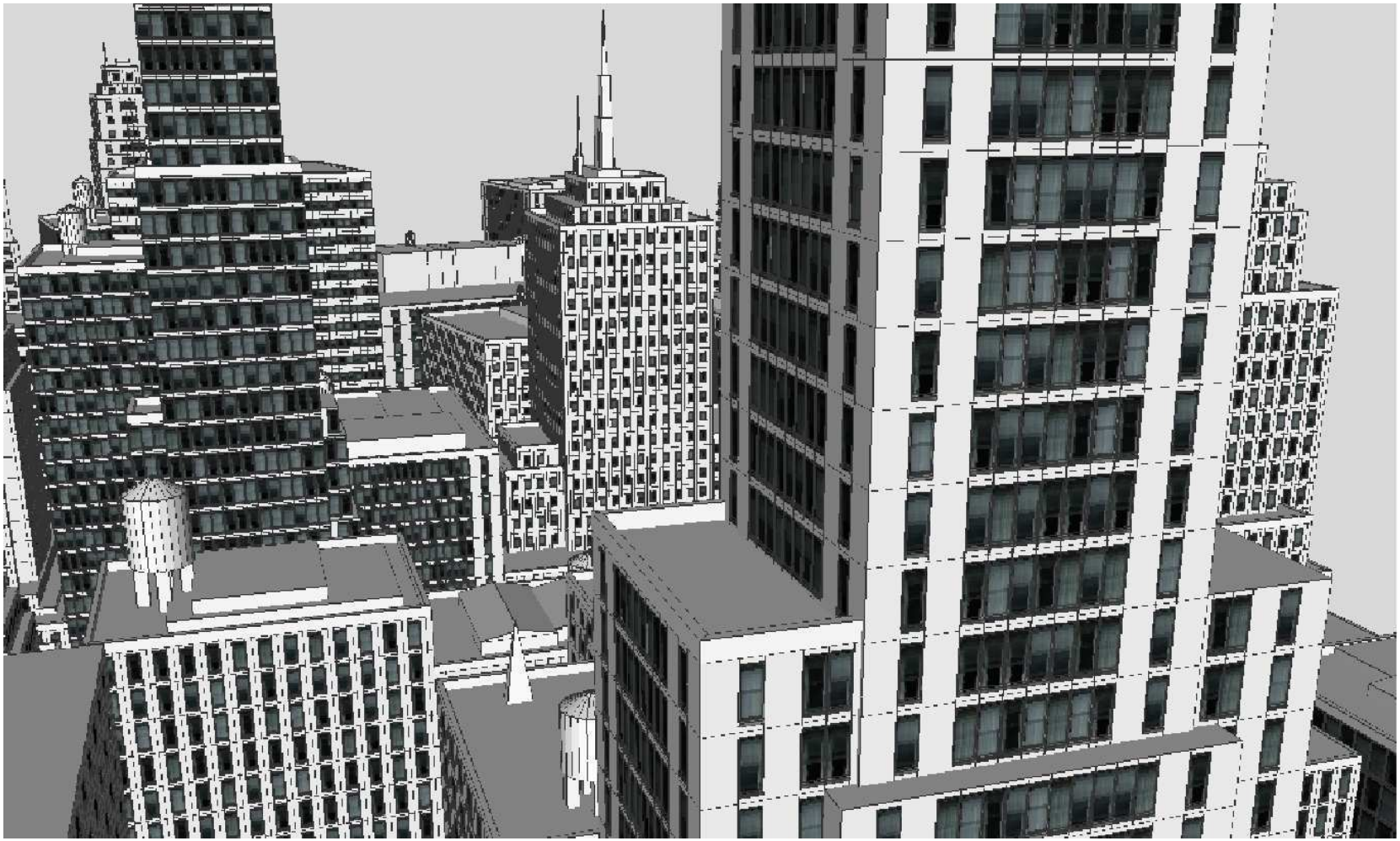


Where is my research about?

- Annotation of urban scenes
  - Skyline detection
  - 3D building reconstruction
  - Window detection

Application examples of annotation of urban scenes

- 3D city models



Application examples of annotation of urban scenes

- 3D city models
- Driving simulation

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Application examples of annotation of urban scenes

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  - 'noord-zuidlijn'

Outline

Skyline detection application example

- Horizon detection for Unmanned Air Vehicles

Skyline detection in urban scenes

Skyline detection in urban scenes

- Edge detection based on intensity change

Skyline detection in urban scenes

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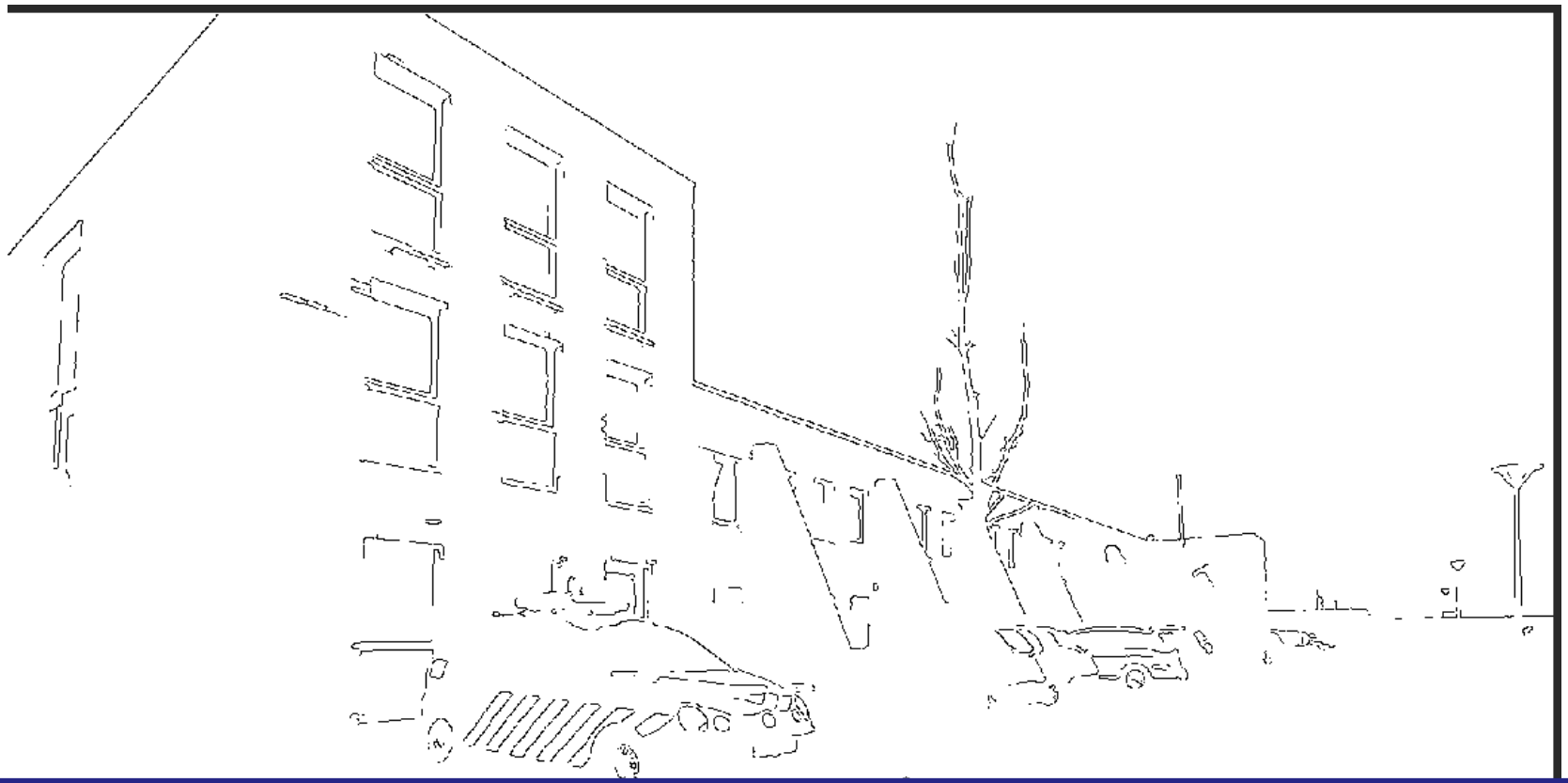
- Canny edge detection

Skyline detection in urban scenes

- Edge detection based on intensity change
- Canny edge detection
- Result: binary image (edge or no edge)



Skyline detection algorithm

- Top sharp edge assumption
  "The first sharp edge (seen from top to bottom) in the image represents the skyline."

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- Algorithm:
  - Apply gaussian smoothing
  - The image is sliced in #w pixelcolumns
  - Each column present #h binary edge values (edge or no edge)
  - y-location of the first edge value is stored

Skyline detection result

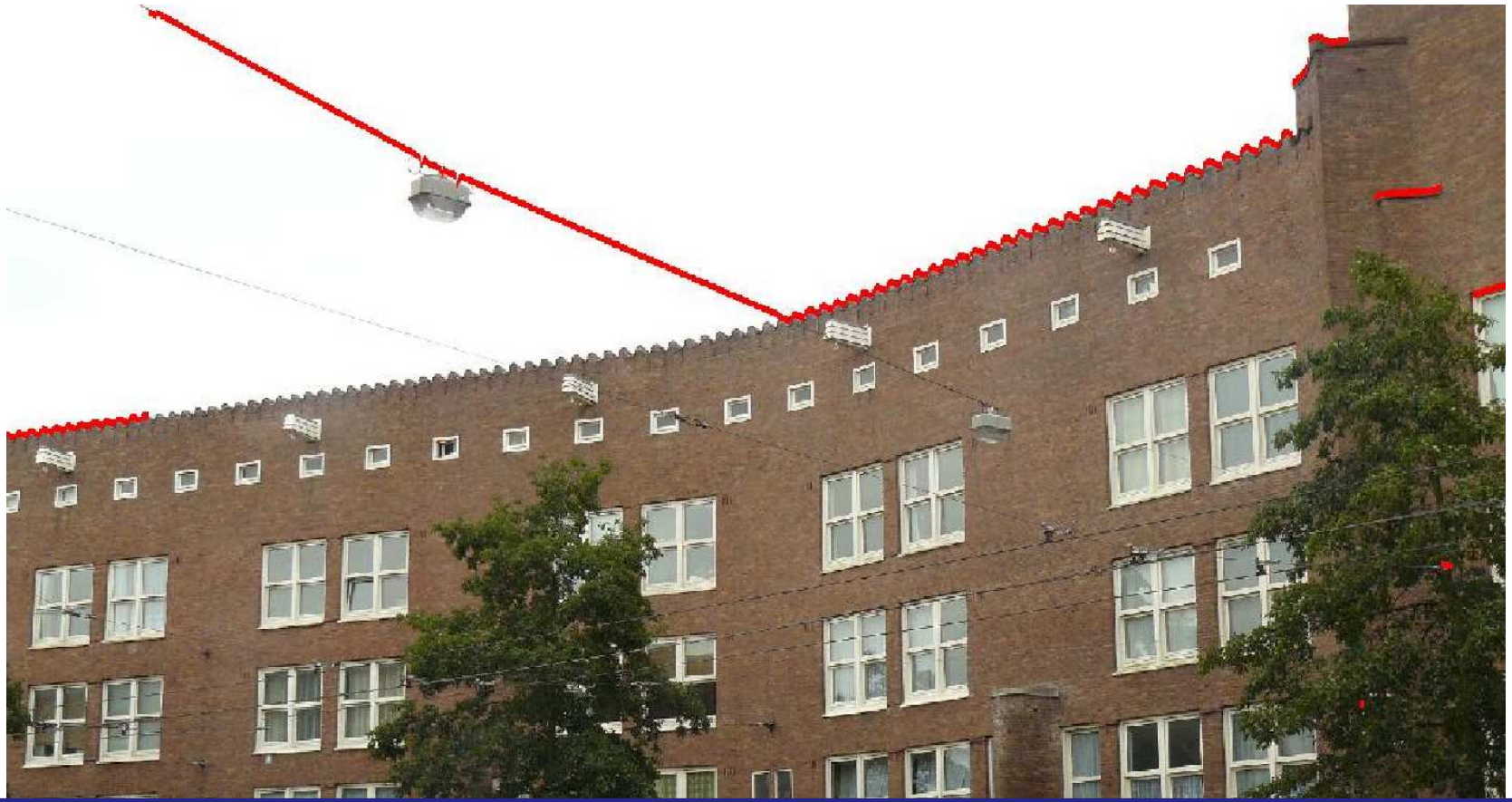
Skyline detection result

Future research

Hypothesis based skyline detection, assumption

"The first sharp edge (seen from top to bottom) in the image represents the skyline."

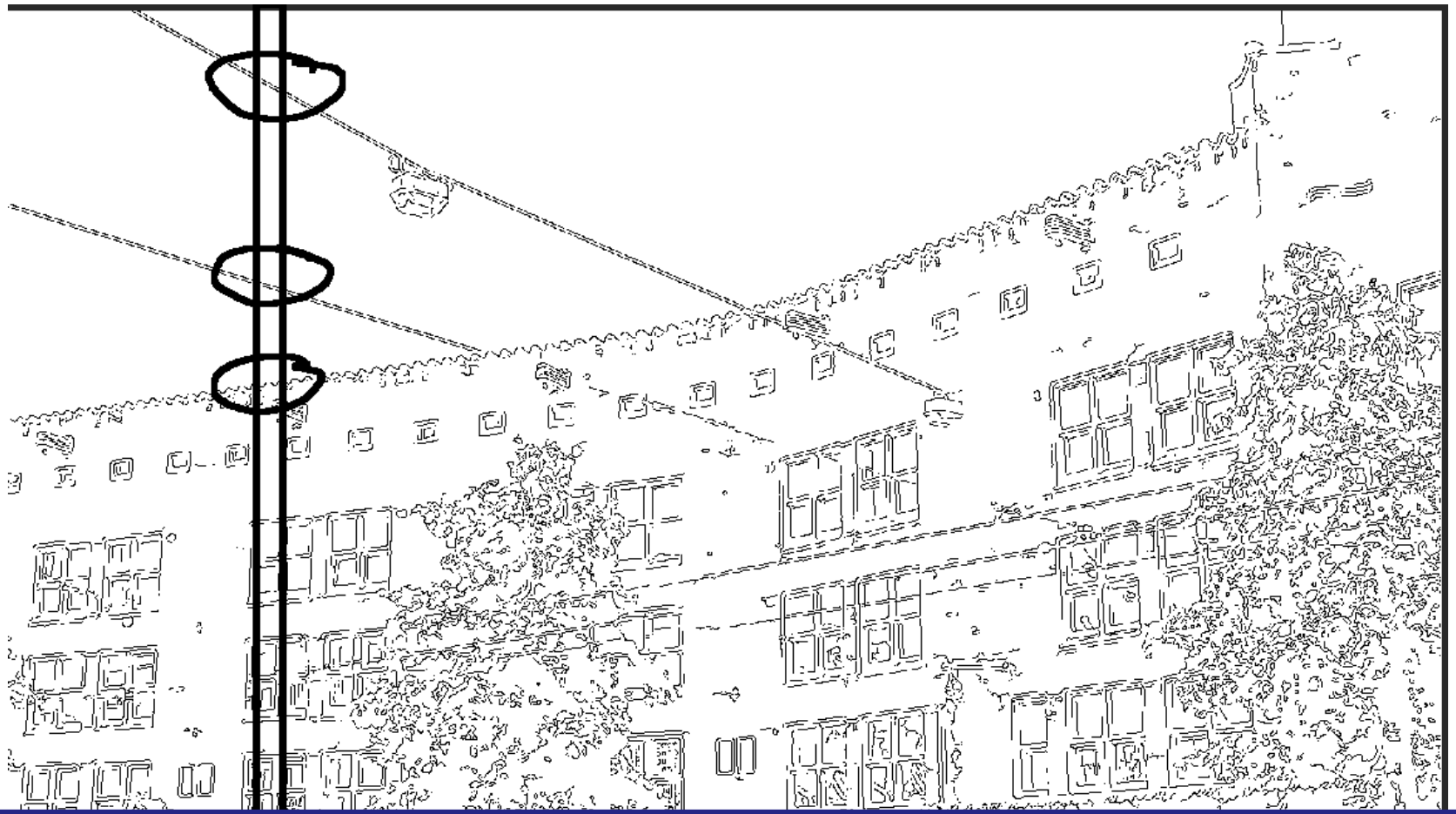
- Example of a scene where this assumption is violated



Hypothesis based skyline detection, assumption

- Change of assumption

"The skyline is part of the first n sharp edges (e.g. $n = 3$)



Hypothesis based skyline detection, algorithm

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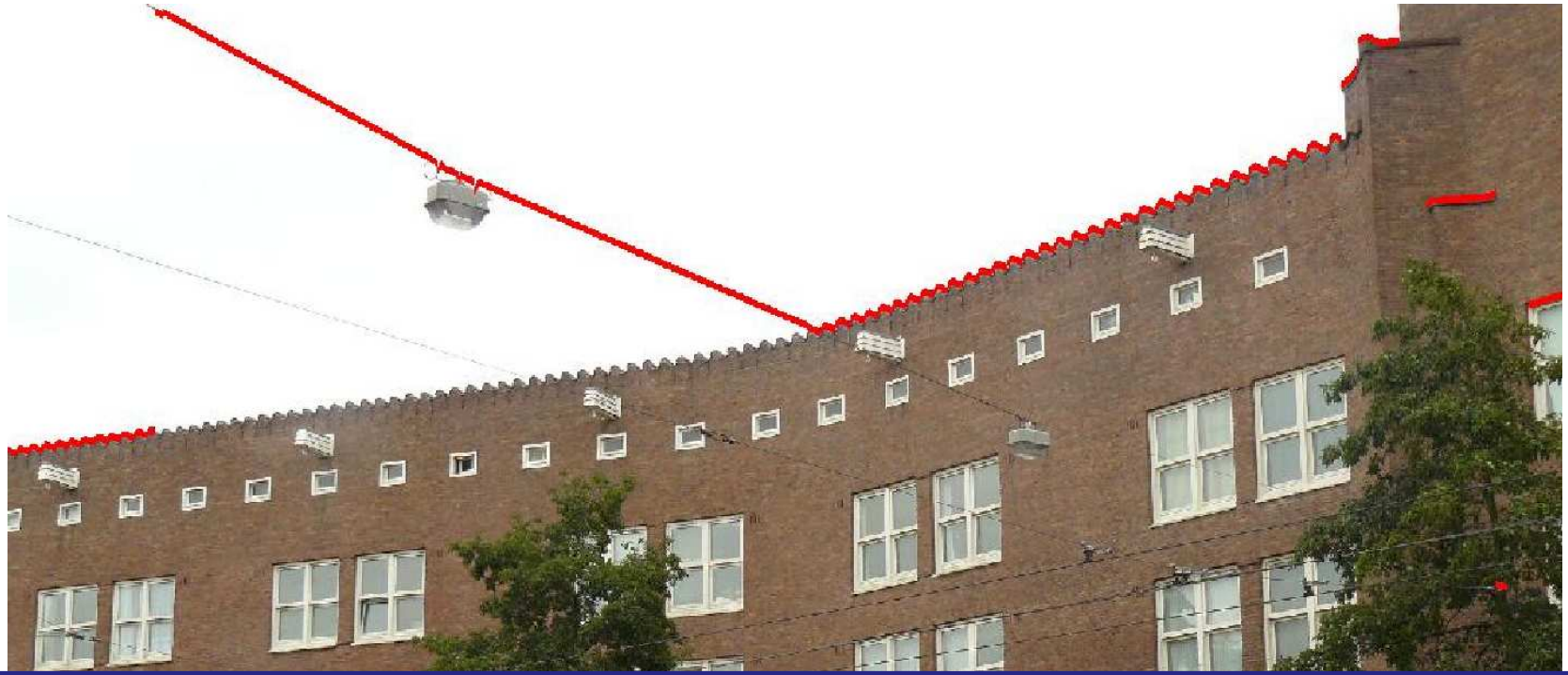
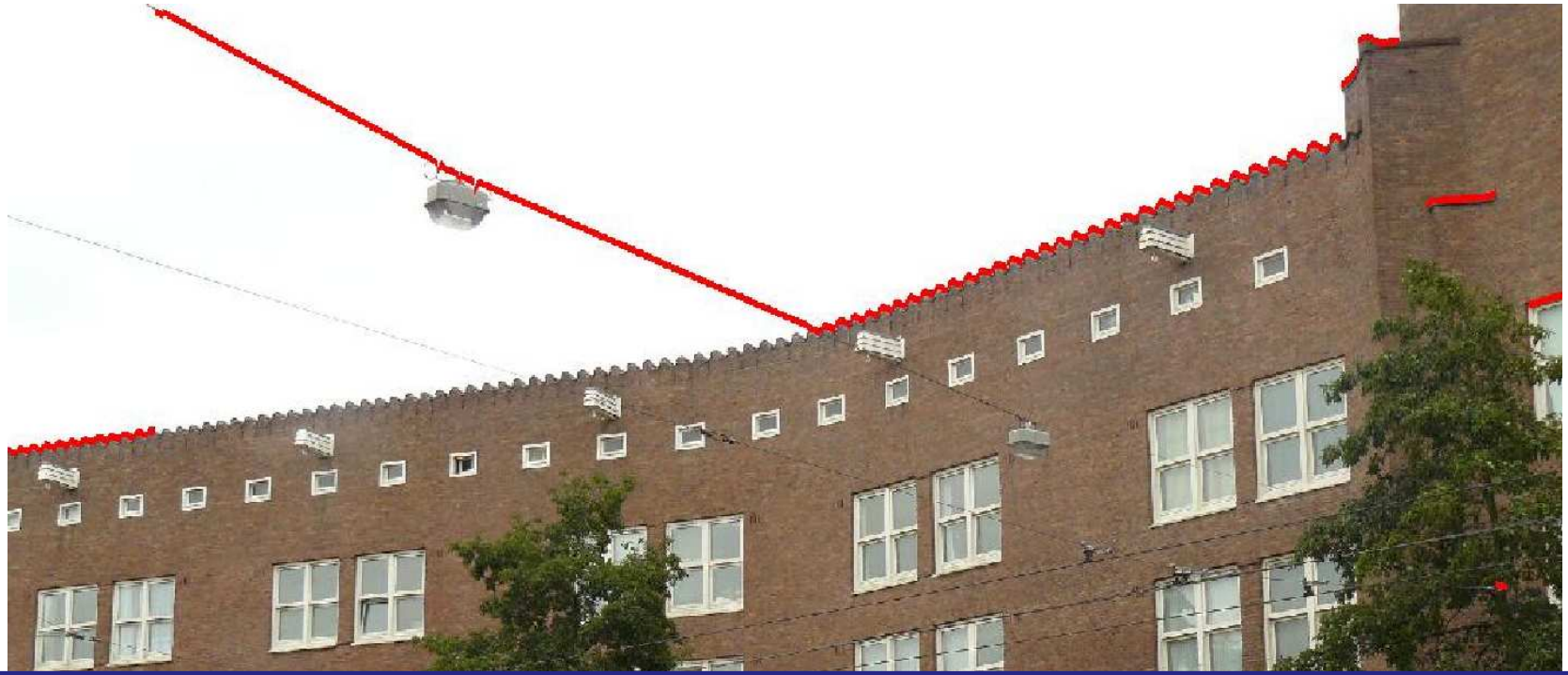
Hypothesis based skyline detection, algorithm

- Generate *n* hypothesis
- Classify hypothesis with additional info



Hypothesis based skyline detection, algorithm

- Generate *n* hypothesis
- Classify hypothesis with additional info
  - texture



Hypothesis based skyline detection, algorithm

- Generate *n* hypothesis
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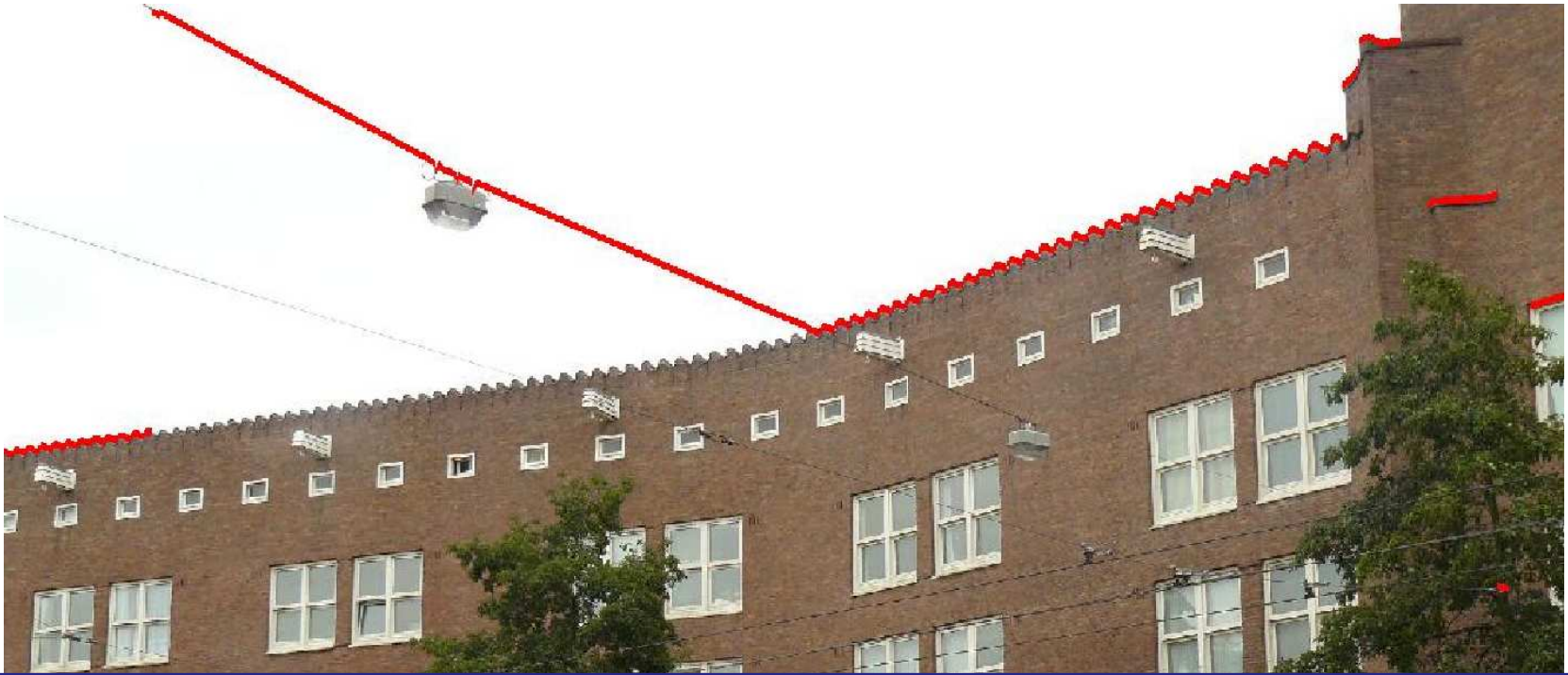
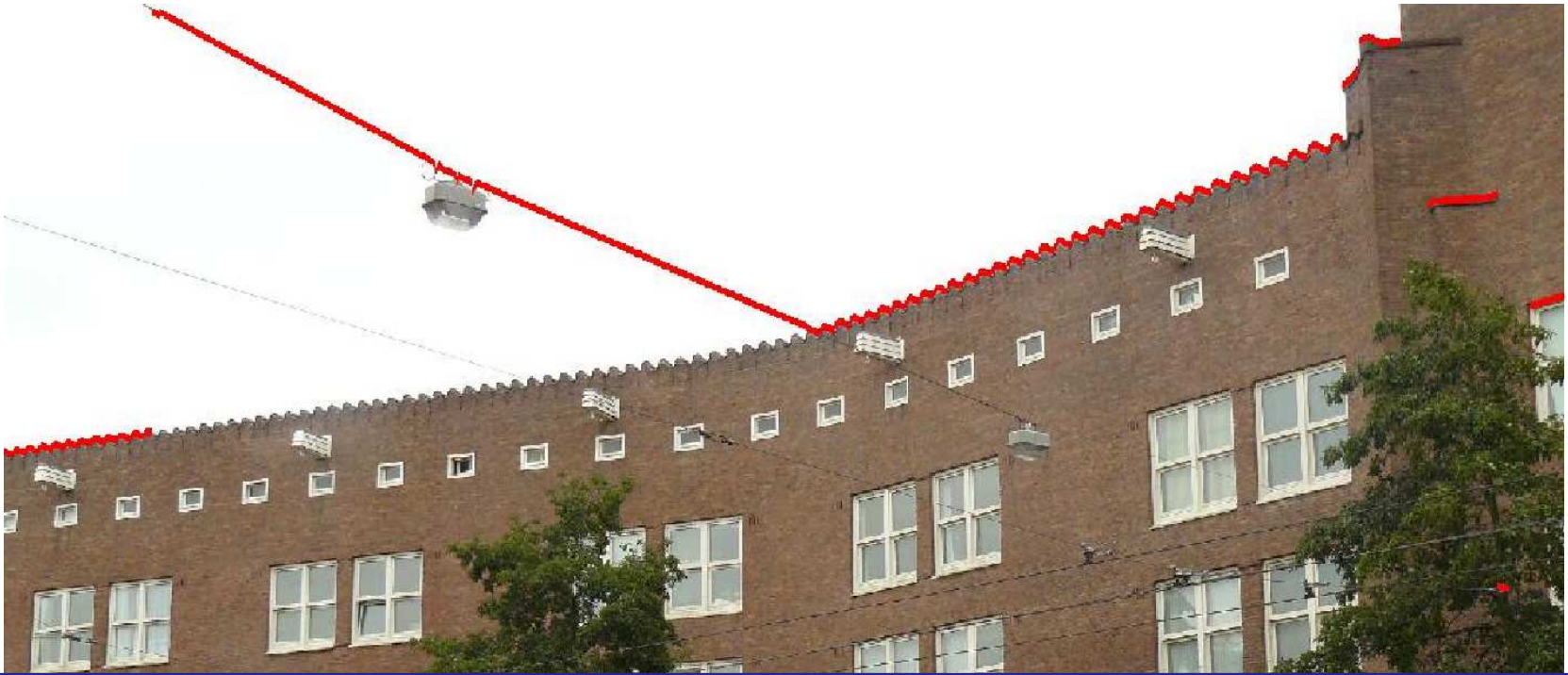
  - texture
  - color



Hypothesis based skyline detection, algorithm

- Generate *n* hypothesis
- Classify hypothesis with additional info
  - texture
  - color
  - height variation



Expected result on hypothesis classification based on color

Expected result classification based on height variation

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Conclusion

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Conclusion

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  - is simple and has a low complexity
  - works wel under the assumption skyline is upper edge
  - needs future research
    - can provide a set of hypothesis which should be evaluated using additional features (e.g. color and height variation)

Outline

Overview

- Create (top view) 2D model of the scene using *Openstreetmap*

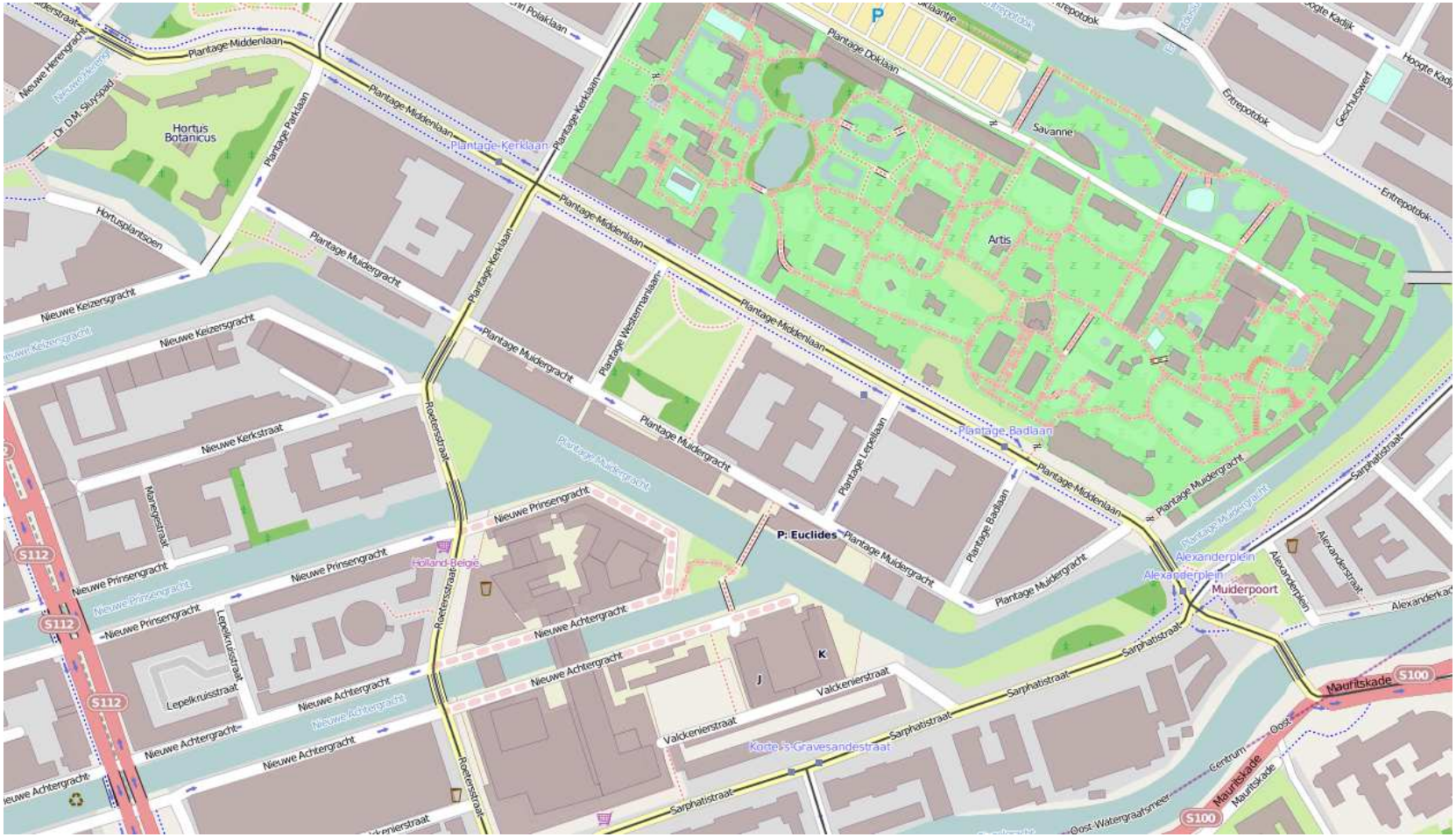
Overview

- Create (top view) 2D model of the scene using *Openstreetmap*
- Align 2D model with the scene

Overview

- Create (top view) 2D model of the scene using *Openstreetmap*
- Align 2D model with the scene
- Transform the 2D model to a 3D model by extending the walls

Extract 2D model



Align 2D model

- *FIT3D toolbox*

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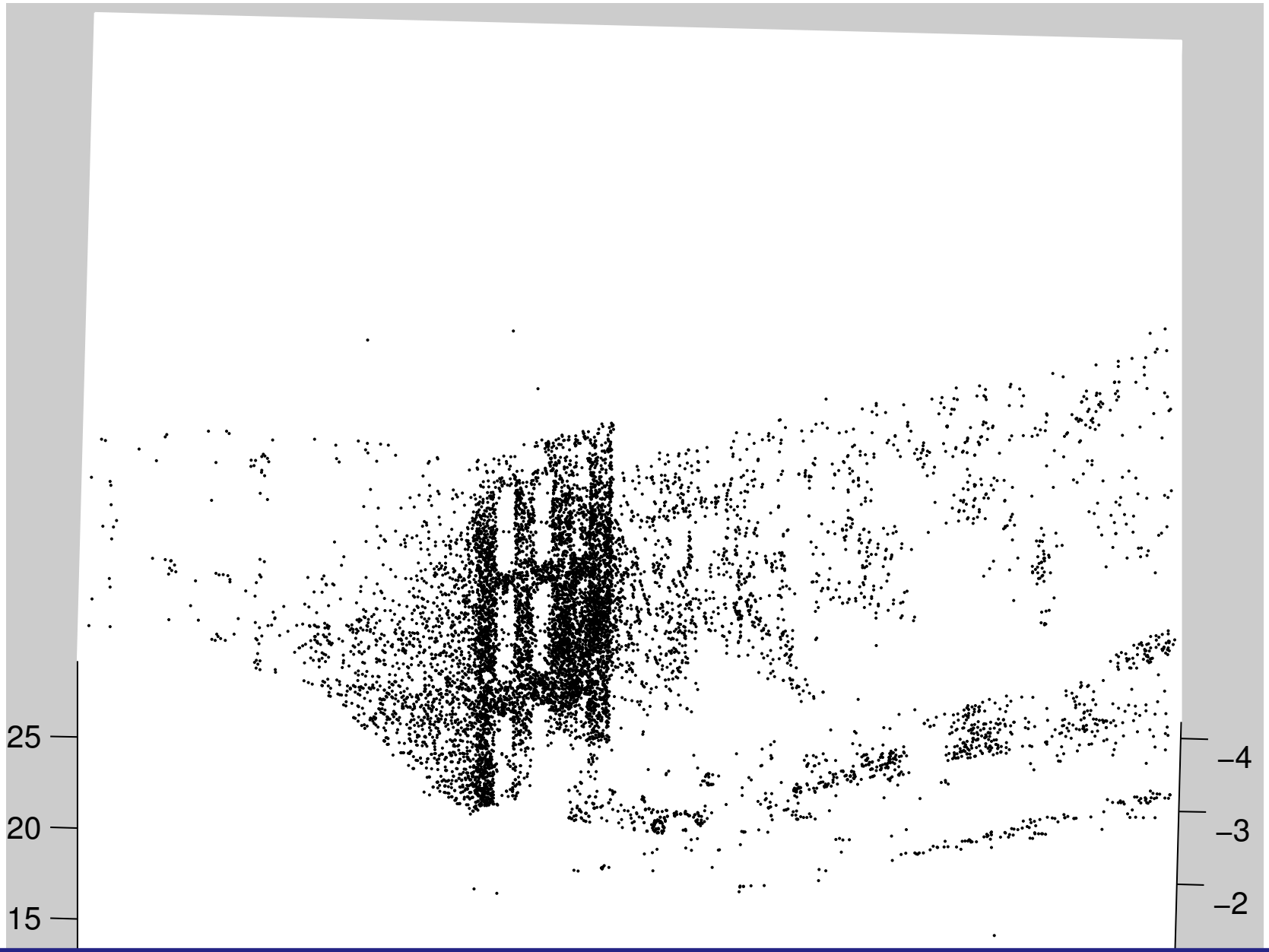
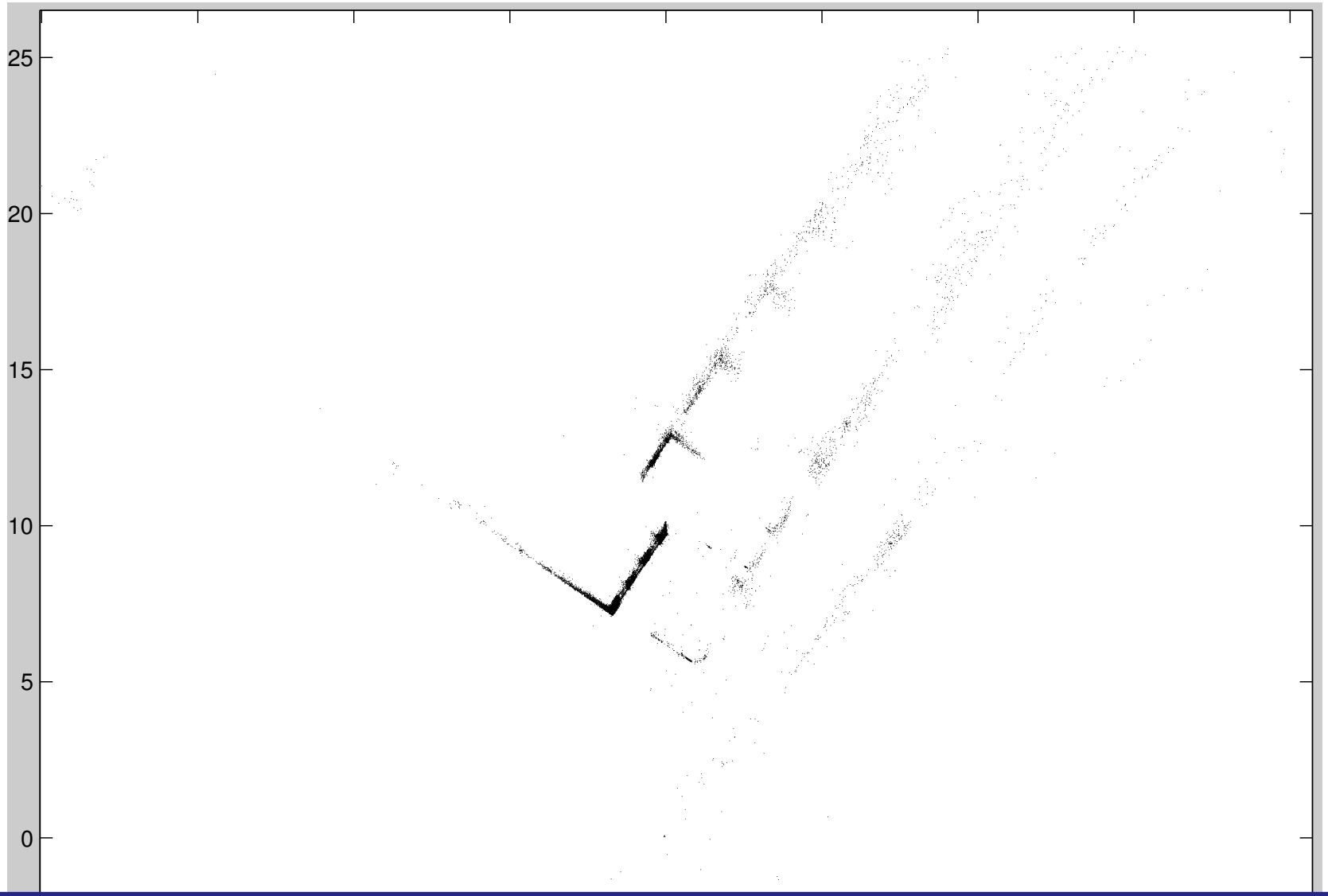
  - Input: sequence of images that contain different views of the building

Align 2D model

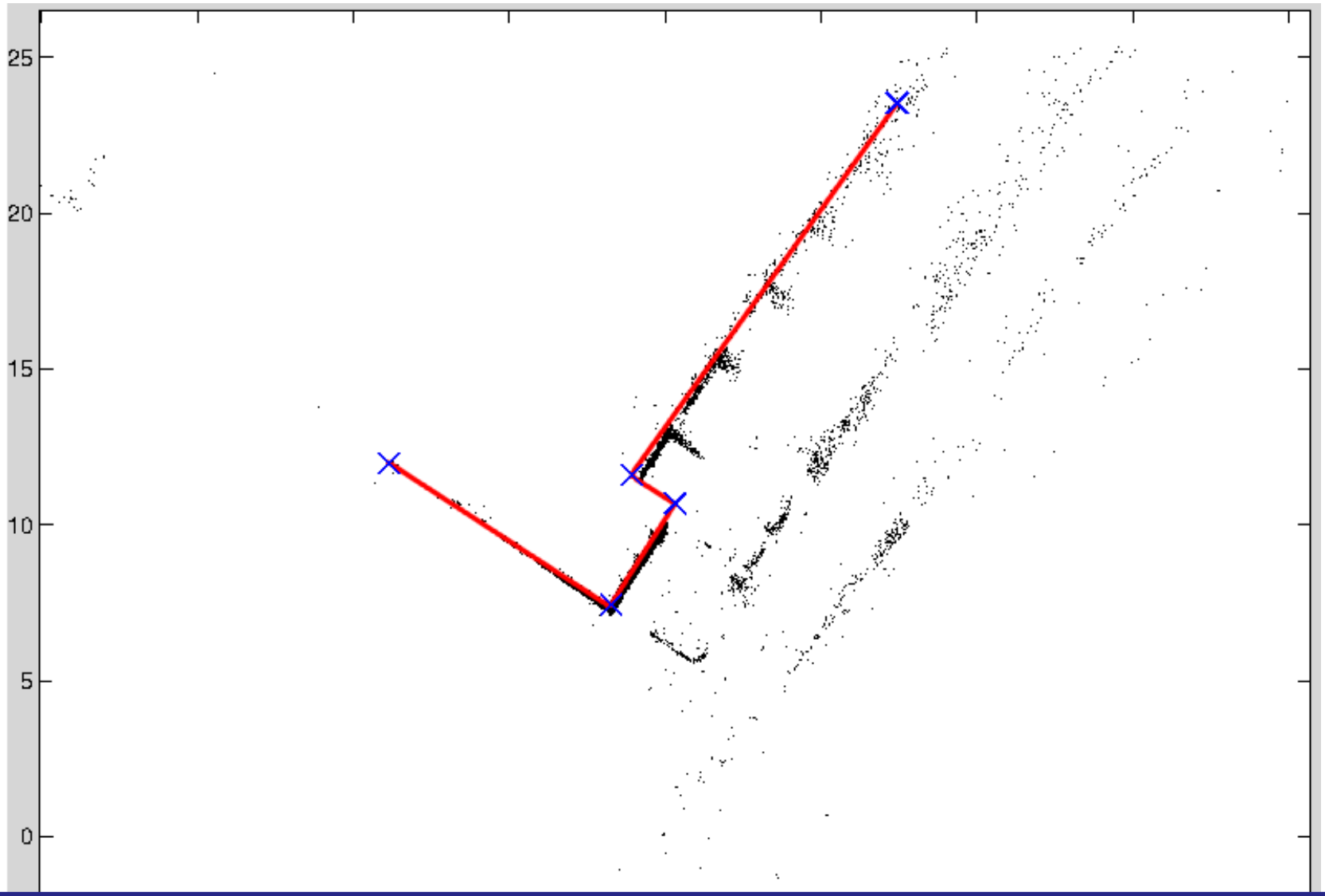
- *FIT3D toolbox*
  - Input: sequence of images that contain different views of the building
  - Output: a 3D point cloud of the building


25
20
15
−4
−3
−2

Align 2D model



Align 2D model



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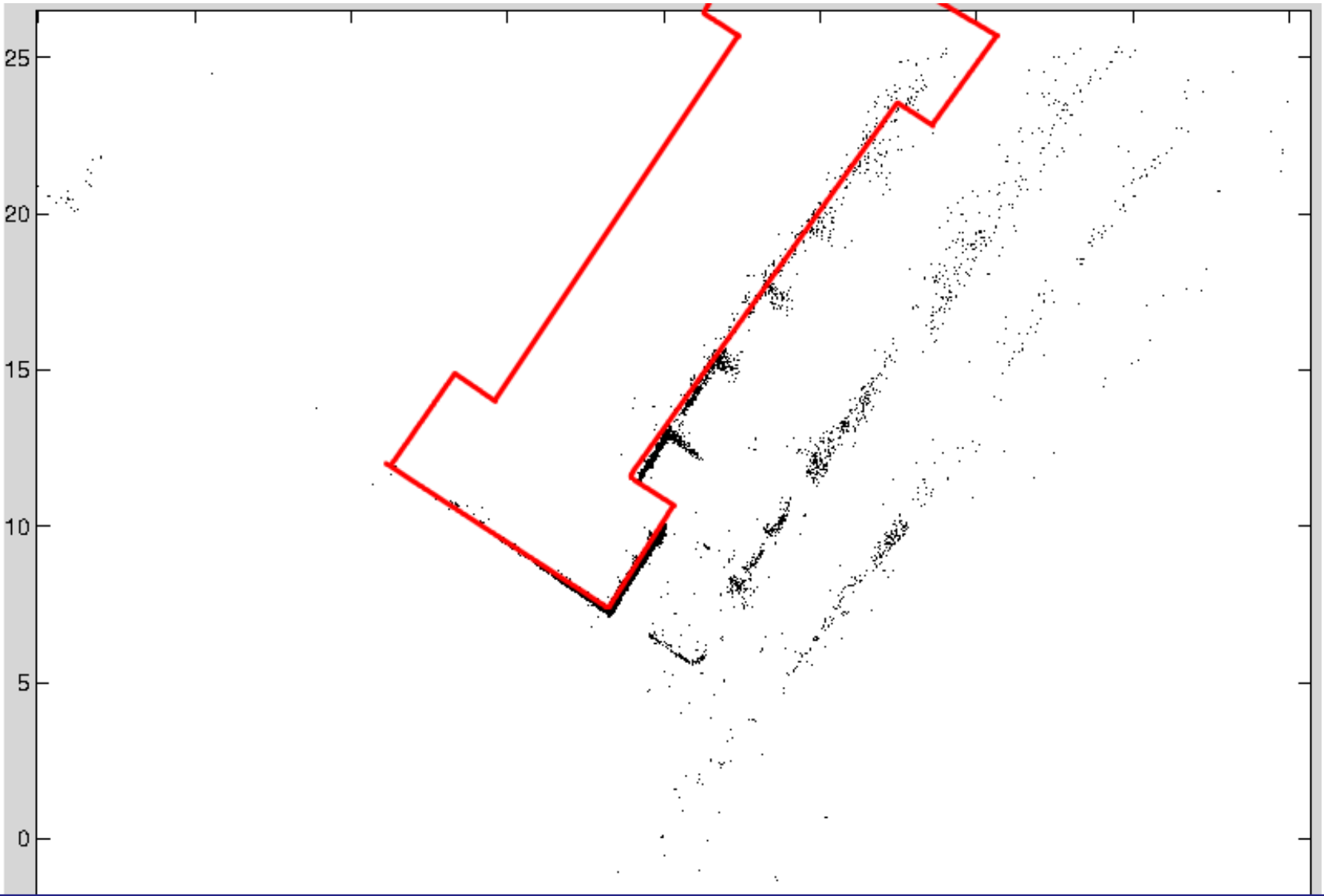
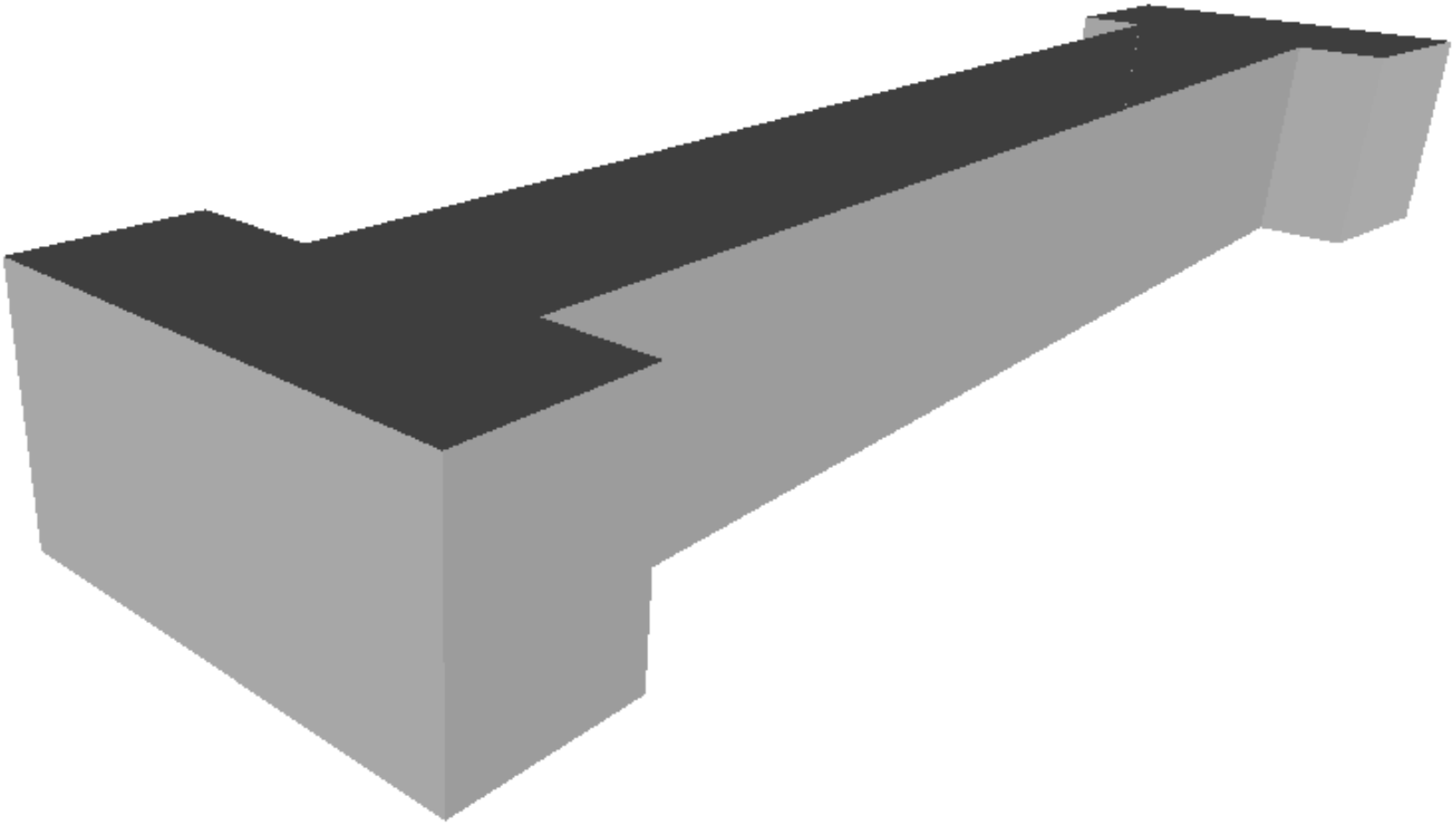


Results



Wall height estimation

- Wall heights of 3D model are not accurate

Wall height estimation

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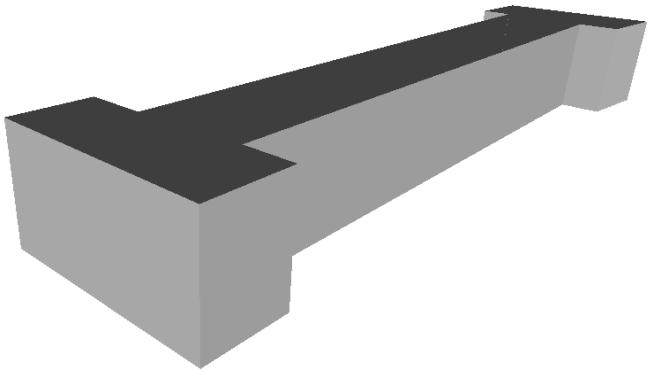
- Improve the 3D model by wall height estimation



(c)

(d)

Assumptions

- Straight lines assumption:
  - *Straight lines in the skyline are likely to come from the building contour*
- Flat roof assumption:
  - *building contour is equal to upper side of building walls*

Extracting line segments

- Output of skyline detector

Extracting line segments

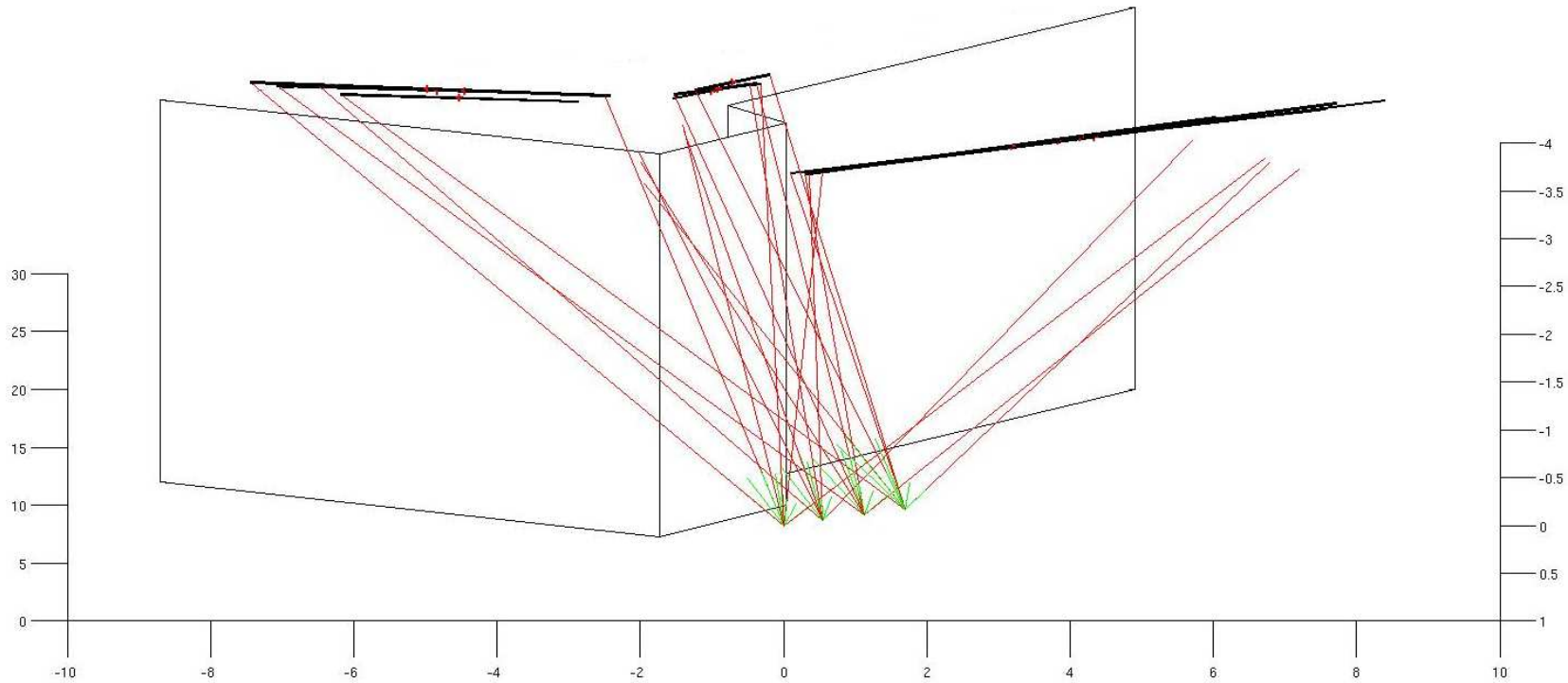
- Output of skyline detector
- Hough transform

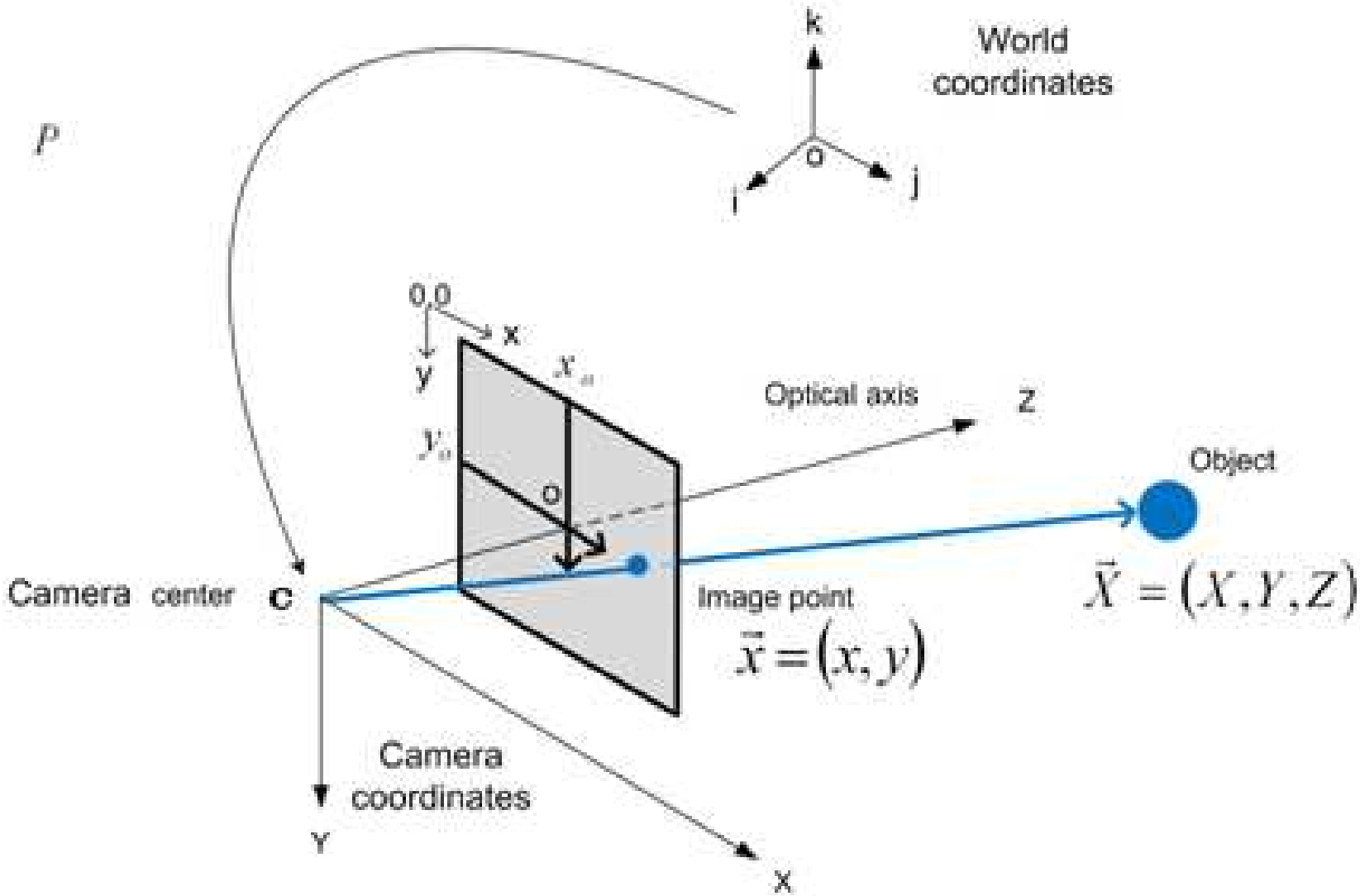
Project to the 3D model

- Estimate wall heights

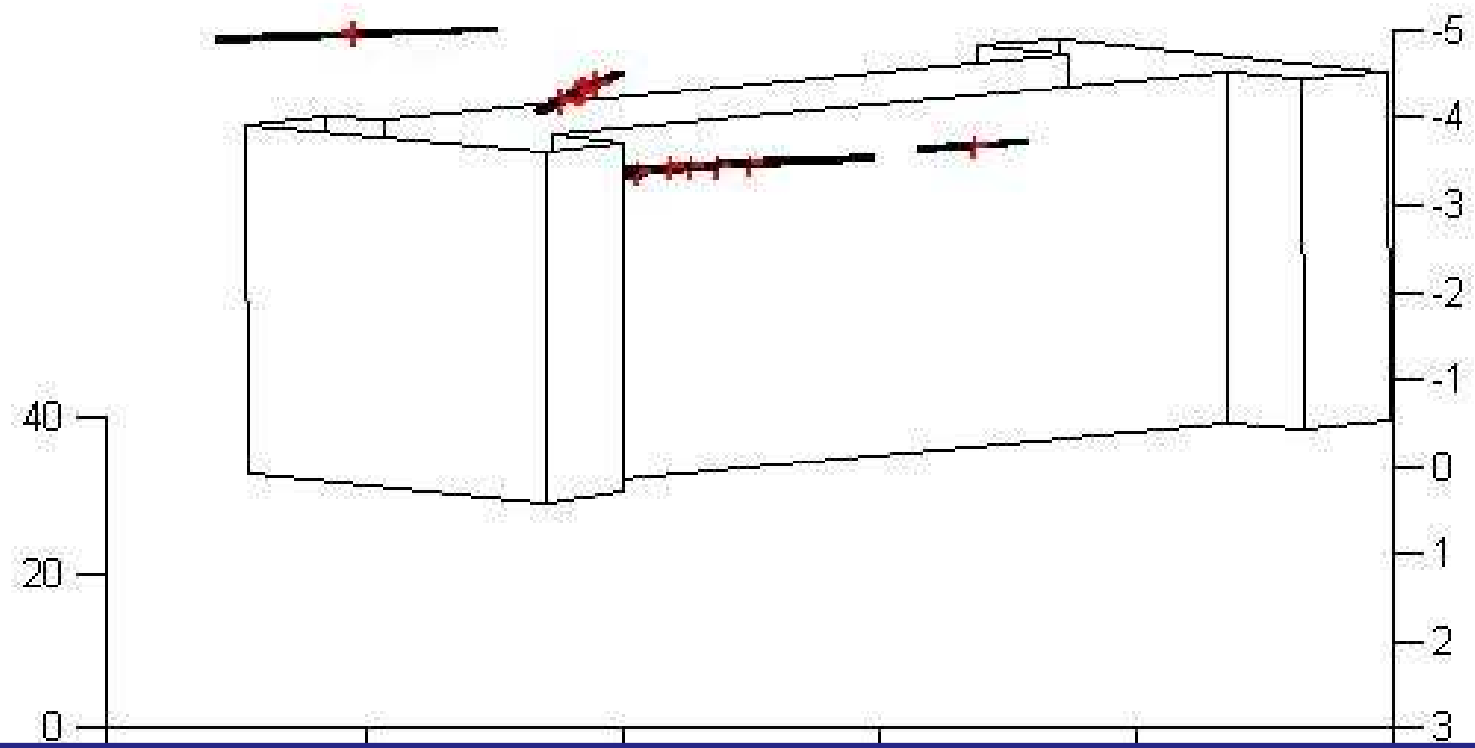
Project to the 3D model

- Estimate wall heights
- Project line segments to specific walls of 3D model




k
World coordinates
P
o
i
j
0,0
x
y
x_o
y_o
Optical axis
z
o
Object
Camera center C
Image point
$\vec{x} = (x, y)$
$\vec{X} = (X, Y, Z)$
Camera coordinates
Y
X

Results



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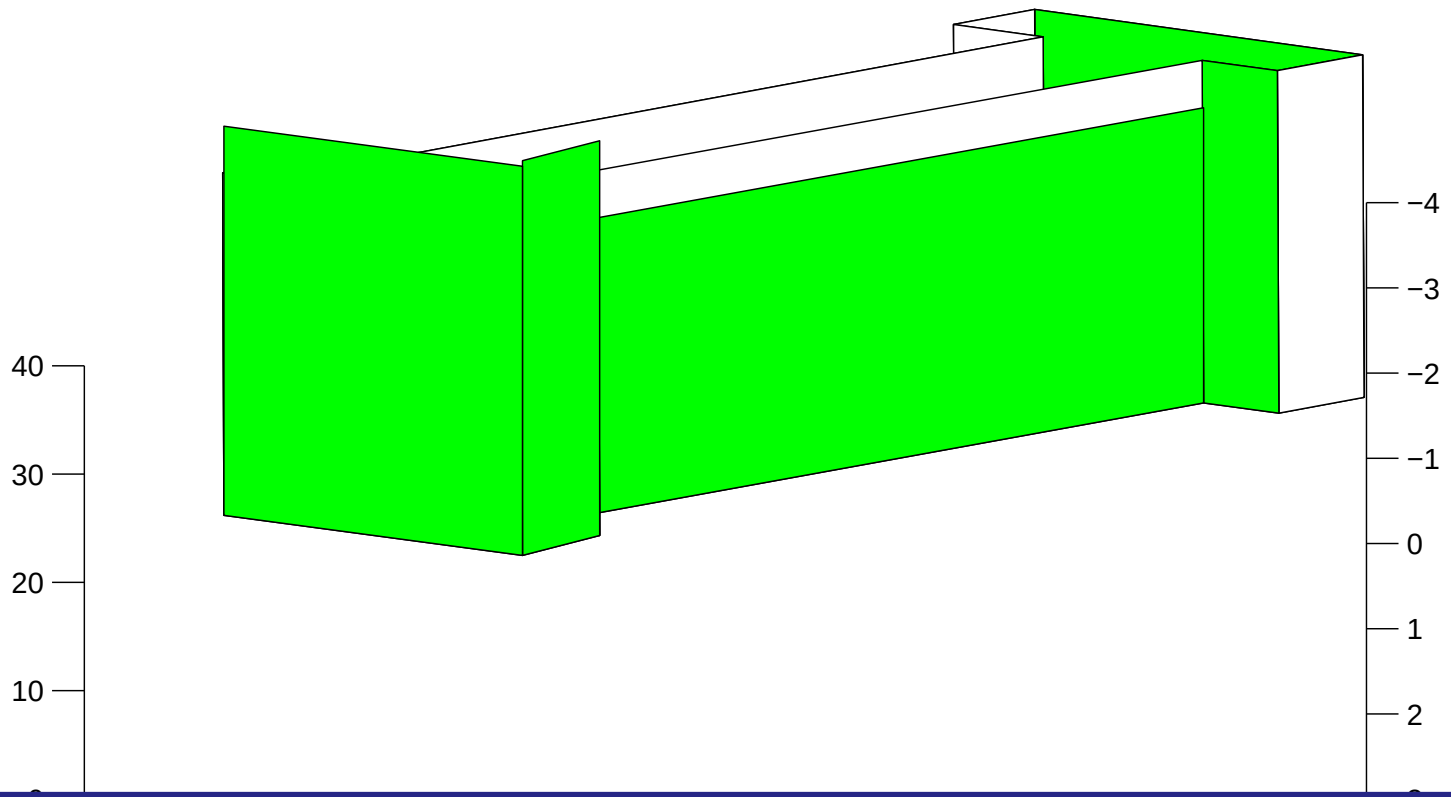
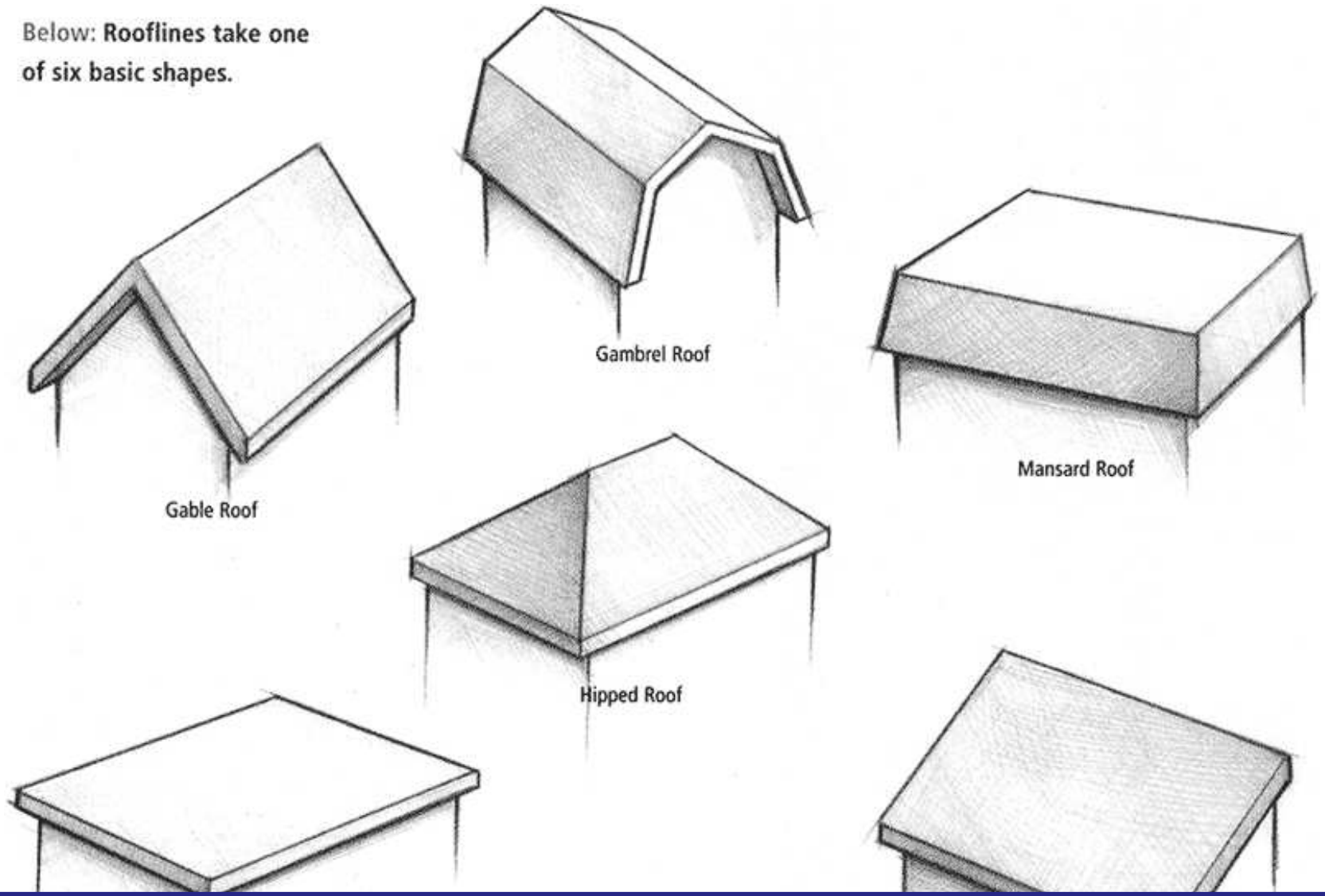


Future research



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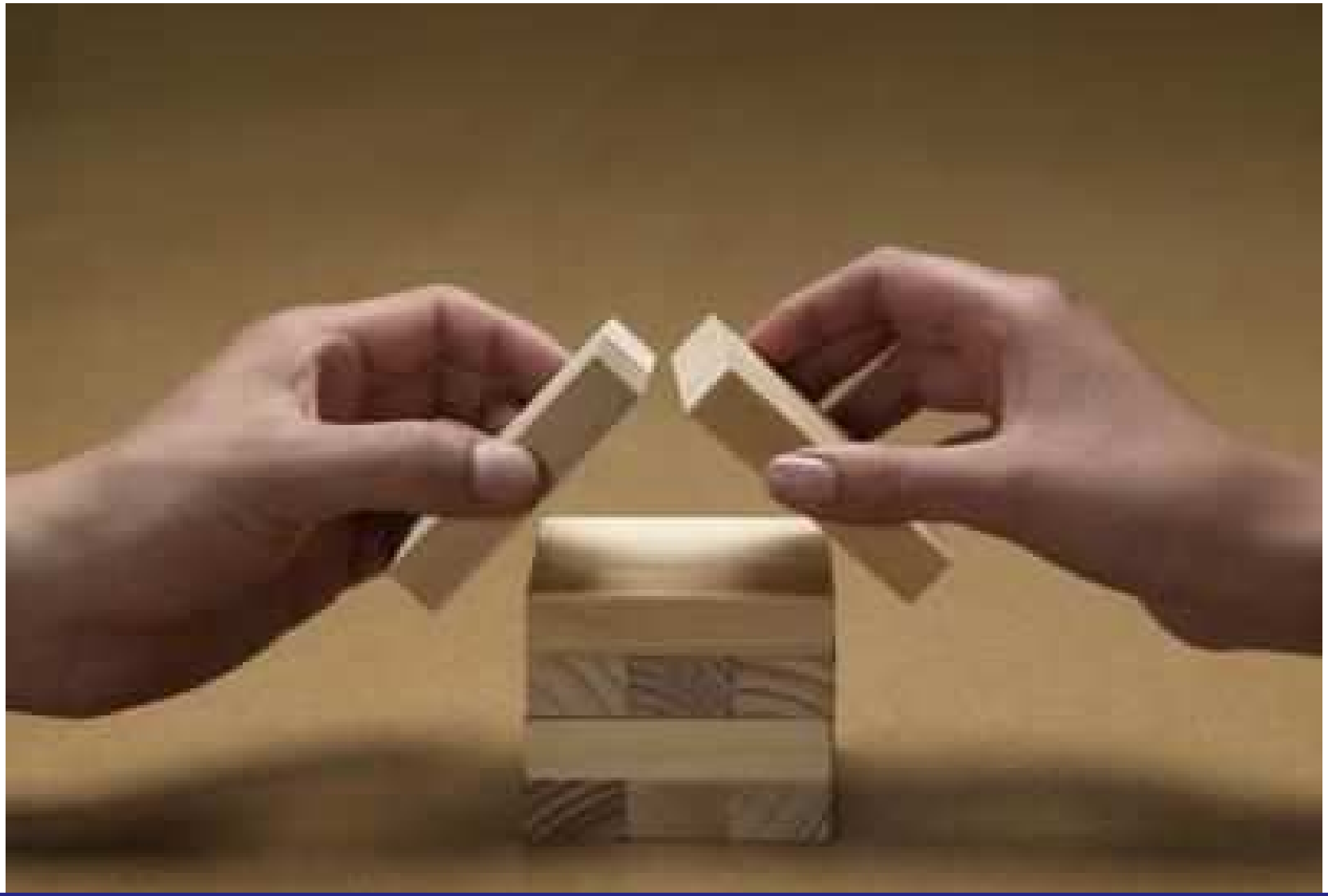

Outline

(e)

(f)

Outline Window detection

- Method I: Connected corner approach
  - invariant to viewing direction
- Facade rectification
- Method II: Histogram based approach
  - frontal view only
  - uses histograms of Houghlines

Method I: Connected corner approach

Situation

- Window = frame + glass (+ subwindows)

Situation

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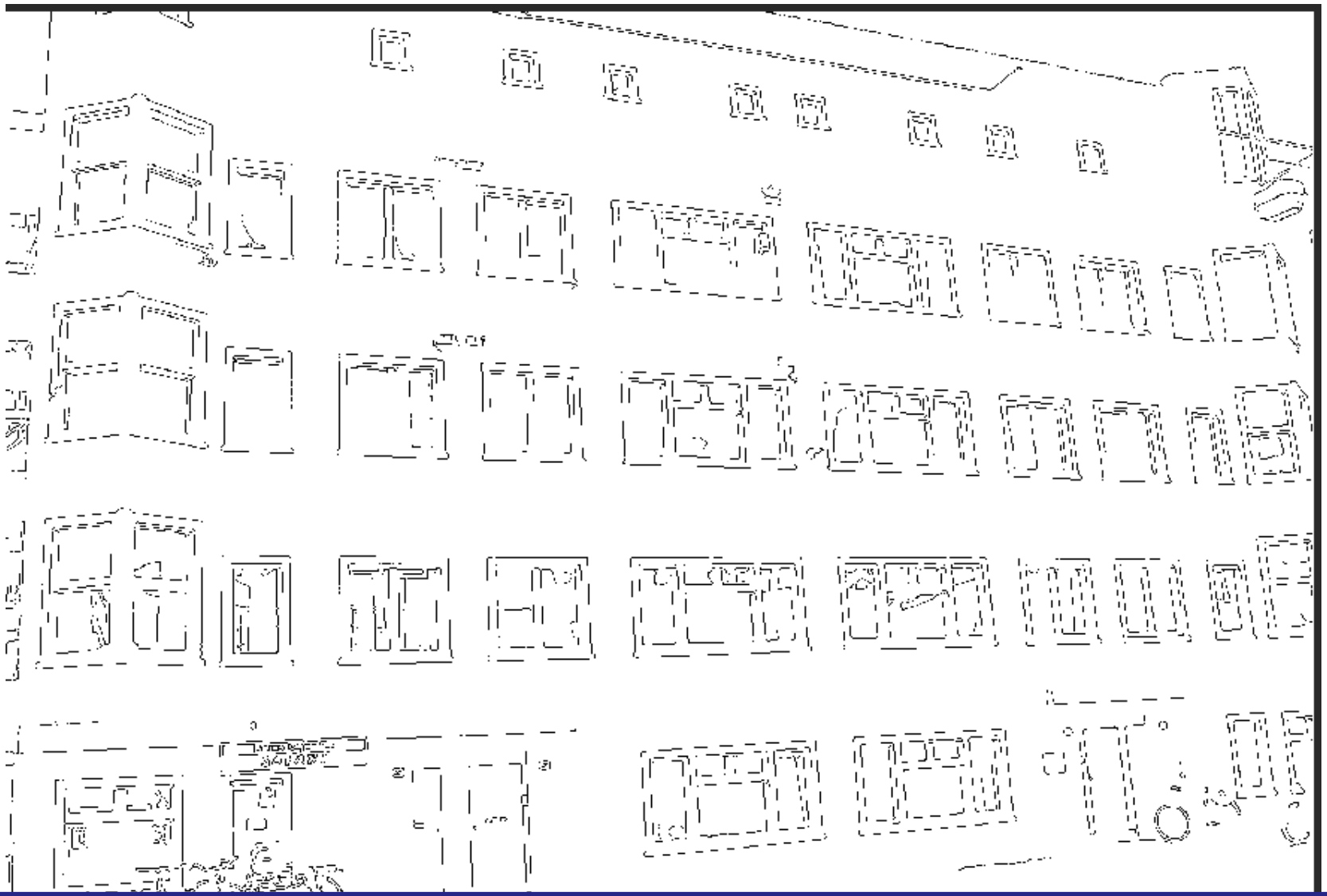
Situation

- Window = frame + glass (+ subwindows)
- Color difference, frame, glass
- Produce edges in horizontal and vertical direction

Original

Edge detection



The idea

- *"horizontal and vertical edges that come from the same (sub)window frame share a corner"*

Edge detection and Houghline extraction

- Canny edge detector

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- Two groups of straight lines (Houghlines)
  - θ-constraint

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  - Horizontal, $\theta = [-30..0..30)$ degrees
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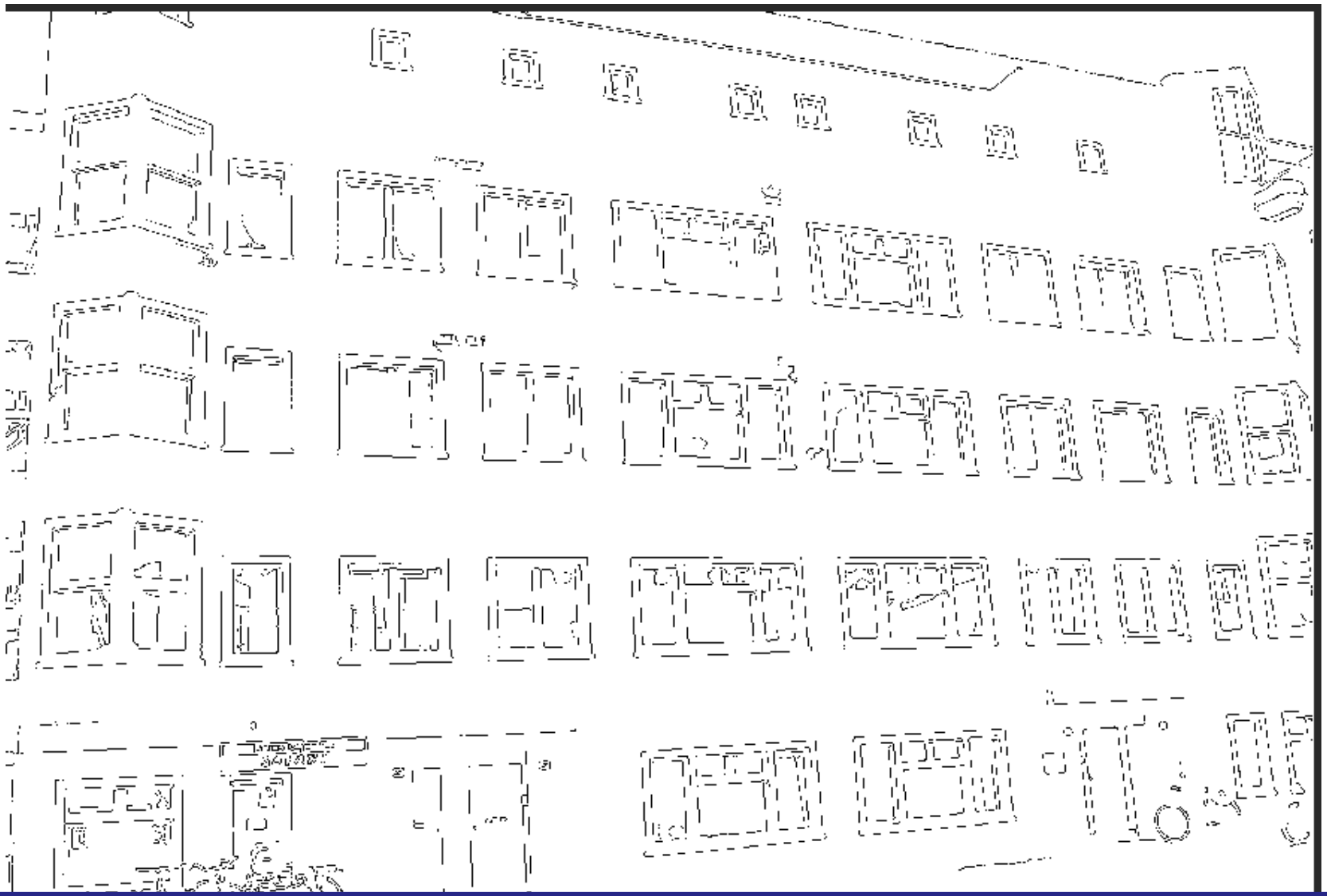
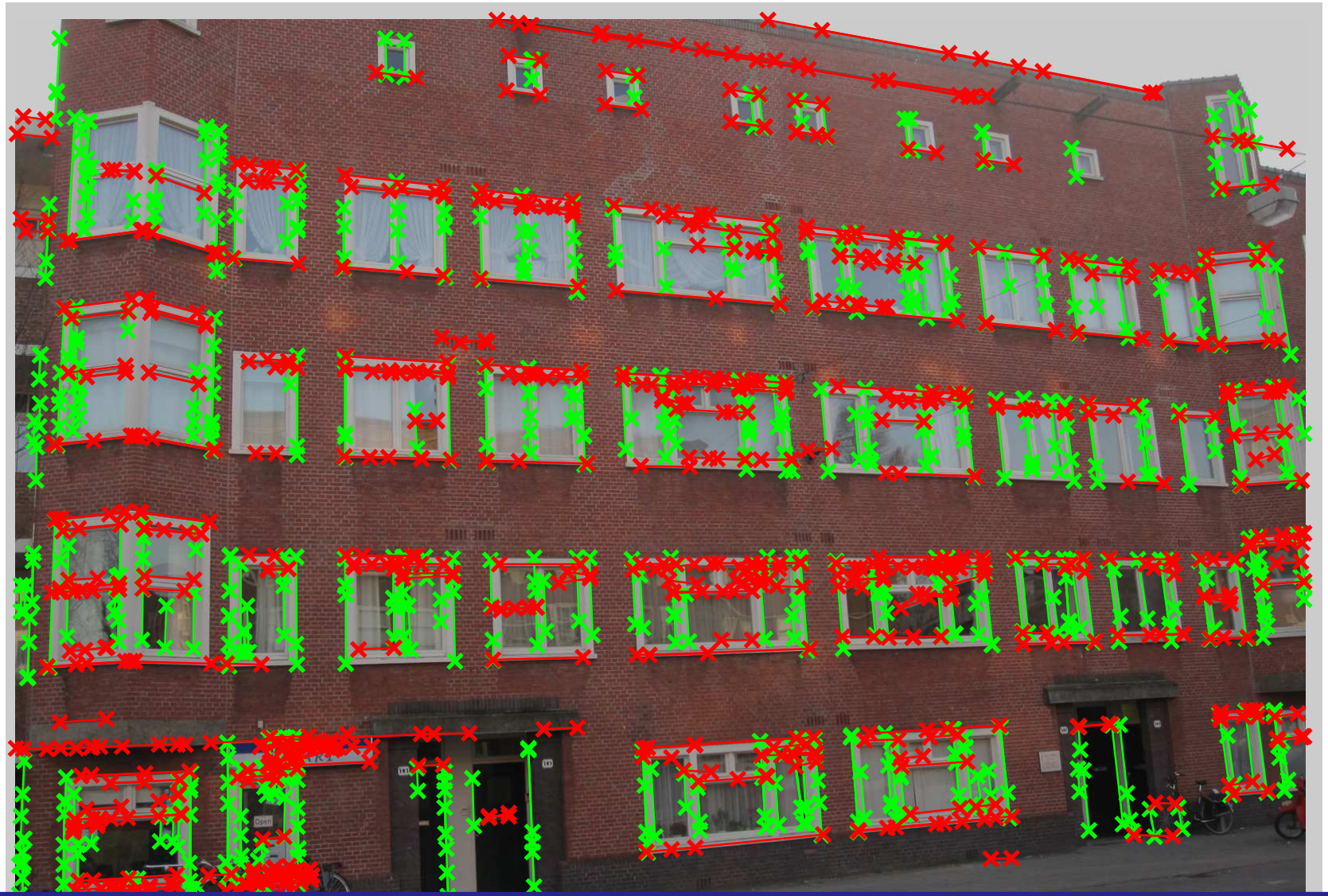
- Why the use of angle ranges?
  - Camera not exactly upright
  - Facade view contains an angle, perspective distortion

Original

Edge detection



Result of θ constrained Hough transform



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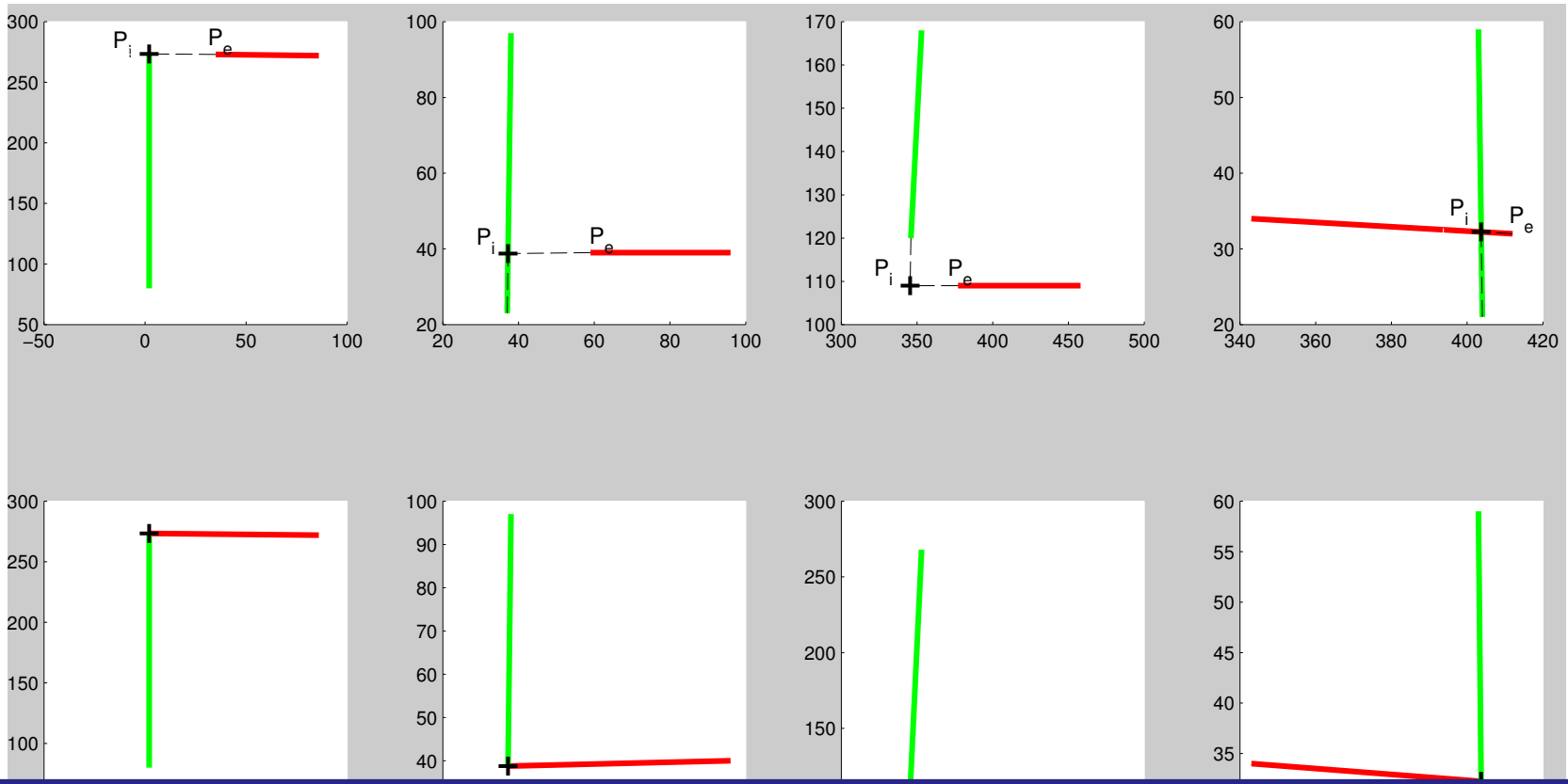
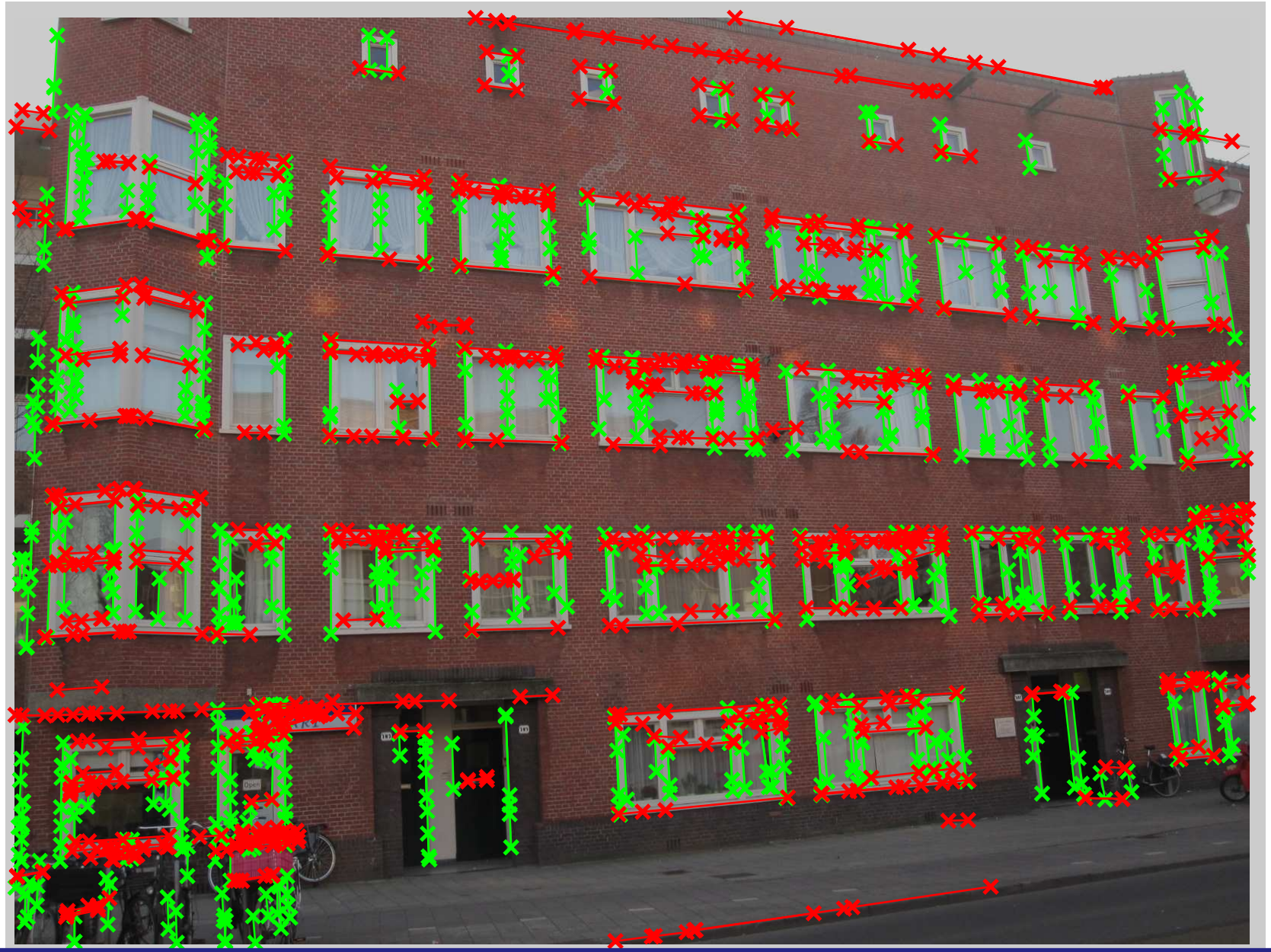
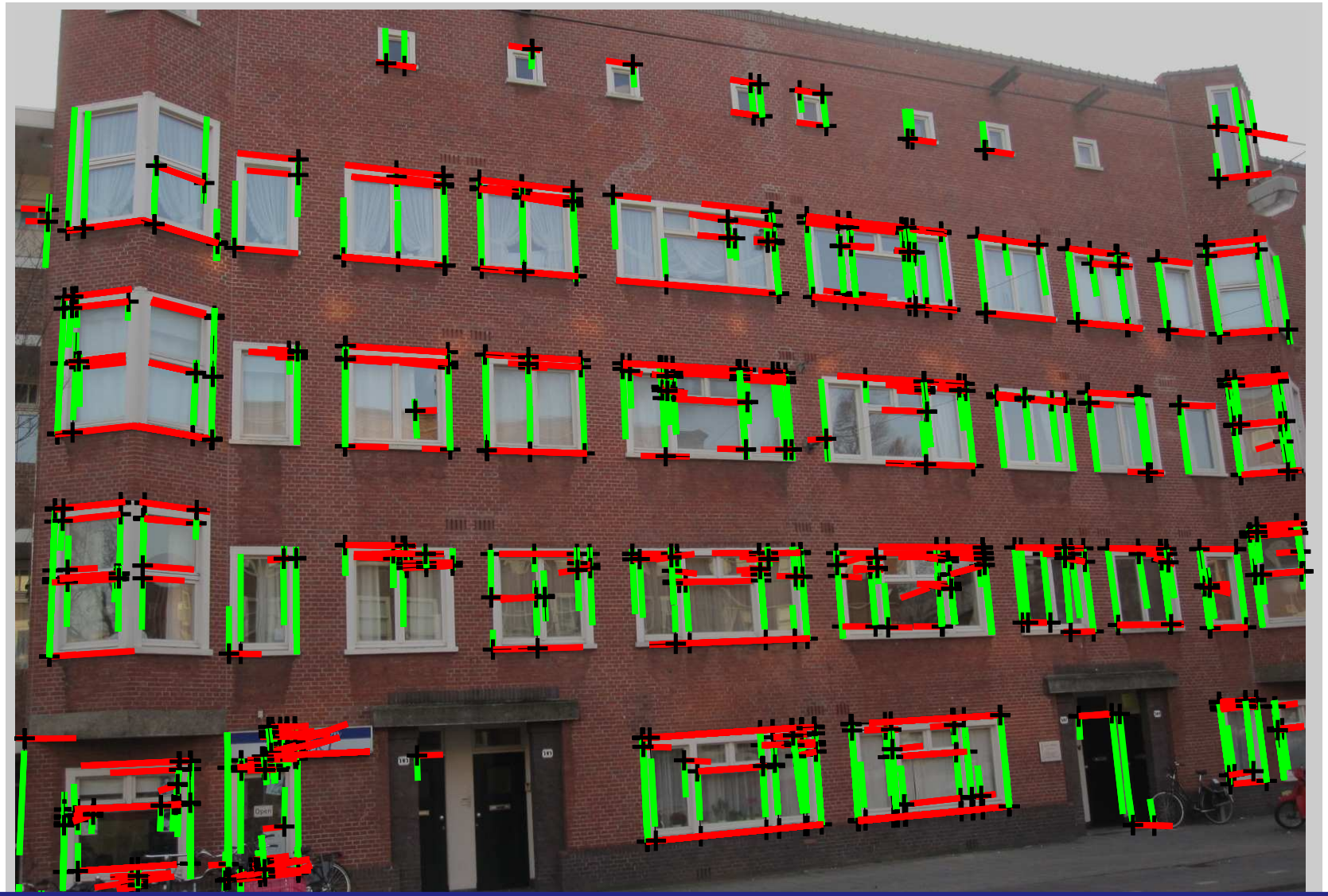




Connected Corners



Window area extraction

- How to extract the window areas?

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- Mirror from diagonal through endpoints

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- L-shapes becomes quadrangle window areas

Results

Future research

- L-shapes, U-shapes

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- L-shapes, U-shapes
- Analysis of substructure of windows
  - Cluster connected corner on location and length
  - Close connected corners of same size will be grouped
  - Maximum intercluster distance correlates with size subwindow
  - Assume nr of subwindows to estimate
    - max and min size of window
    - number of clusters
    - max intercluster distance

Method II: window detection

- Assumes that the windows are

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  - orthogonal

Method II: window detection

- Assumes that the windows are
  - orthogonal
  - aligned

Aligned but not orthogonal

Facade rectification

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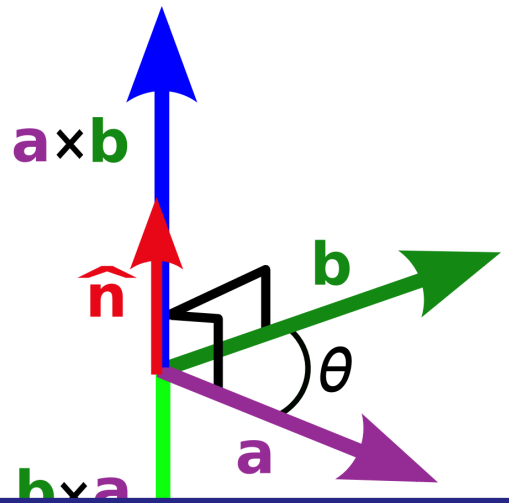
- Wall produces a normal vector: b
- Camera's heading: a
- Rotation matrix R is calculated and applied



Facade rectification

- FIT3D gives
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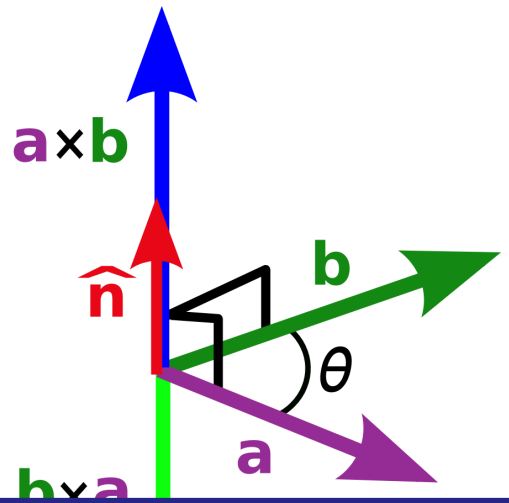
  - camera's heading
- 3D model gives plane that corresponds to wall
- Wall produces a normal vector: *b*
- Camera's heading: *a*
- Rotation matrix R is calculated and applied
  - orthogonal rotation vector *a* x *b*



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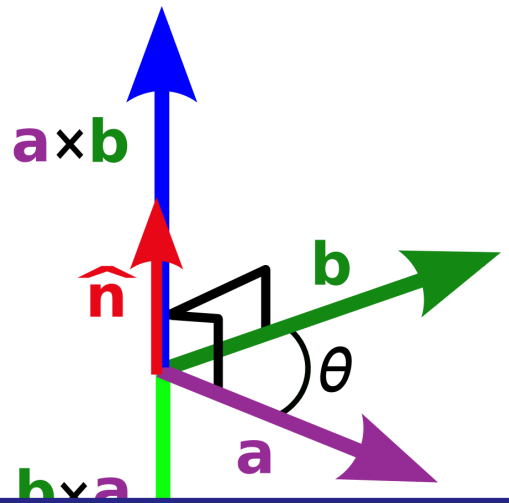
- Wall produces a normal vector: b
- Camera's heading: a
- Rotation matrix R is calculated and applied
  - orthogonal rotation vector $a \times b$
  - angle θ



Unrectified facade

Rectified facade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Extracting the window alignment

- Window alignment line
  - *"A horizontal or vertical line that aligns multiple windows"*

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- Alignment lines provide grid of blocks

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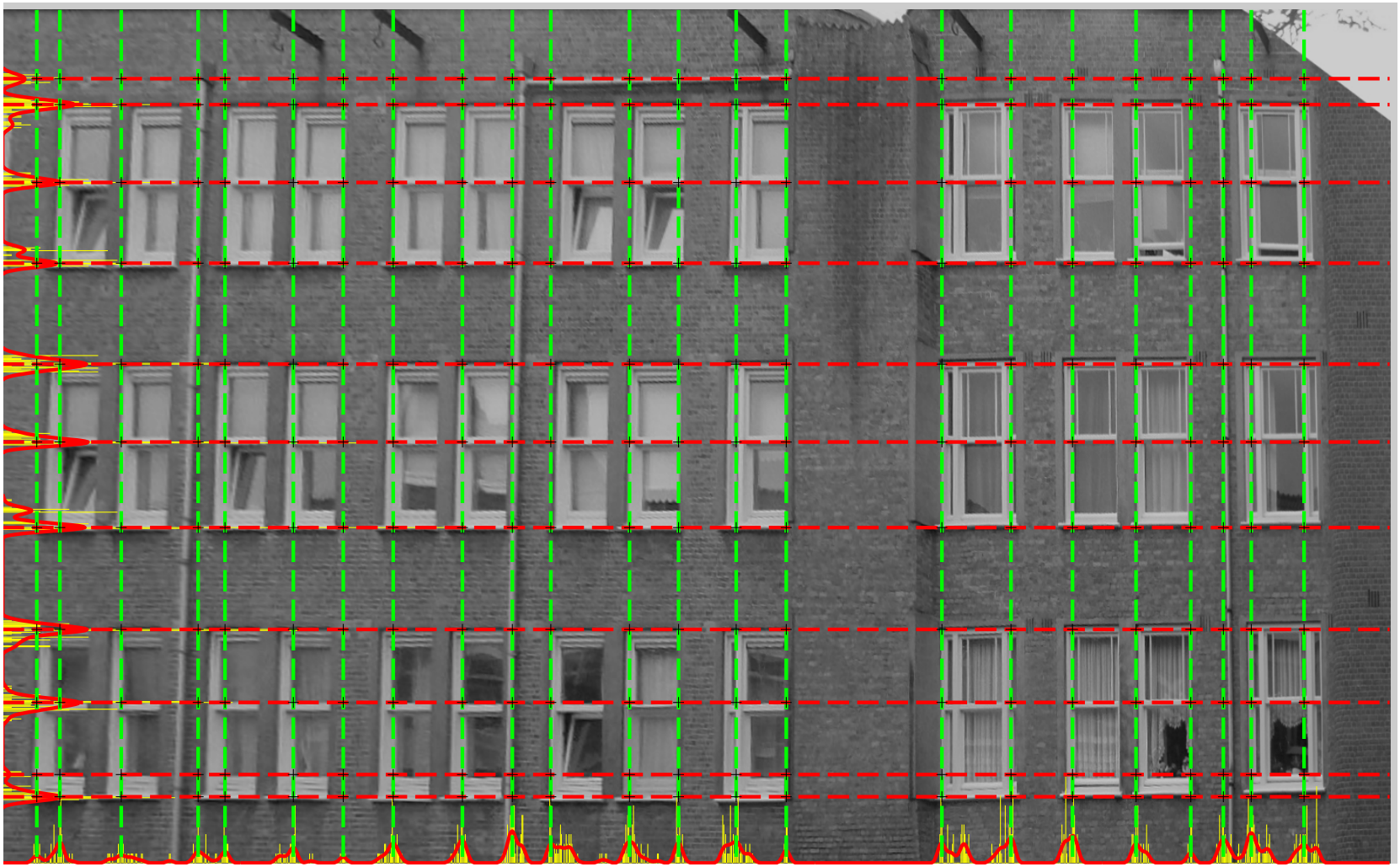
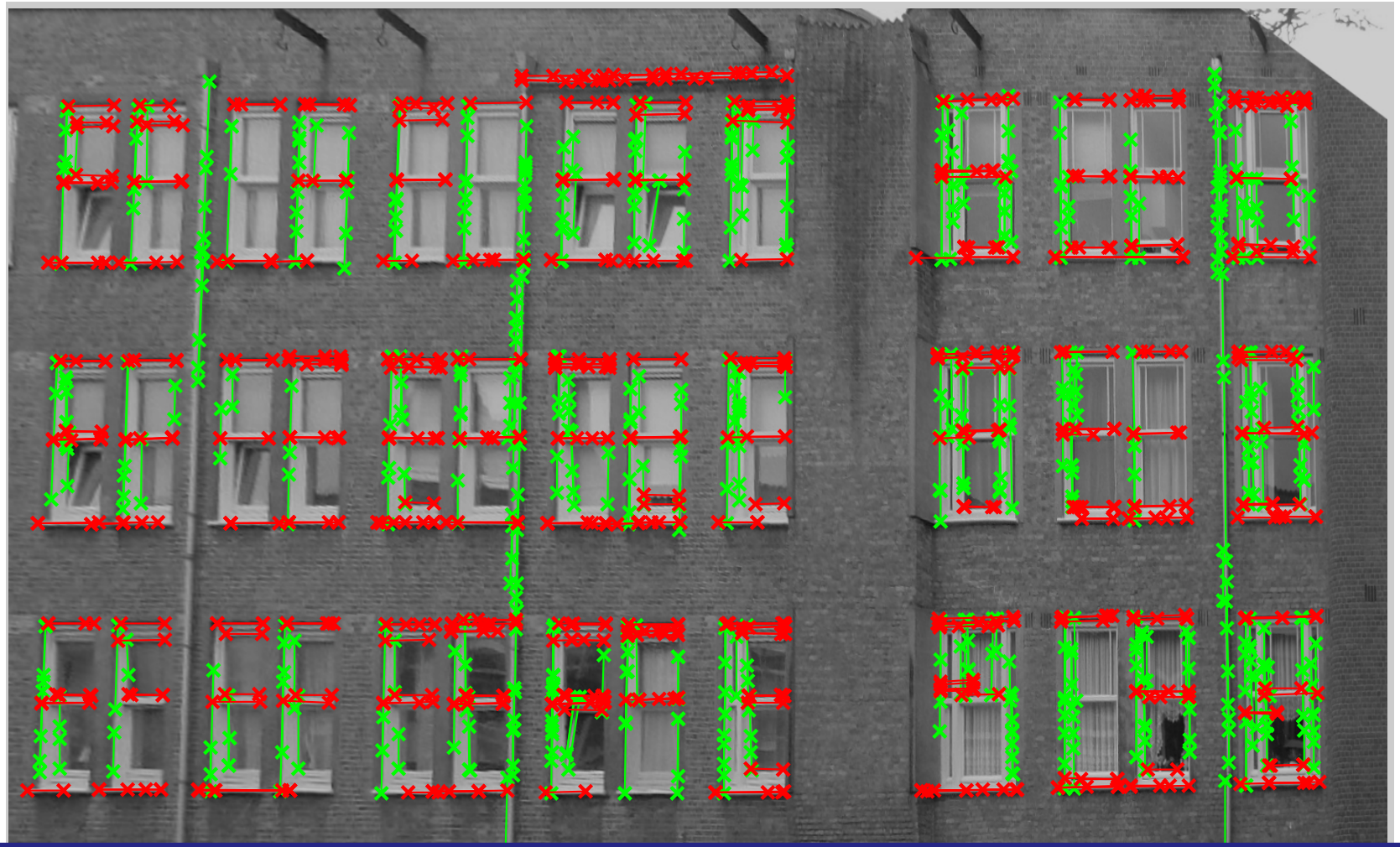
- Alignment lines provide grid of blocks
- Window, non-window areas

Window alignment lines example



The idea

- Amount of Houghlines high at window locations



The algorithm for vertical alignment (columns)

- Isolate *vertical* Hough lines

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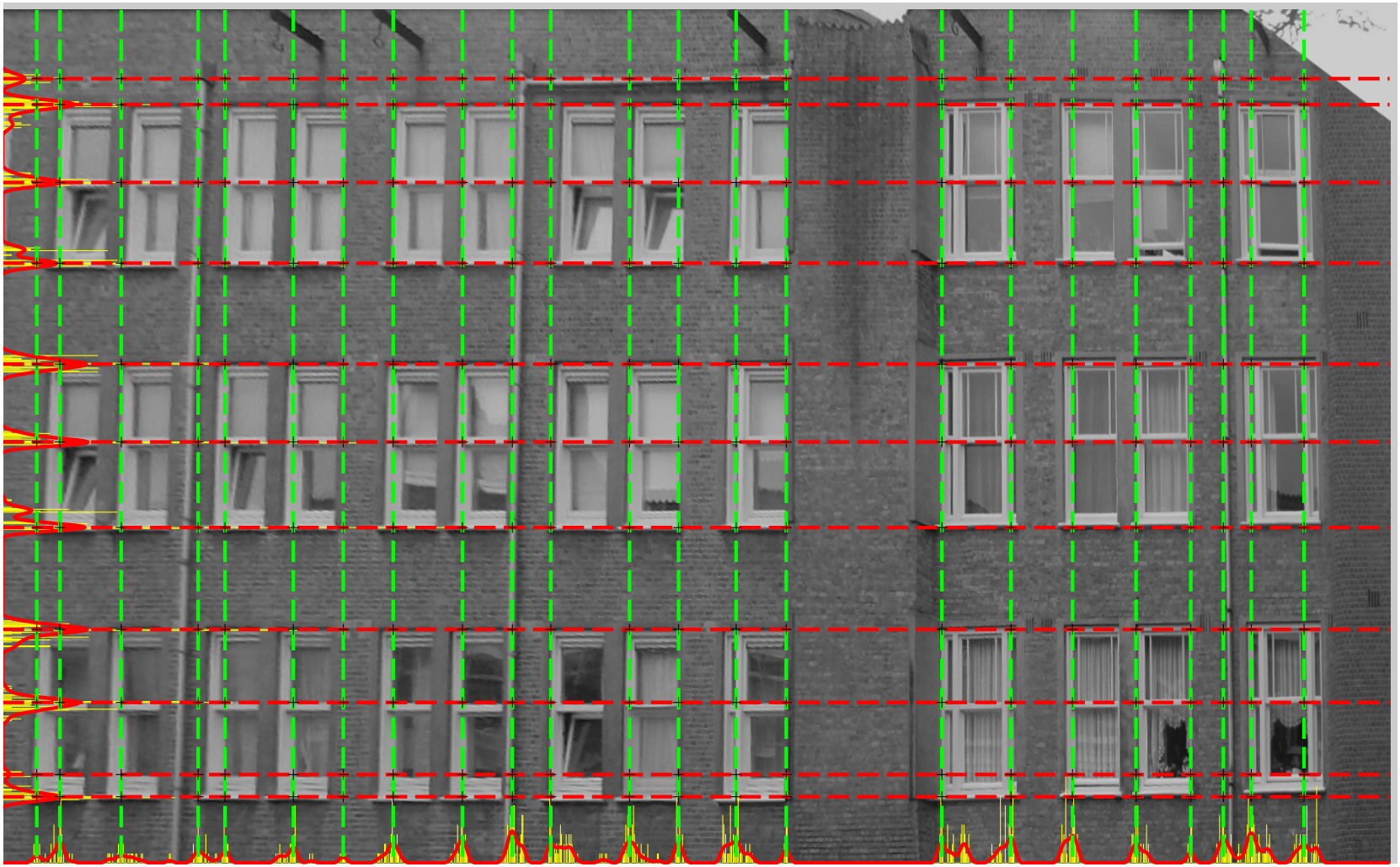
- Create histogram: count number of values on each x-position

Window alignment lines



Peak (area) extraction

- Smooth histogram function

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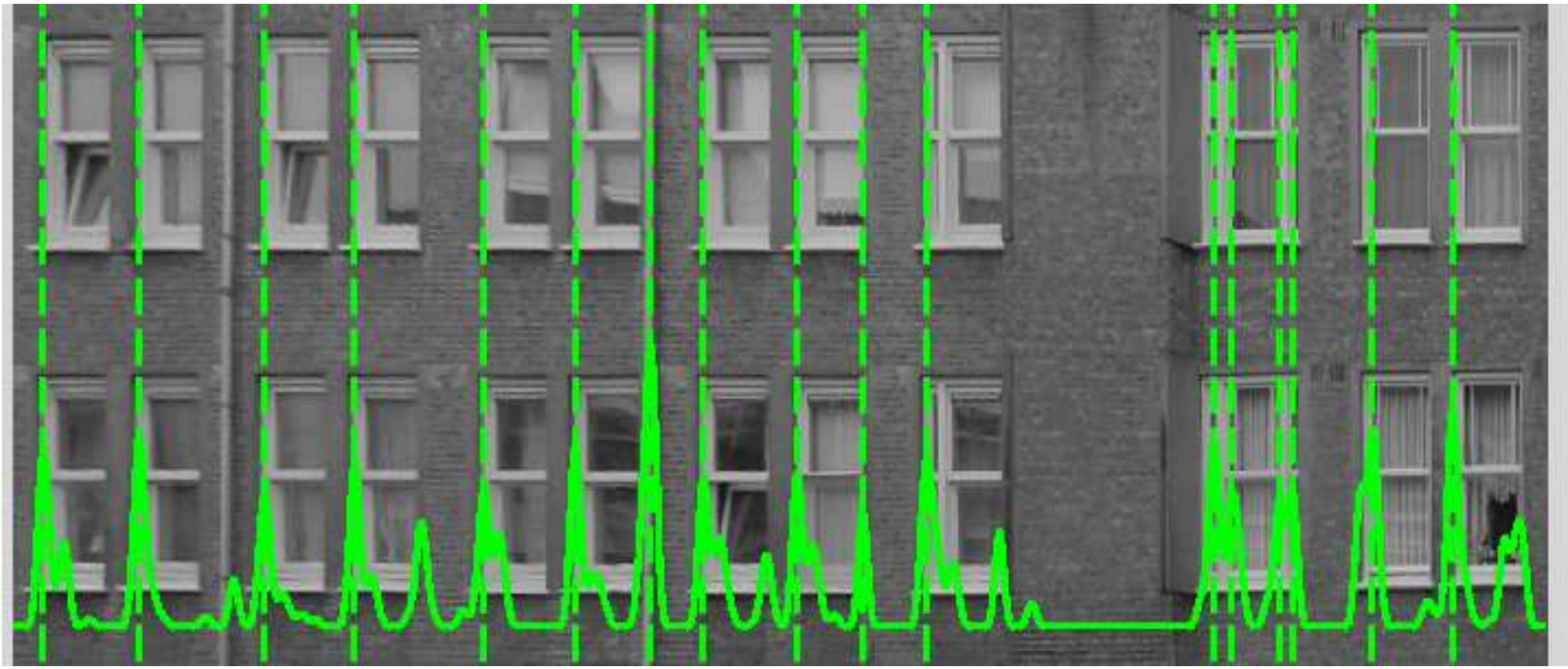
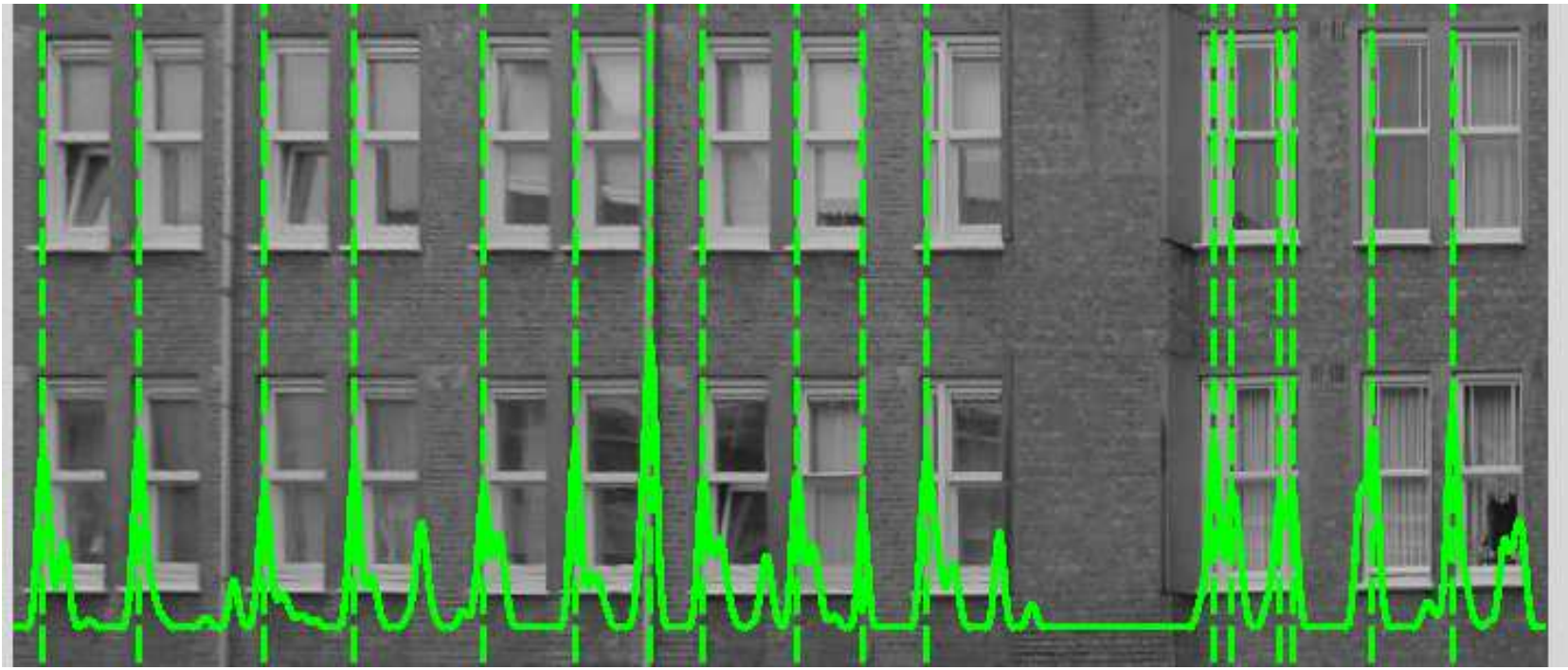
- Locate maximum for each peak area
- Draw alignment line on peaks



Reasons for improvement

- Window alignment at wrong locations
- Right side of window frame of first 4 columns not found
- Main reason: perspective distortion creates occlusion effect



Alternative window alignment

- Previous method:

Alternative window alignment

- Previous method:
  - Line segment endpoints

Alternative window alignment

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- Alternative method:
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  - Horizontal lines - window columns
  - Histogram shape analysis

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  - a window frame creates horizontal edges

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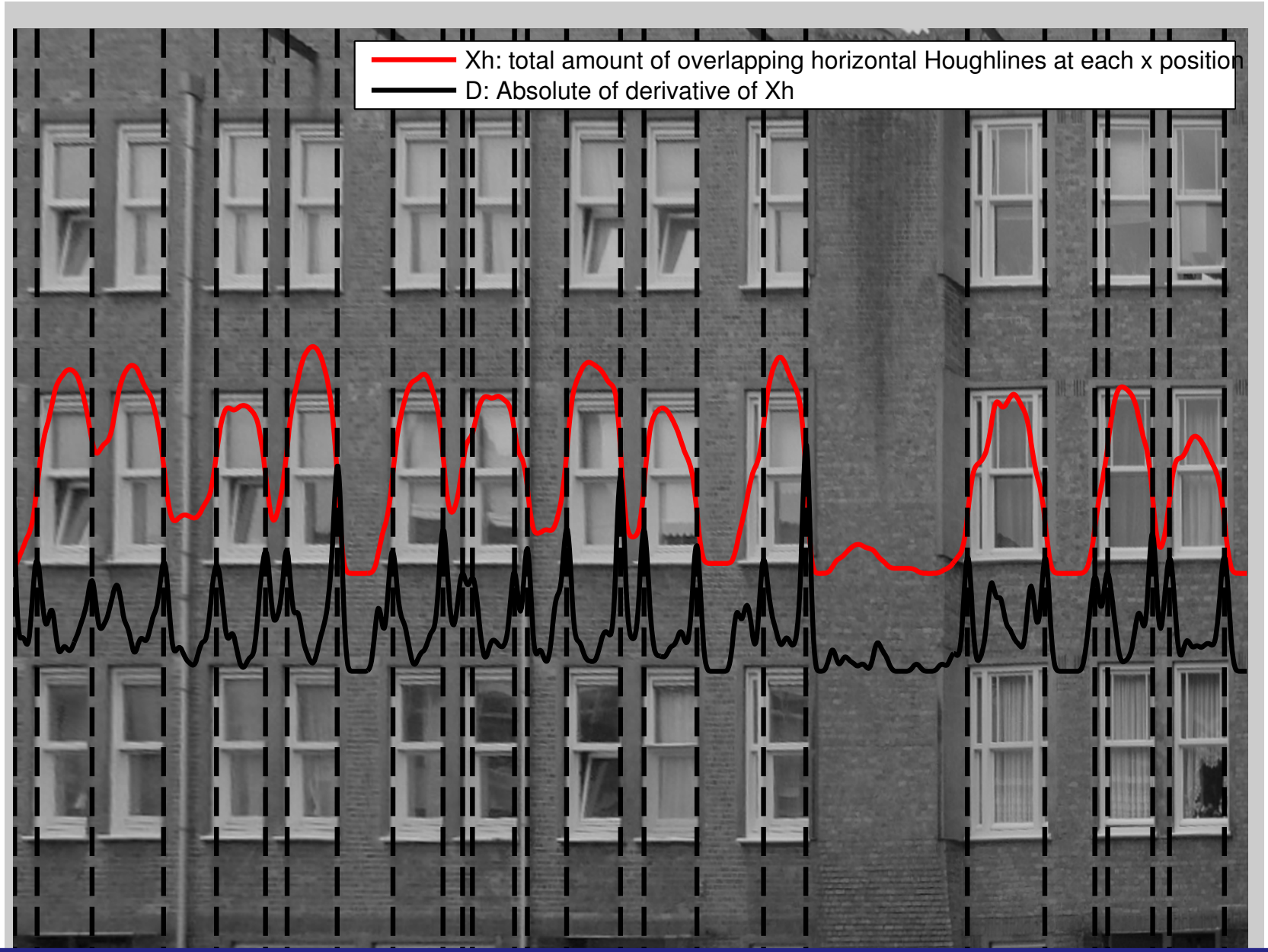
- X_h defines number of overlapping horizontal lines on each x position
- peak function

$$D = abs(X_h')$$


Xh: total amount of overlapping horizontal Houghlines at each x position
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Fusing the window alignment methods

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- Increase threshold (less but more certain alignment lines)
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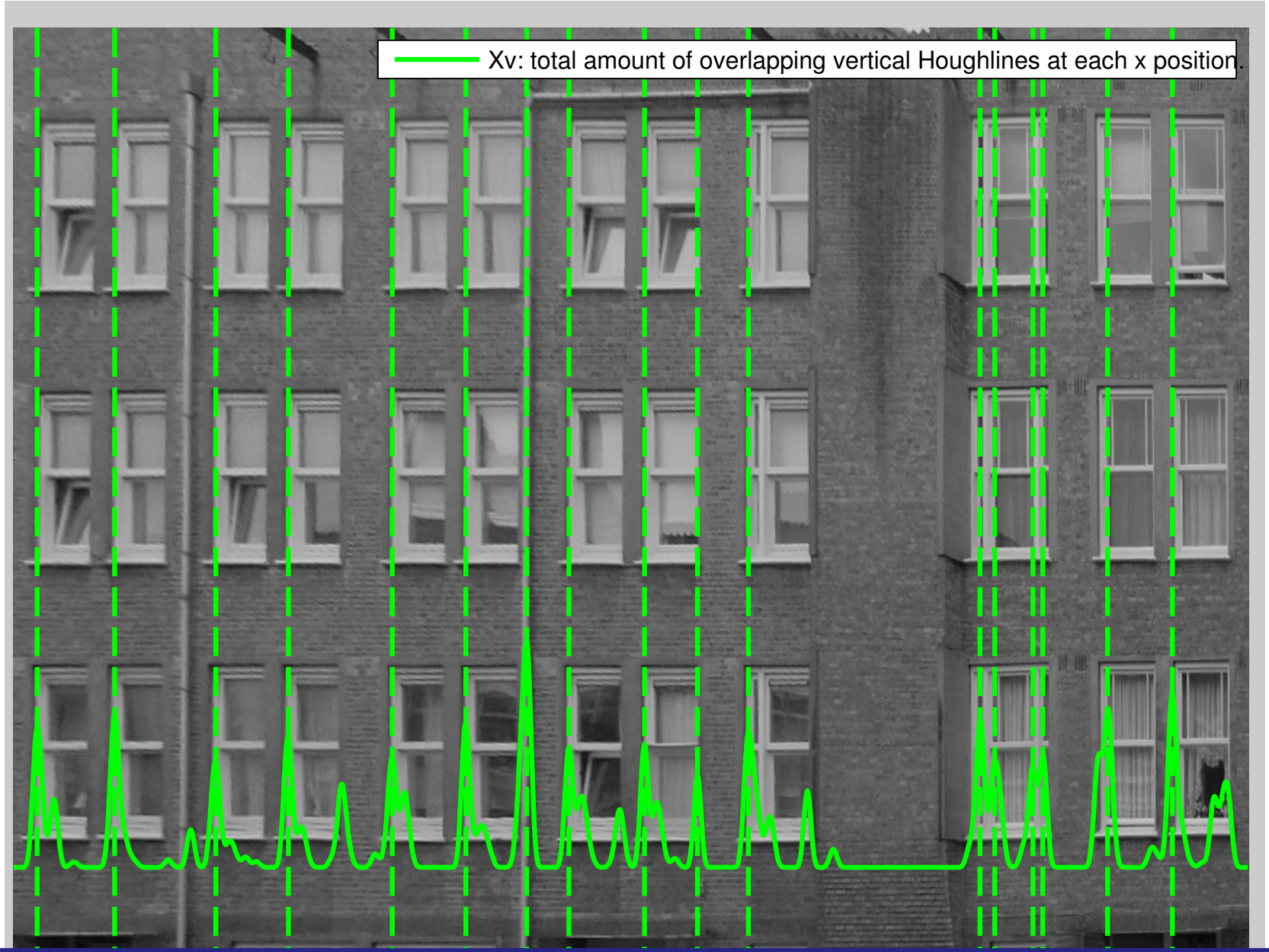
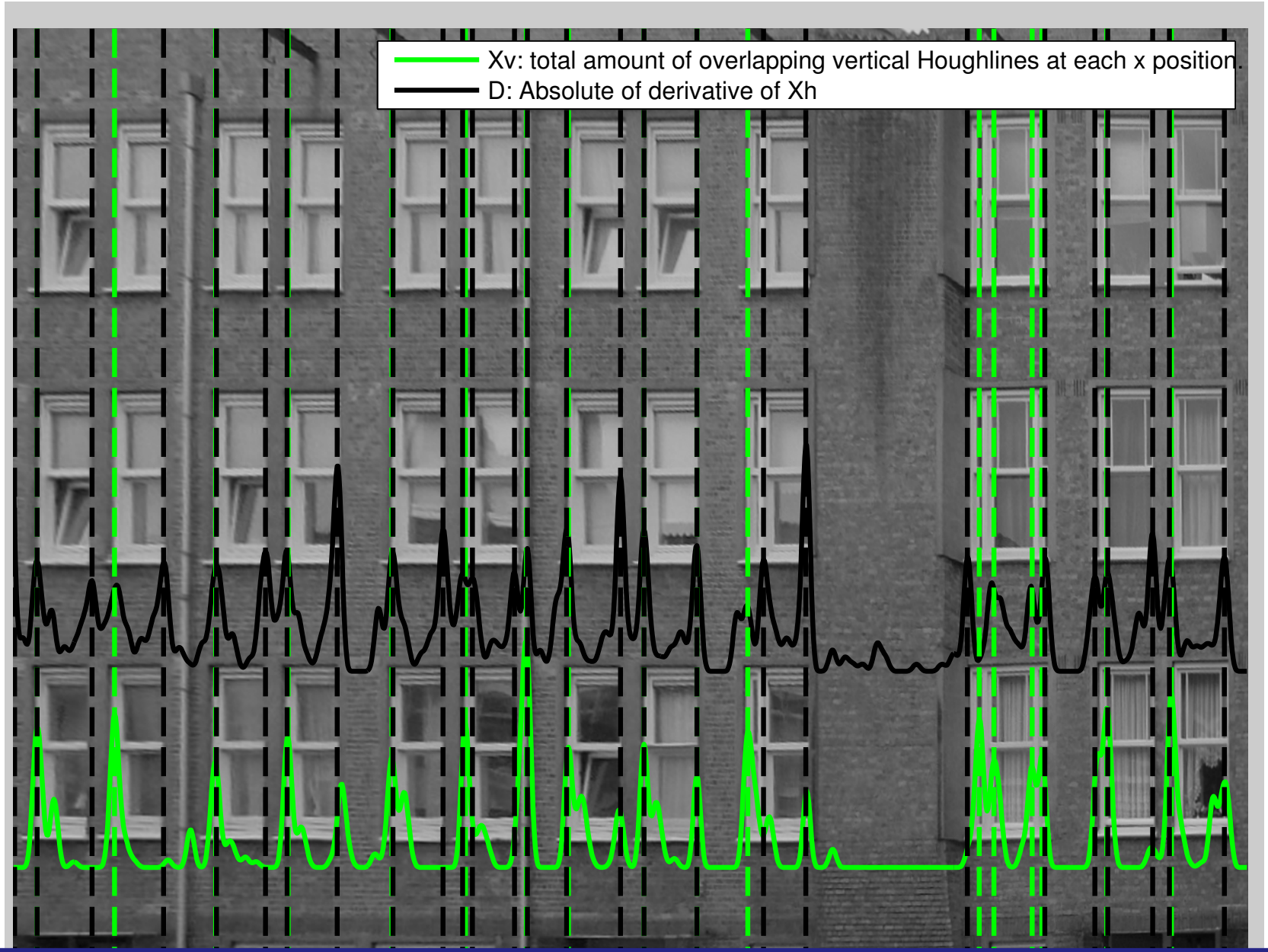
  - Merge peaks that are close


Xv: total amount of overlapping vertical Houghlines at each x position.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Other dataset


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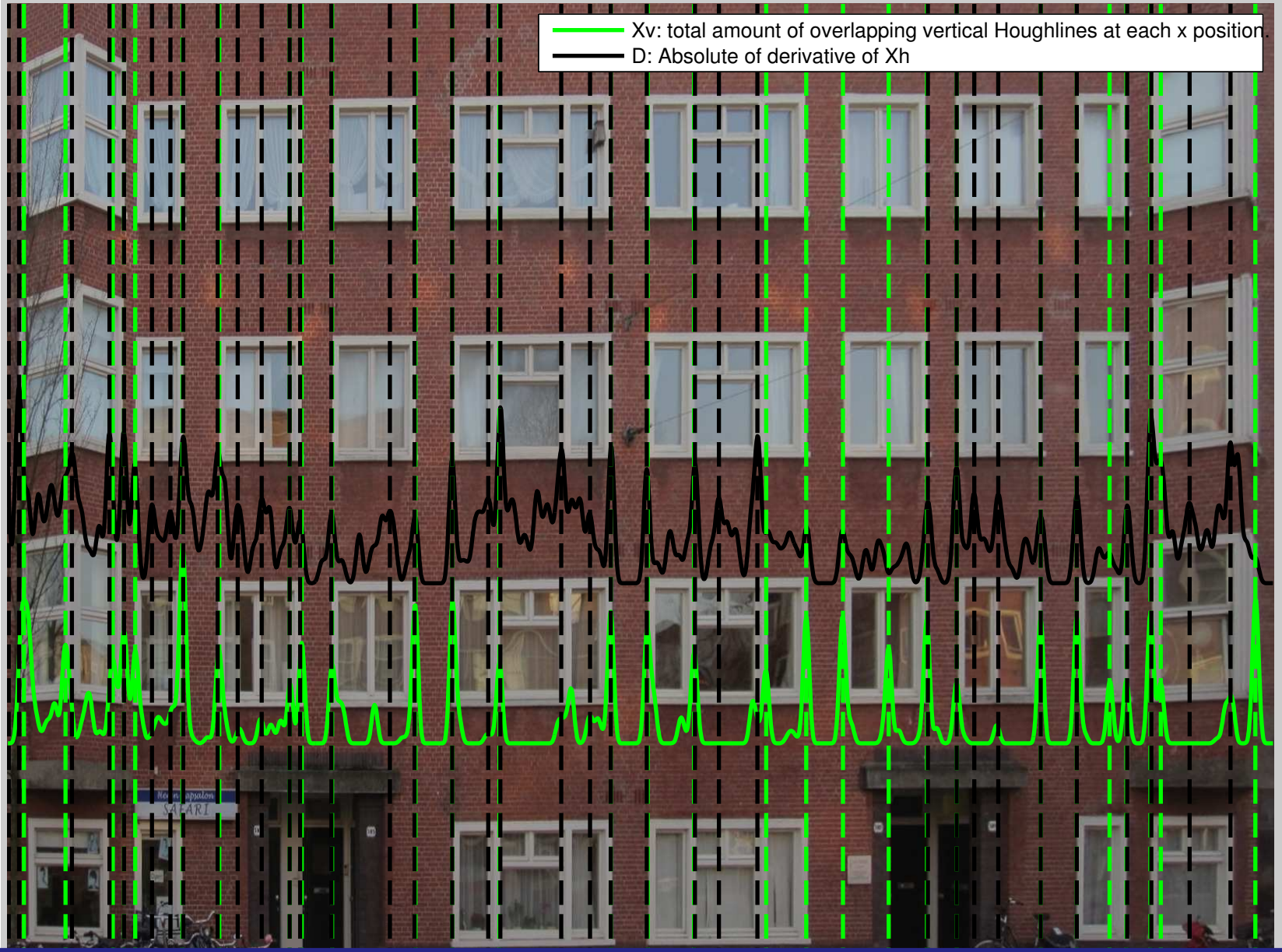
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Window classification

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    - based on shape of histogram function

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Basic window classification assumptions

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  - a block contains a high amount of Houghlines: window
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  - a row or column contains either zero windows or multiple windows

Basic window classification algorithm

- Exploit window alignment:
  - classify full block rows and block columns

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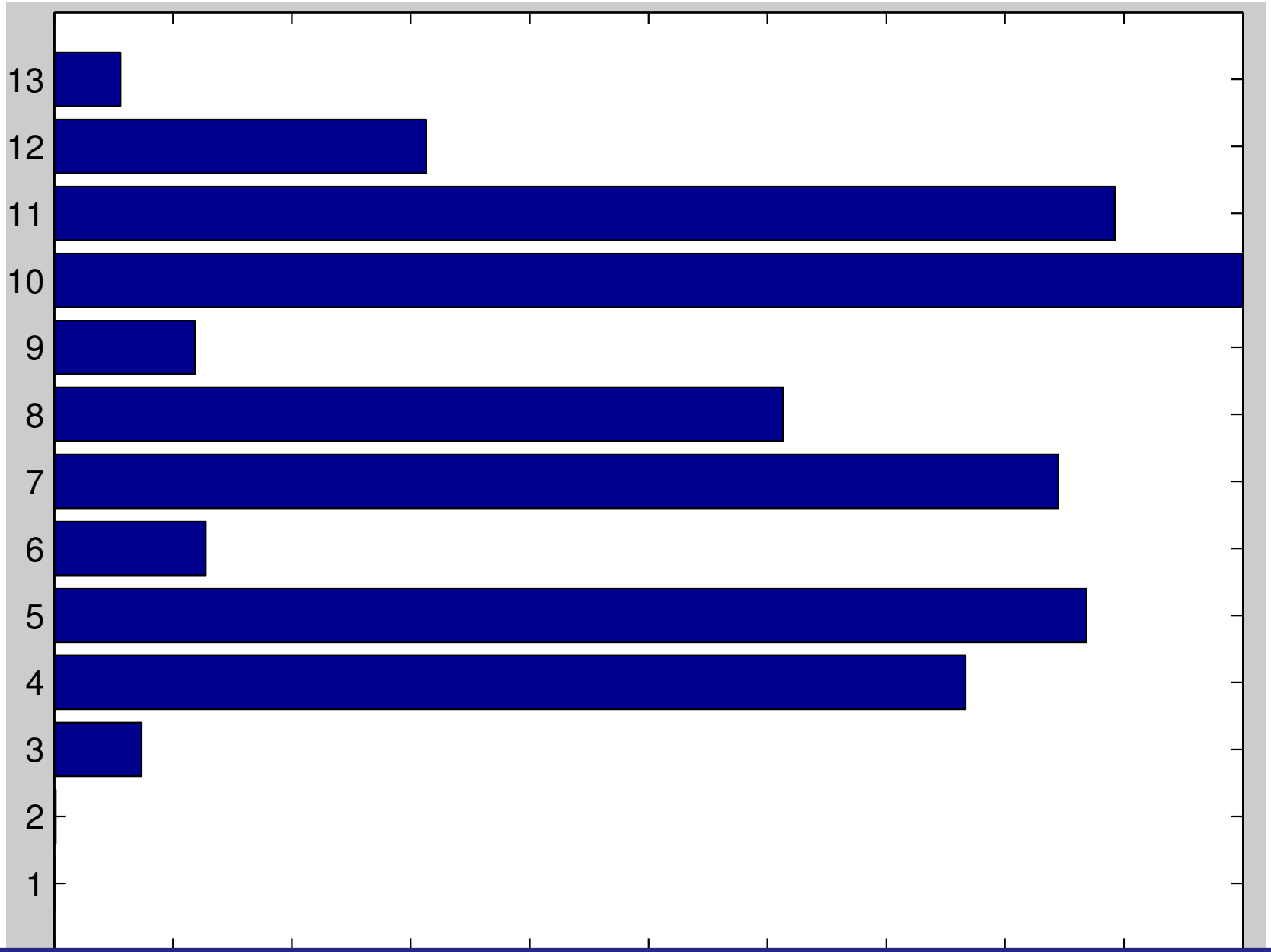
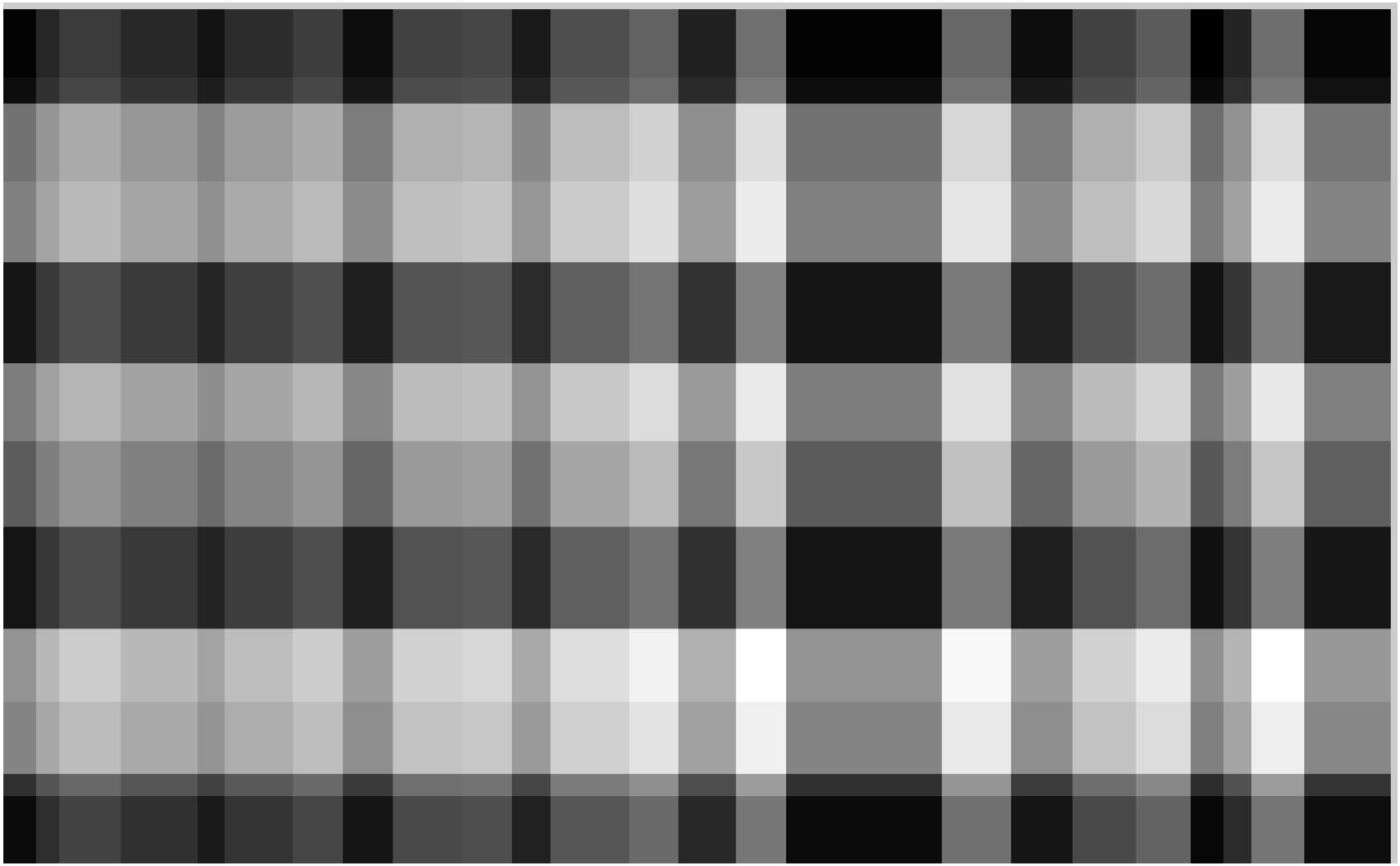
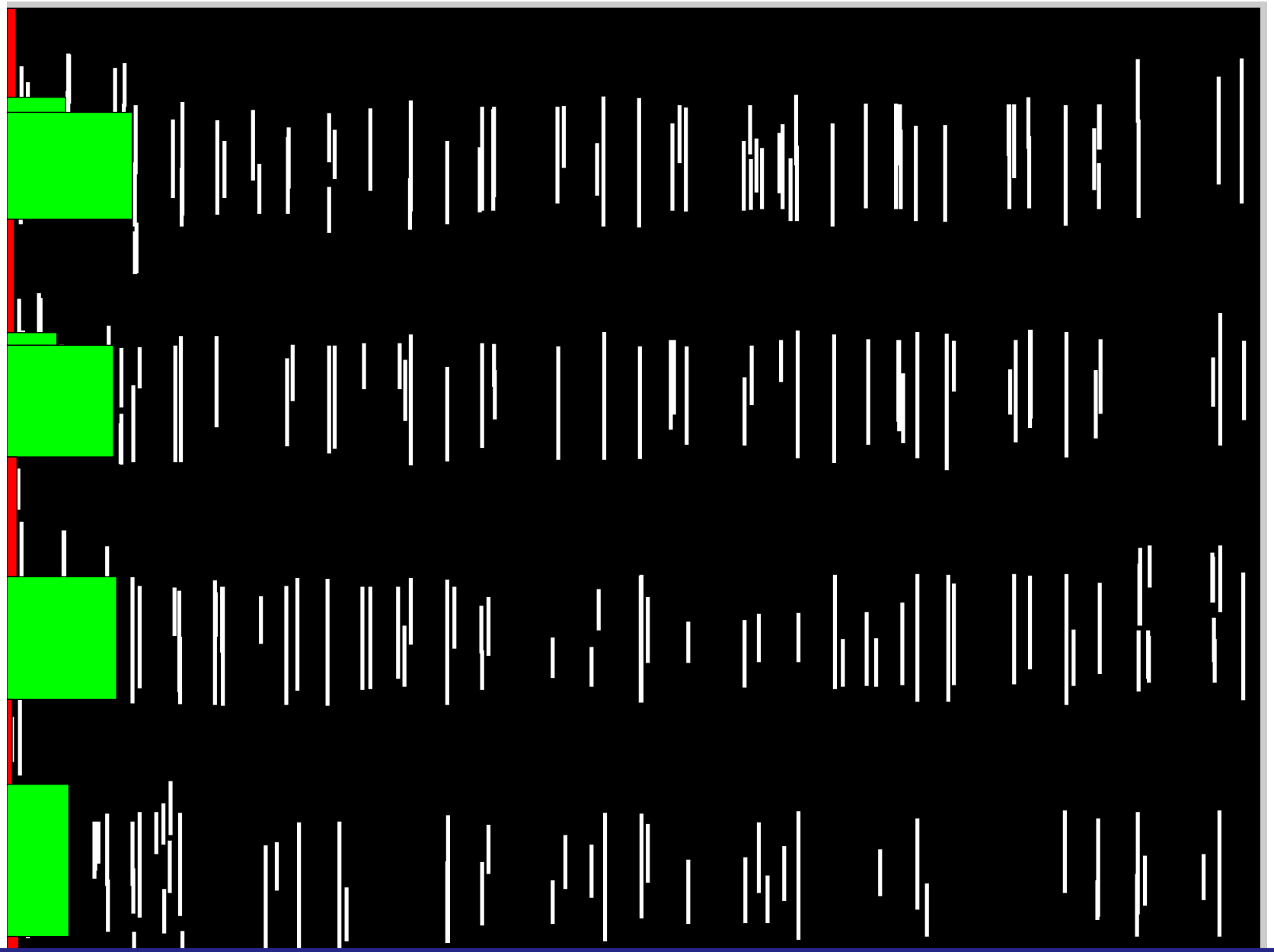
- Output: $||R||$ scalar values that ranks a row being window area or not

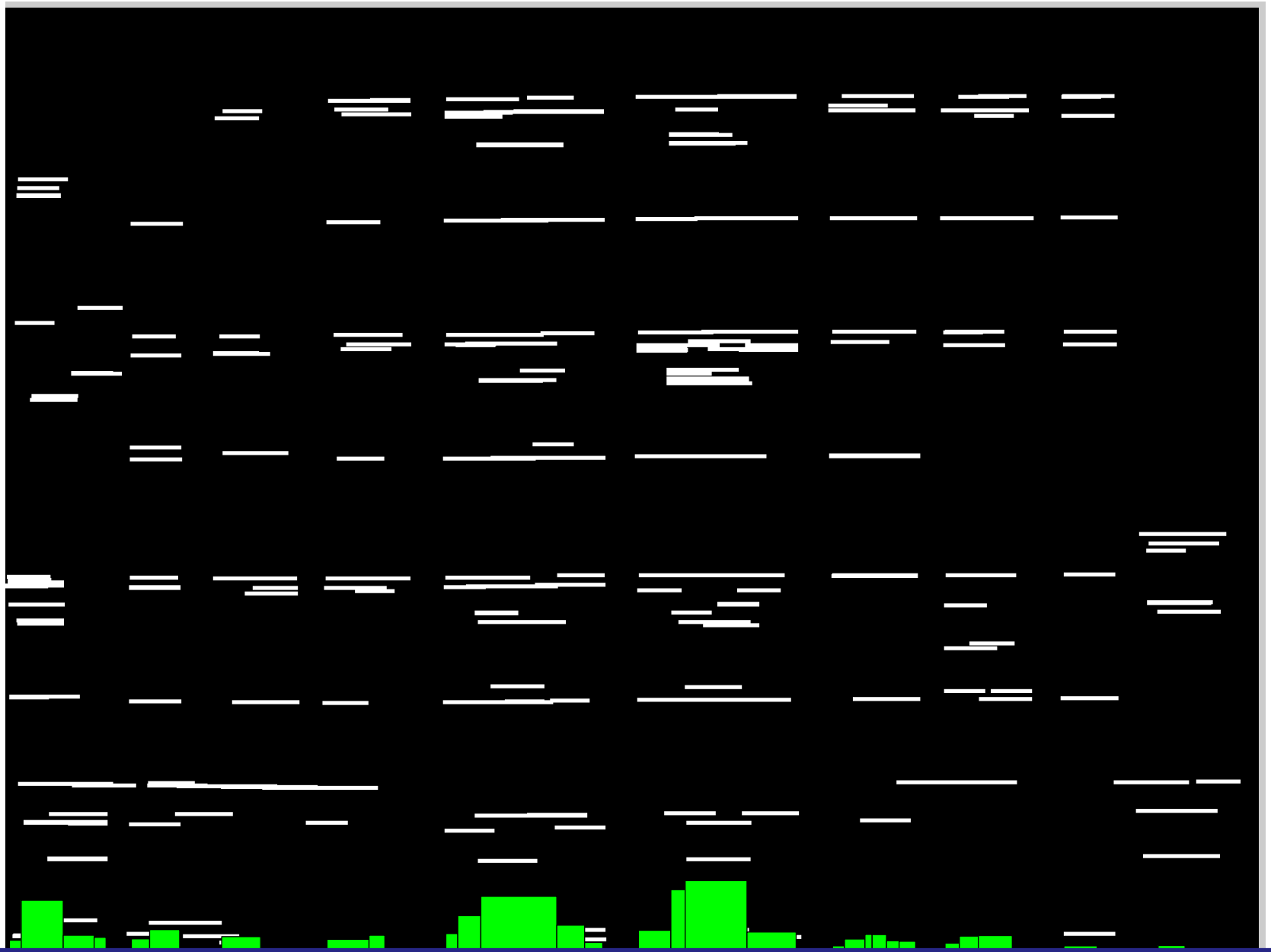

13
12
11
10
9
8
7
6
5
4
3
2
1

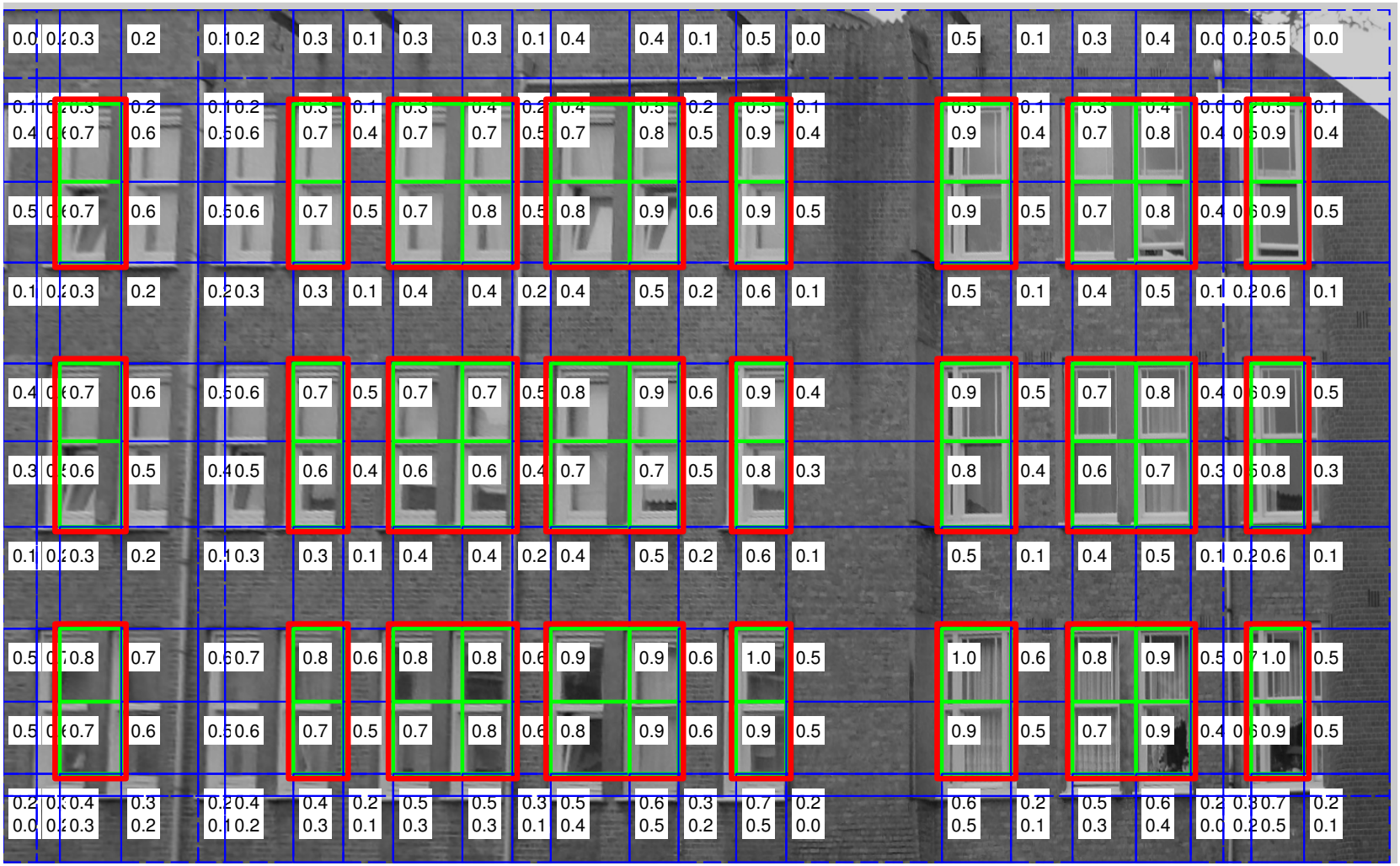


From certainty to classification

- k-means classification on R and C values







Improved window classification

- Use idea of alternative alignment

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- Amount of Houghlines

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  - increases towards center of window area

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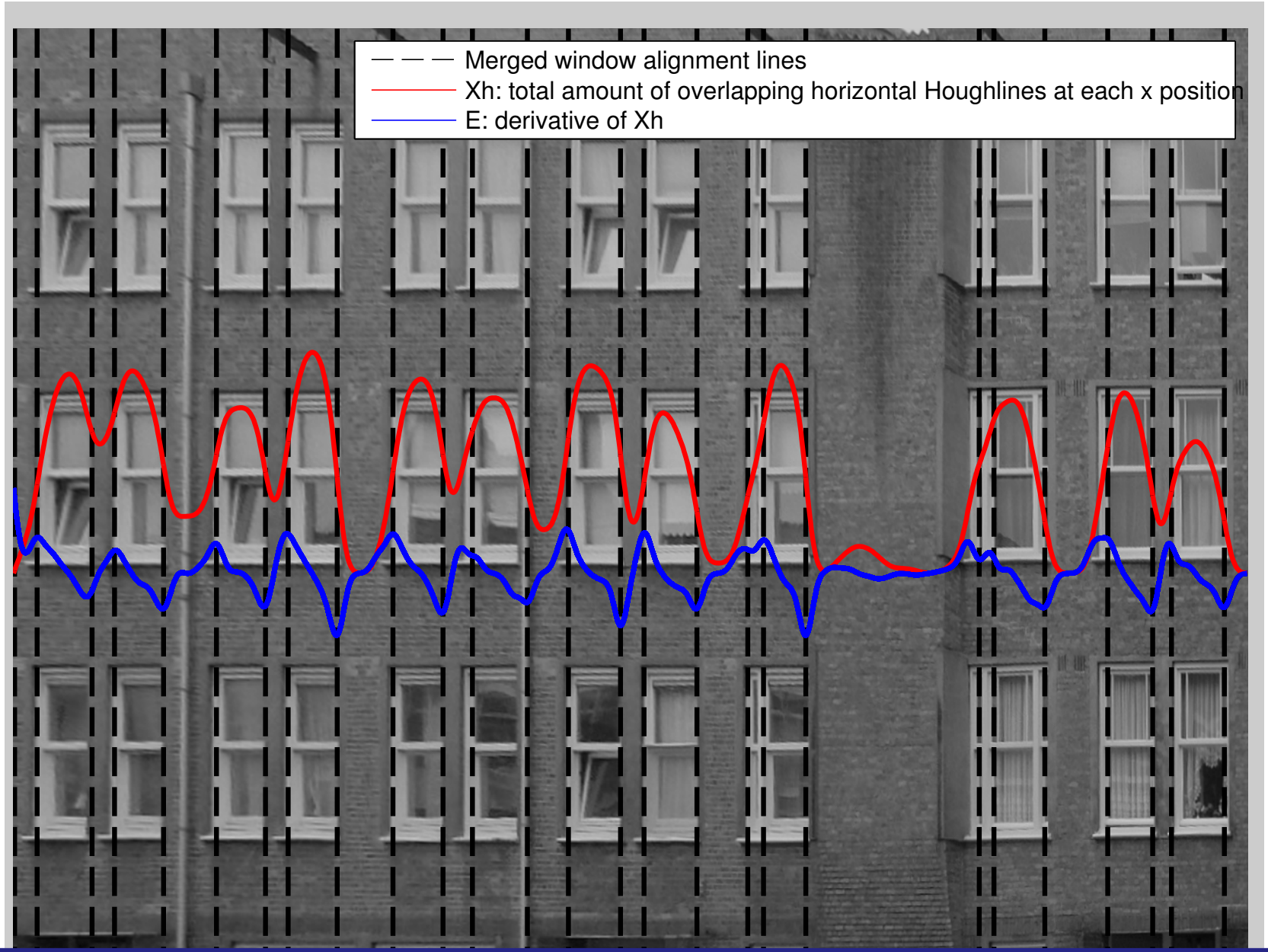
Merged window alignment lines
Xh: total amount of overlapping horizontal Houghlines at each x position
E: derivative of Xh

Algorithm

- Detect concave and convex shape of histogram function Xh

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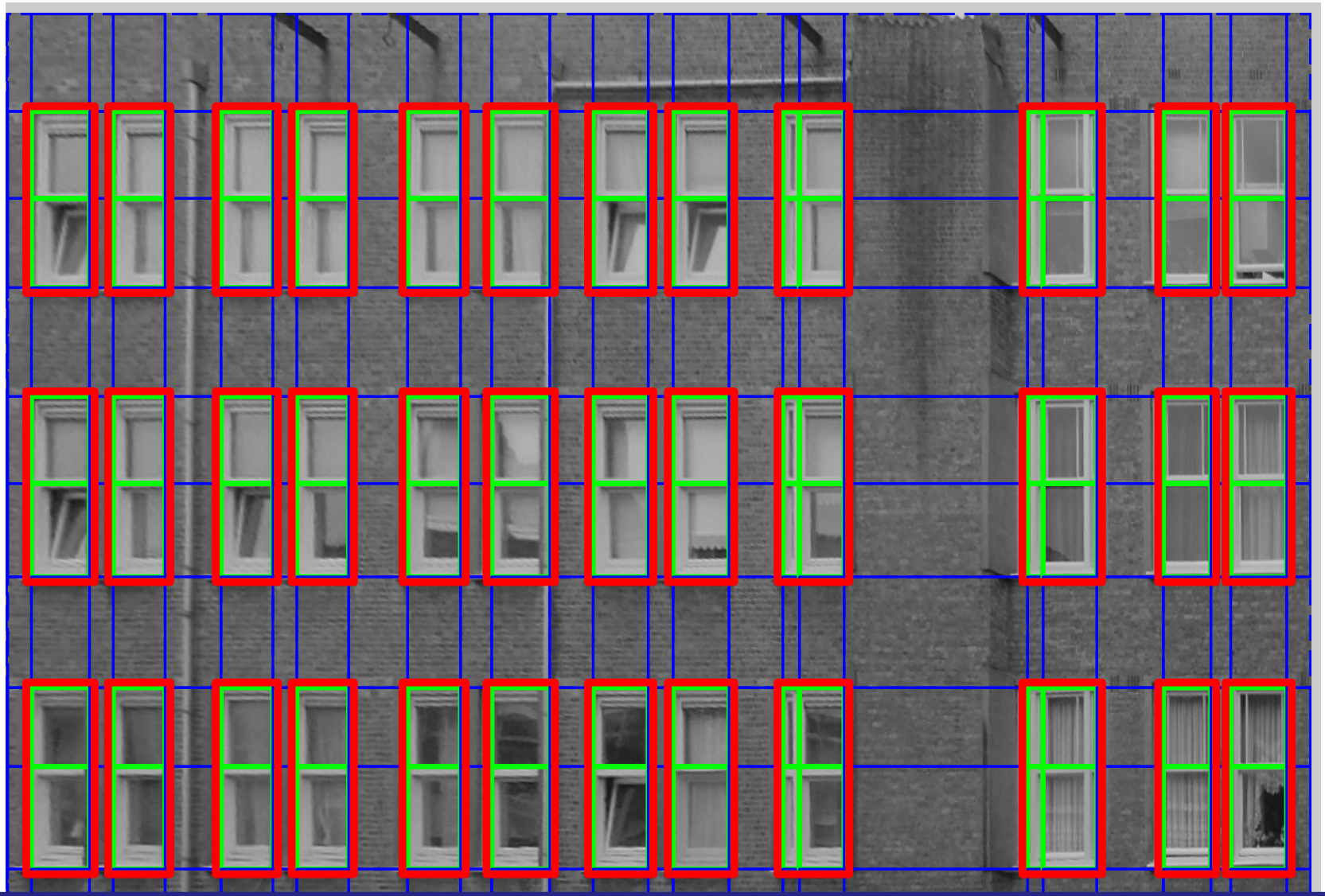
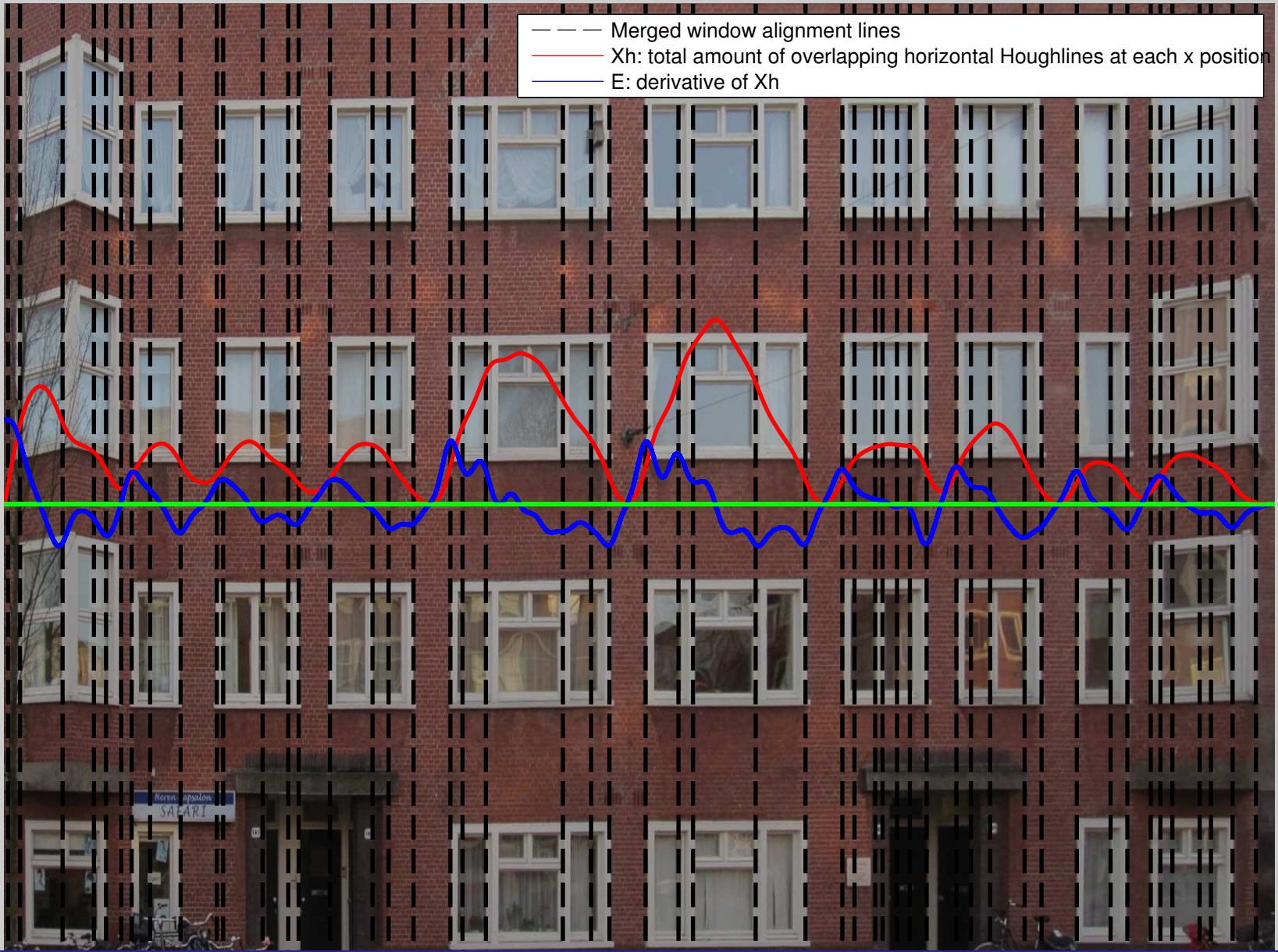
Result



Test on scene that violates assumption

- Windows are *partially* aligned
  - unaligned doors
  - inter row size difference
- Windows differ in size and type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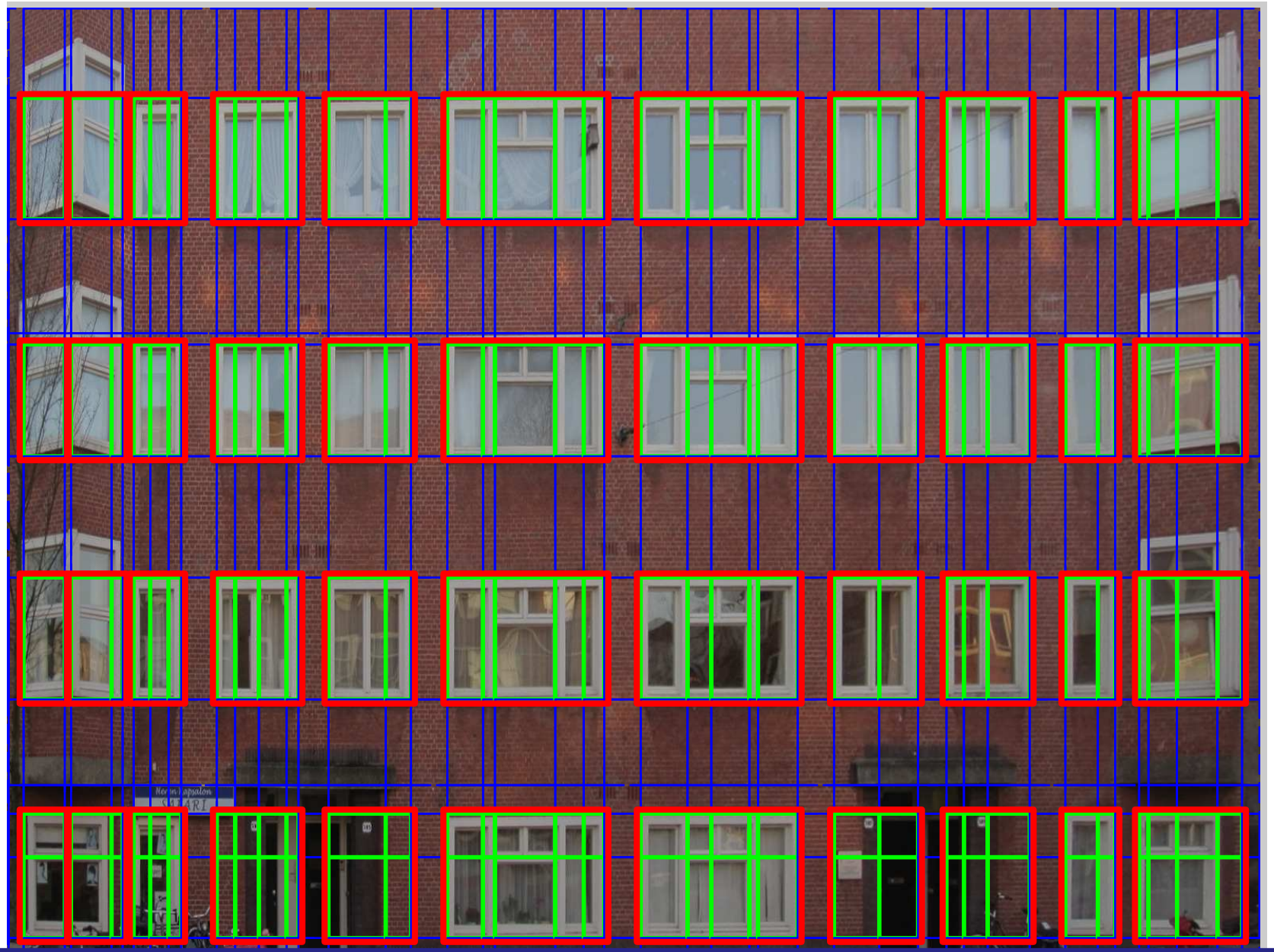

Conclusion:Connected corner

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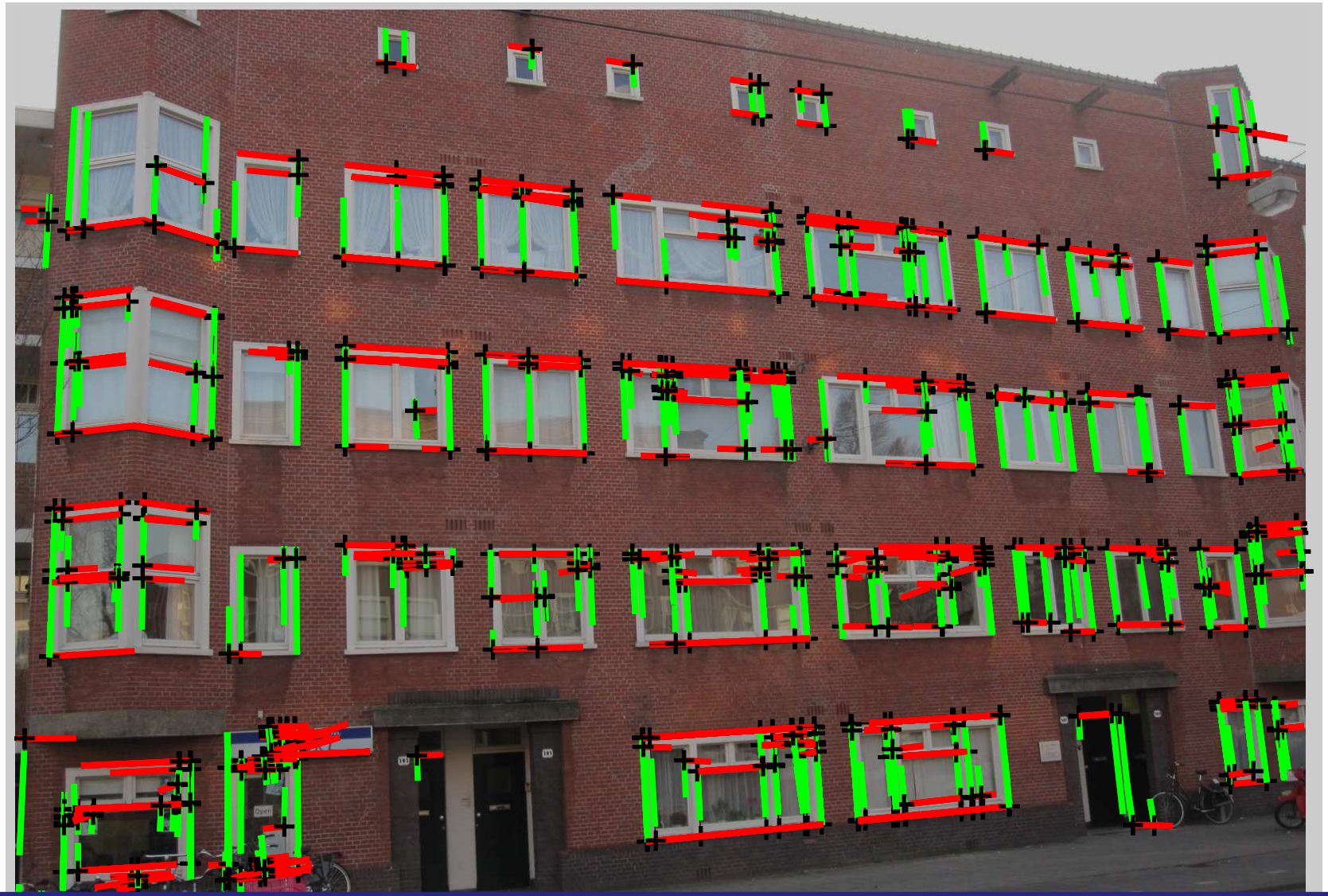

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  - high order (derivative) shape interpretation of the histogram function

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  - the increase/decrease is relative
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- We achieved:

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  - For a set of urban scenes with different properties

Questions

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