Institute of Cartography and Geoinformatics | Leibniz Universität Hannover

Using Hough Analysis and Least Squares Adjustment for the Generalization of Building Footprints

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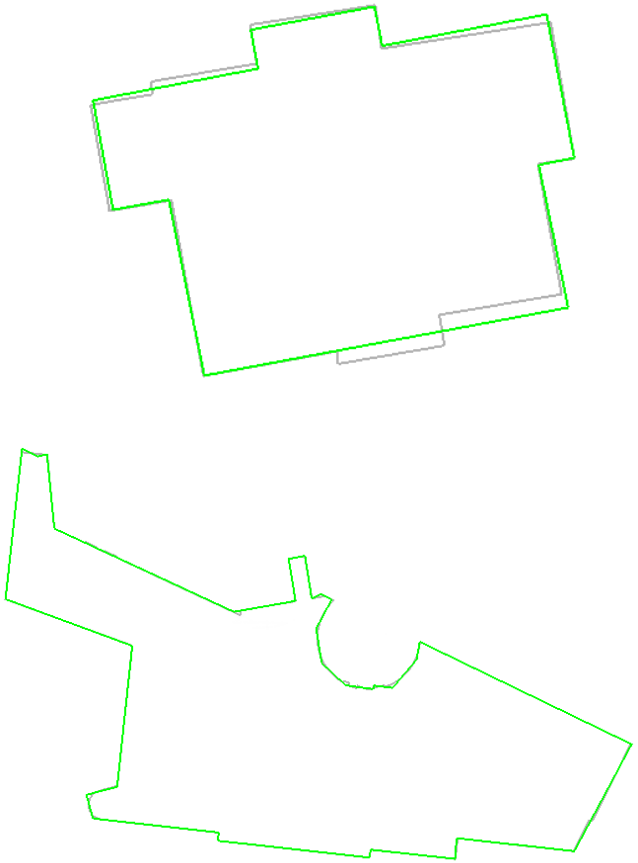
Outline

- Introduction
- Hough Analysis: Generating Initial Segments
- Adjustment: Refining and Fitting the new Segments to the Original Shape
- Joining the Line Fragments
- Results & Issues
- Conclusion and Outlook

Introduction

Application scenarios

- Reasons for footprint simplification
  - Too much detail for given application (e.g. cadastre data)



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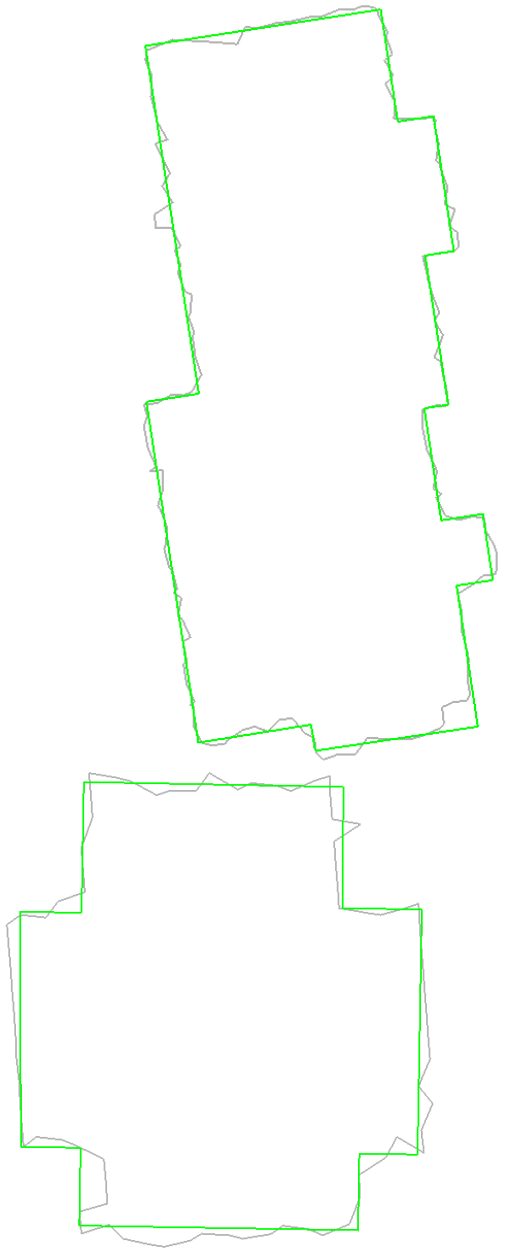
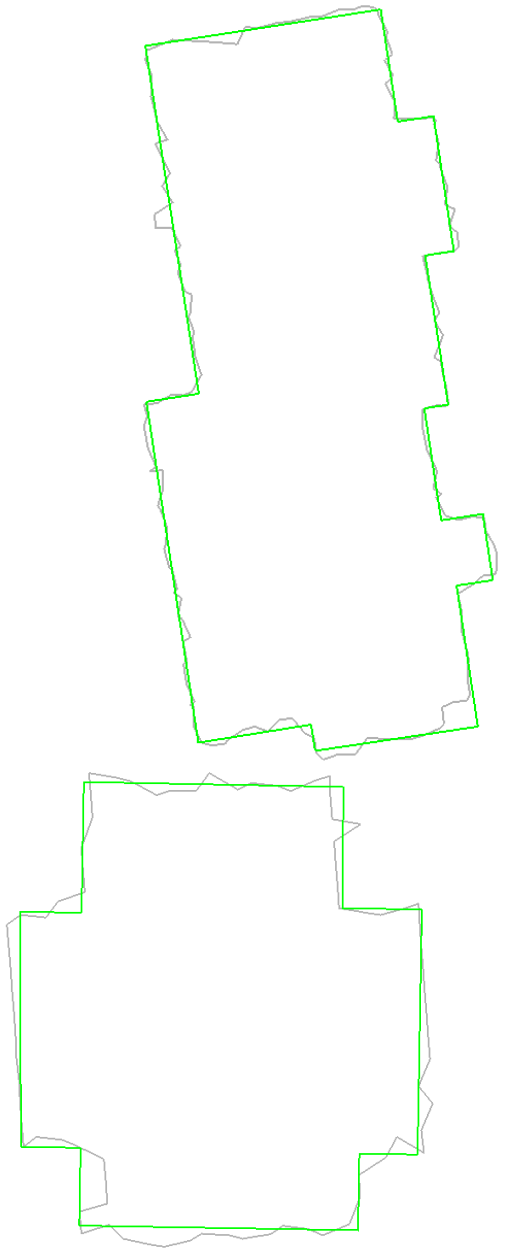
  - Too much detail for given application (e.g. cadastre data)
  - Smoothing and regularization of "noisy" footprints (e.g. from LIDAR)



Application scenarios

- Reasons for footprint simplification
  - Too much detail for given application (e.g. cadastre data)
  - Smoothing and regularization of “noisy” footprints (e.g. from LIDAR)
- Problem definition
  - For the set of points forming the outline of the footprint
  - find a “building-like” (preferring right angles etc.) polygon that best approximates this outline.



A closer look at the problem

- Problem definition
  - For the set of points forming the outline of the footprint, find a "building-like" polygon that best approximates this outline.
- Why is this a hard problem?
  - Approximation? → least squares adjustment
  - What, exactly, is "building-like"? → emphasize right angles and parallel segments
  - **Combinatorial optimization problem nested into the adjustment**
    - Which points of the original outline are mapped to which ones on the approximating shape?
    - How to balance closeness of approximation, reduction of complexity and "building-like"-ness of the result
  - **→ NP-hard problem with weak goals**

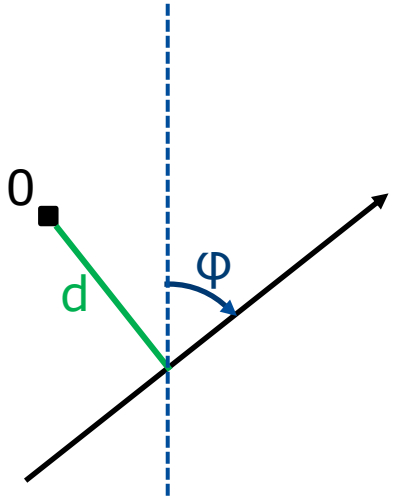
A Heuristic Approach

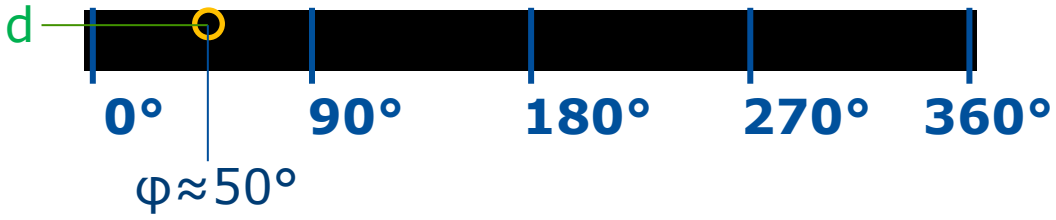
- Workflow
  - Generate a starting solution
    - Hough analysis → line segments
  - Refine the solution
    - Least squares adjustment
    - Fit new lines to sampled original
    - Increasingly emphasize right angles & parallelism
    - Generate, refine, drop segments during the process (combinatorial problem: change assignment of original points to new segments)
    - Fixed number of iterations (good results after < 20 iterations)
  - Connect new segments to form a polygon

Hough Analysis: Generating Initial Segments

Hough Analysis

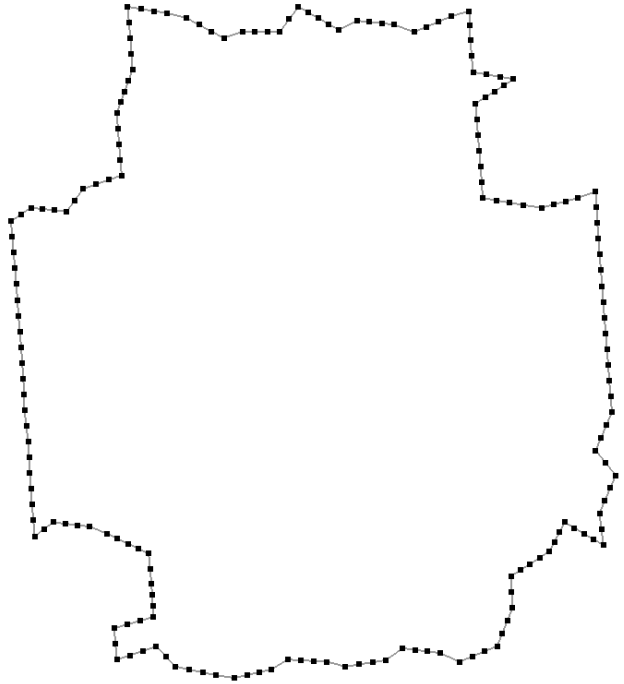
- Transformation Line → Point
- Line in 2D specified by
  - Direction (angle φ)
  - Distance to origin (d)
- Hough space is rastered for analysis (Hough accumulator)
- Difference to classical Hough analysis
  - Directed lines
  - ➔ 360° instead of 180°

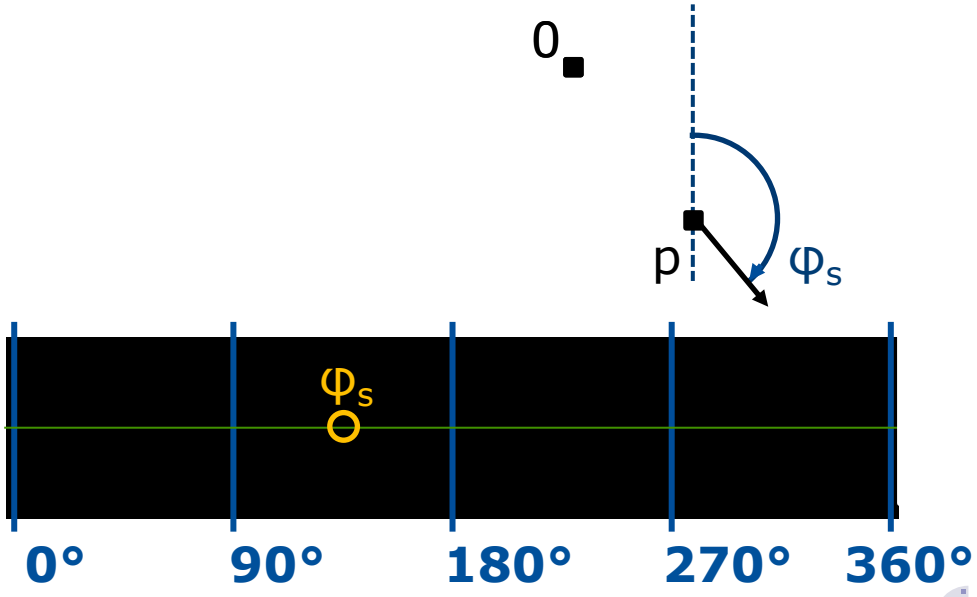




Hough Analysis

- Polygon divided into small segments
  - Each segment as a point in Hough space: too much noise (scattered)





Hough Analysis

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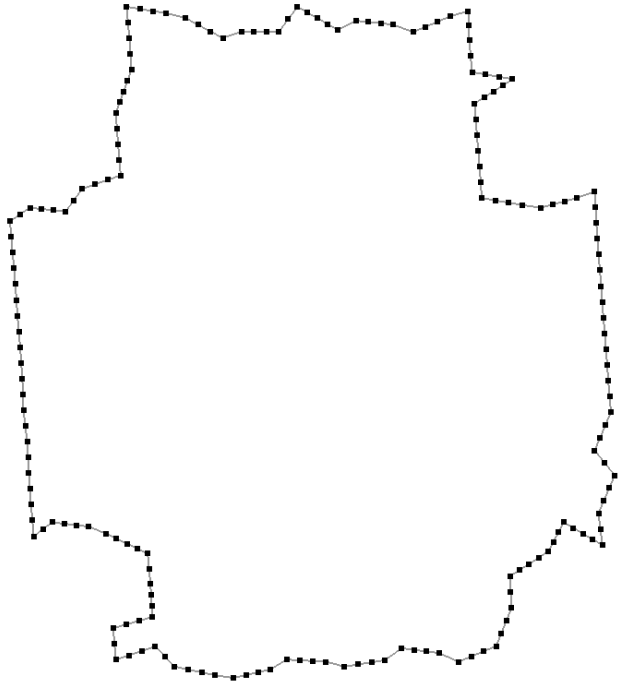
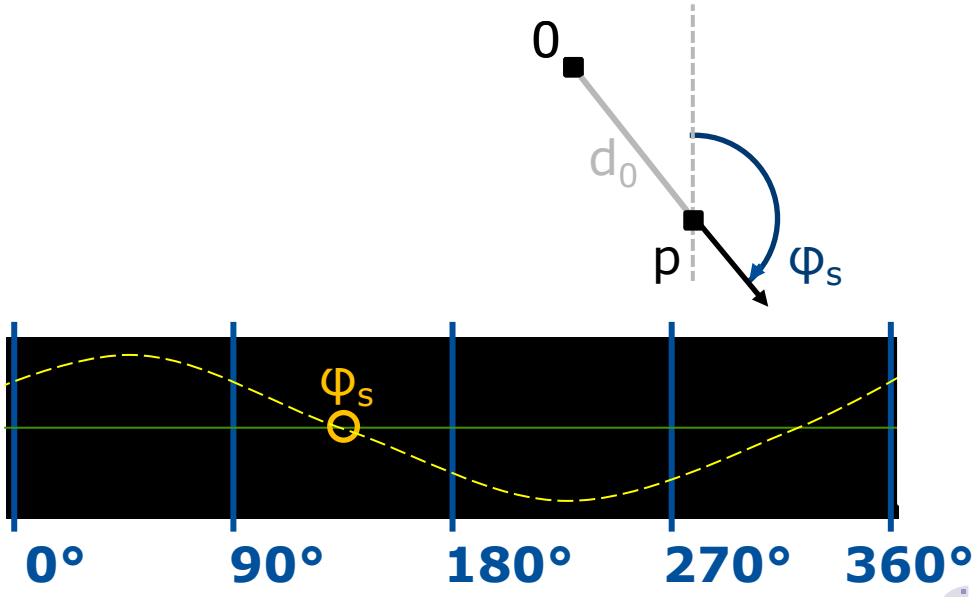
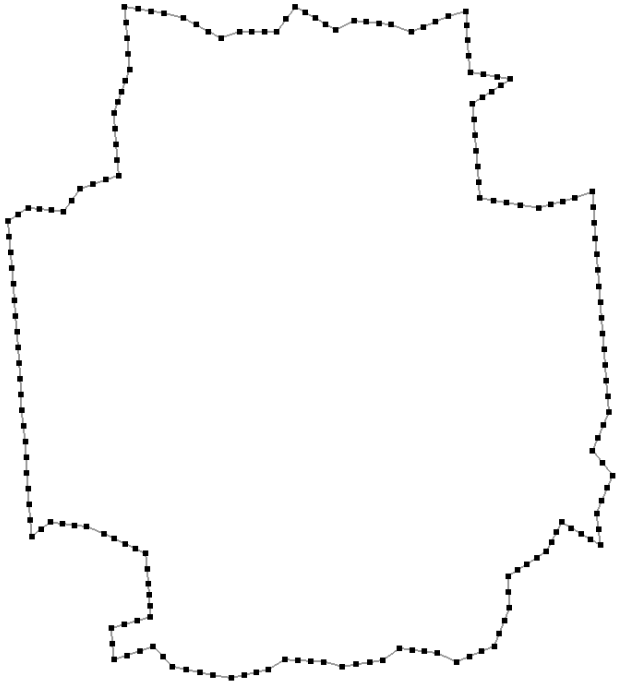
  - Each point as a full sine wave in Hough space: ambiguous

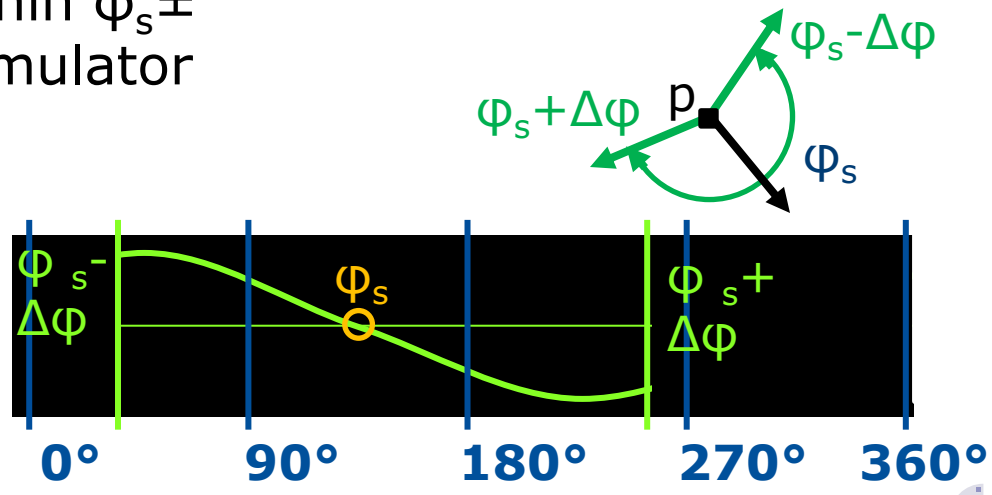




Hough Analysis

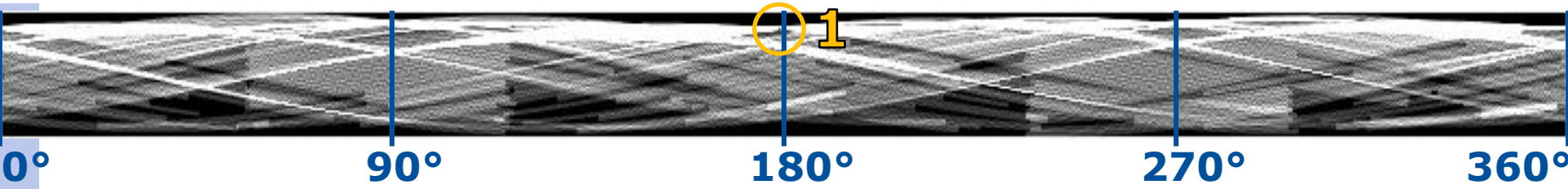
- Polygon divided into small segments
  - Each segment as a point in Hough space: too much noise (scattered)
  - Each point as a full sine wave in Hough space: ambiguous
- Idea: tolerance band Δφ for direction
- Only values for angles within $\varphi_s \pm \Delta\varphi$ are drawn to the accumulator

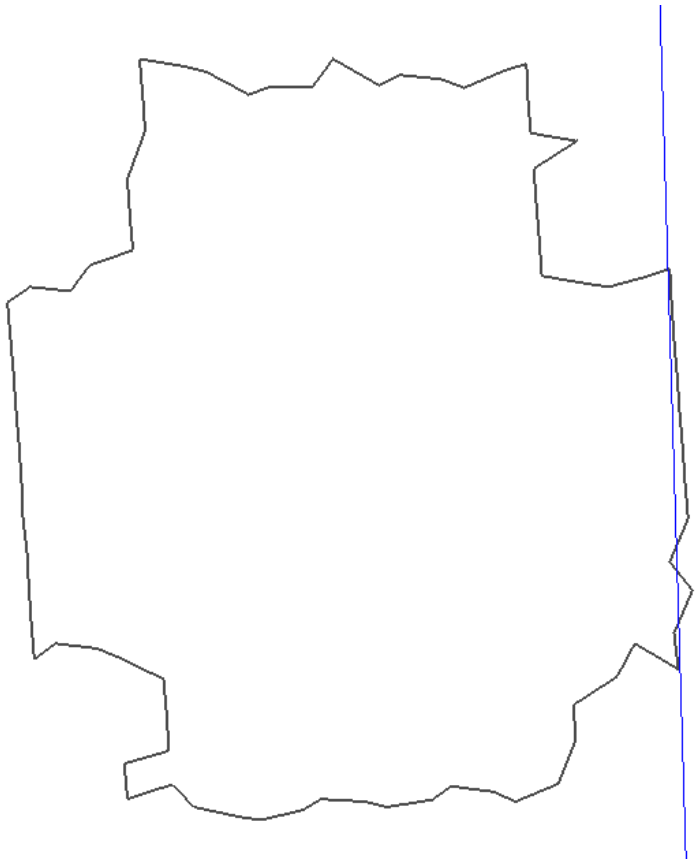




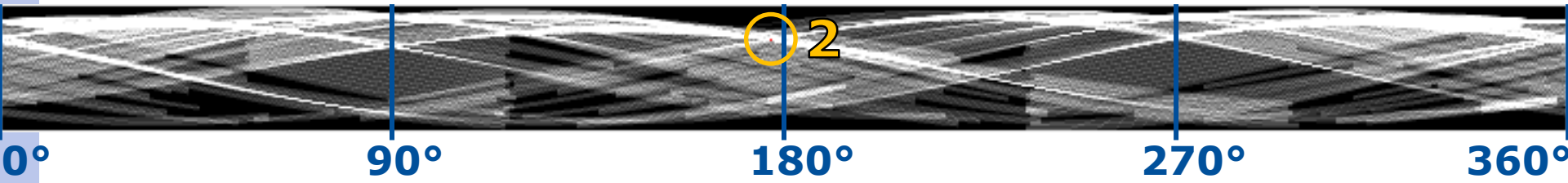
Hough Analysis: Example

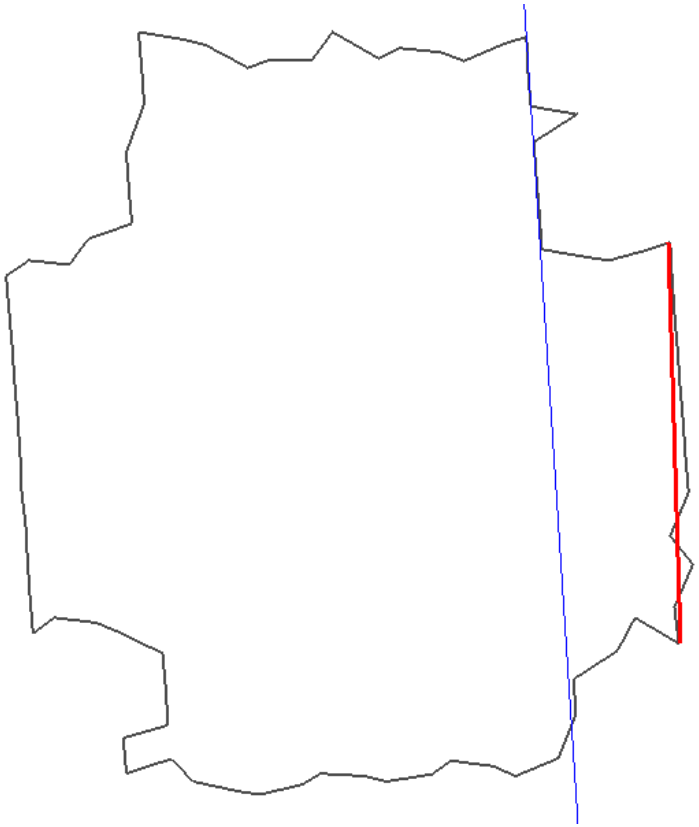
Hough Analysis: Example, step 1



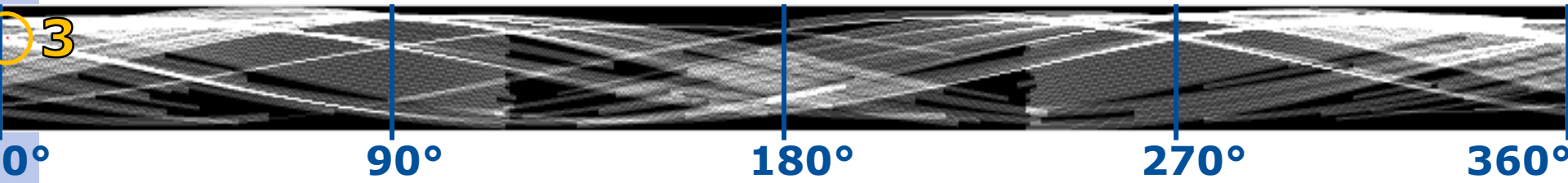


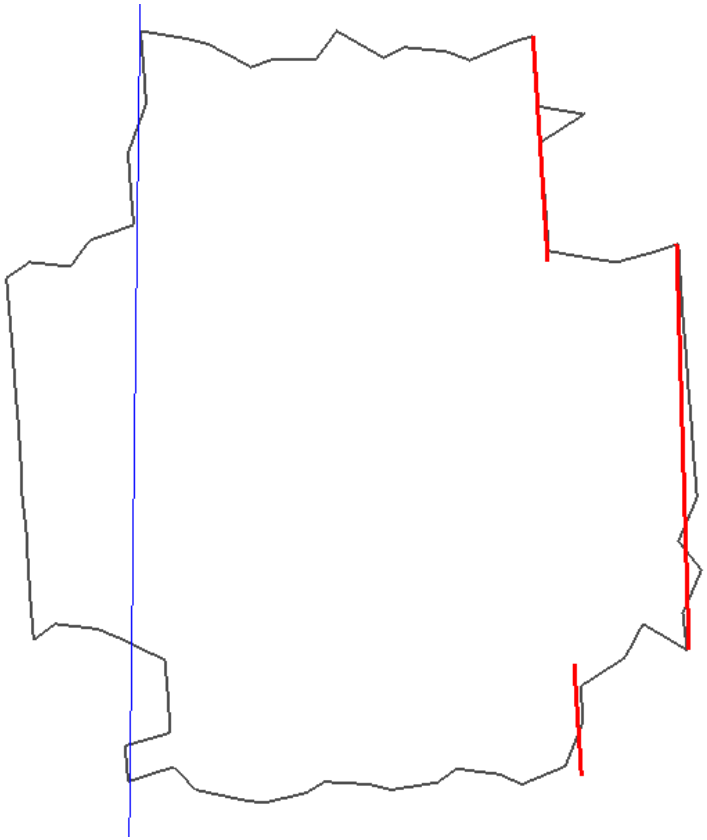
Hough Analysis: Example, step 2



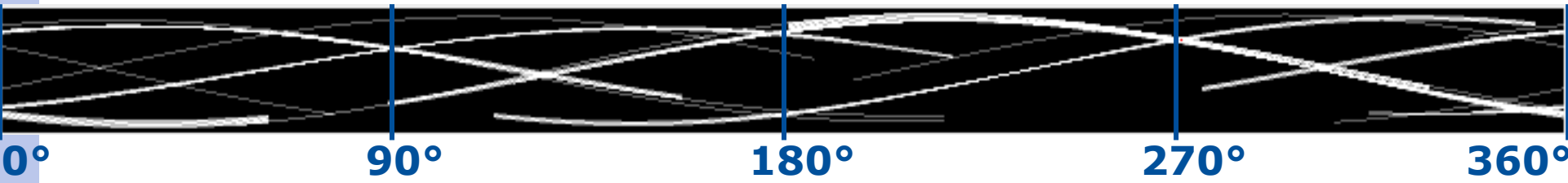


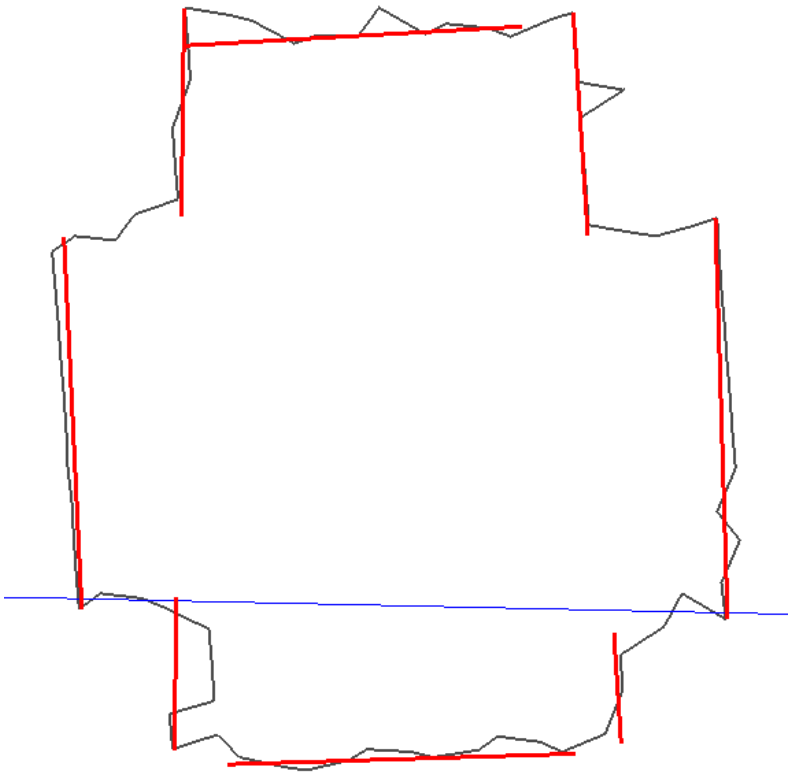
Hough Analysis: Example, step 3





Hough Analysis: Example, step 7





Adjustment: Refining and Fitting the new Segments to the Original Shape

Adjustment process: Workflow

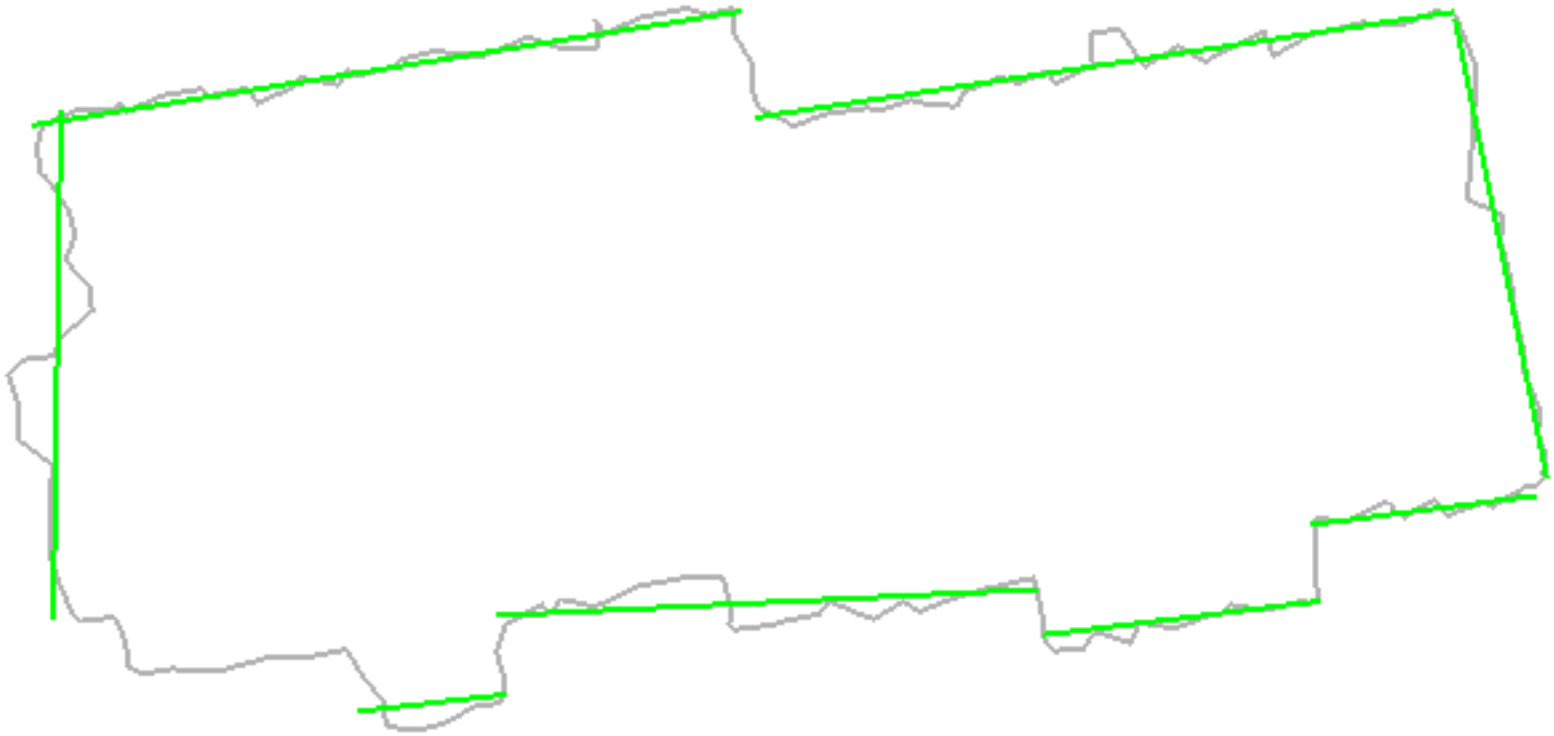
1. Reassign original points between adjacent new segments
   - Assign each point to the closest segment
   - If a segment is too short, it is removed
2. Least squares adjustment (3 steps, linearized)
   - Line hypotheses in HNF: $ax + by + c = 0$
   - Observation equations to
     a) Fit segments to edges (min distance)
     b) Enforce right angles / parallel segments (if almost || or $\perp$)
     c) Shift segments parallel to match edges

- Weights of observations b) and c) are increased with each iteration

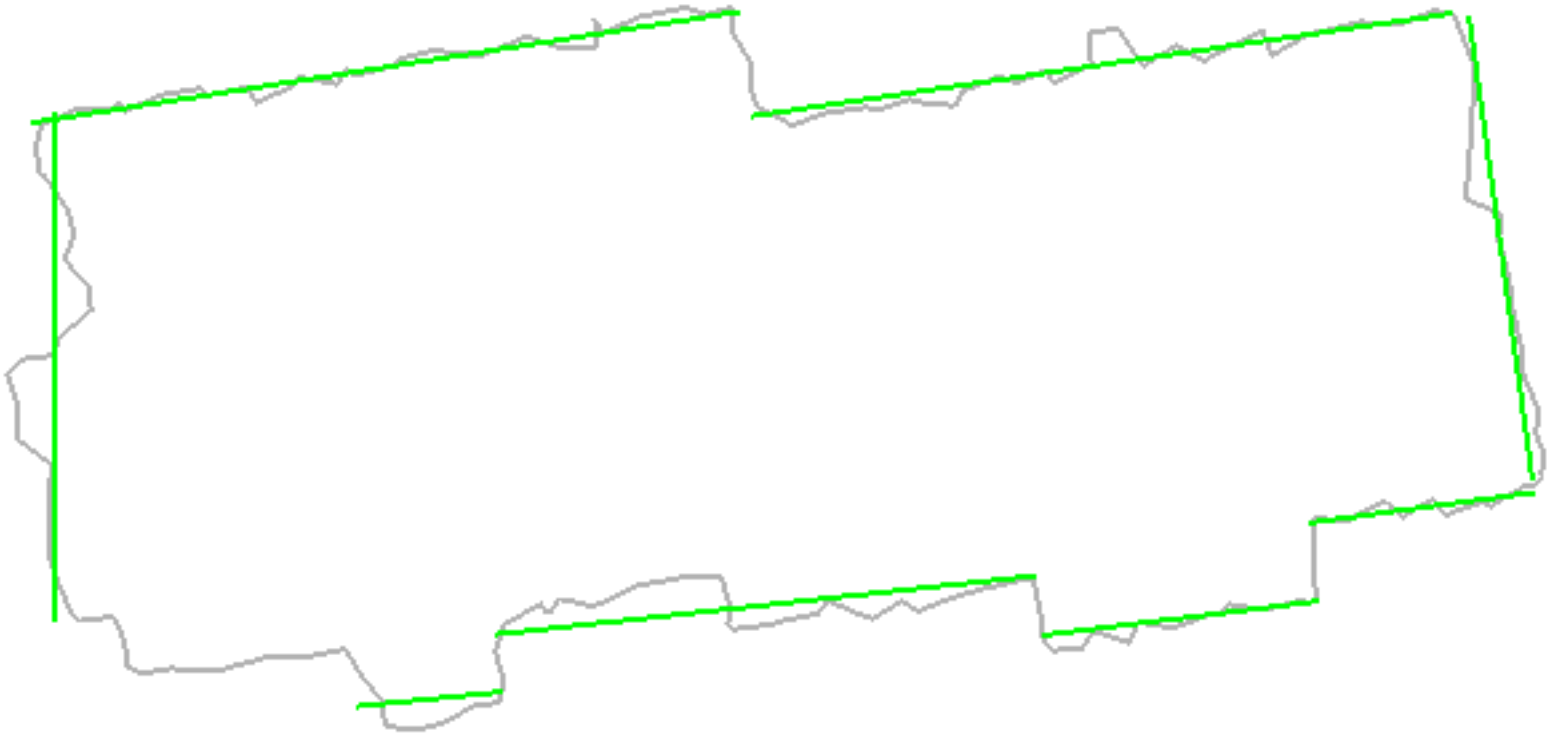
Adjustment: Example

Original shape

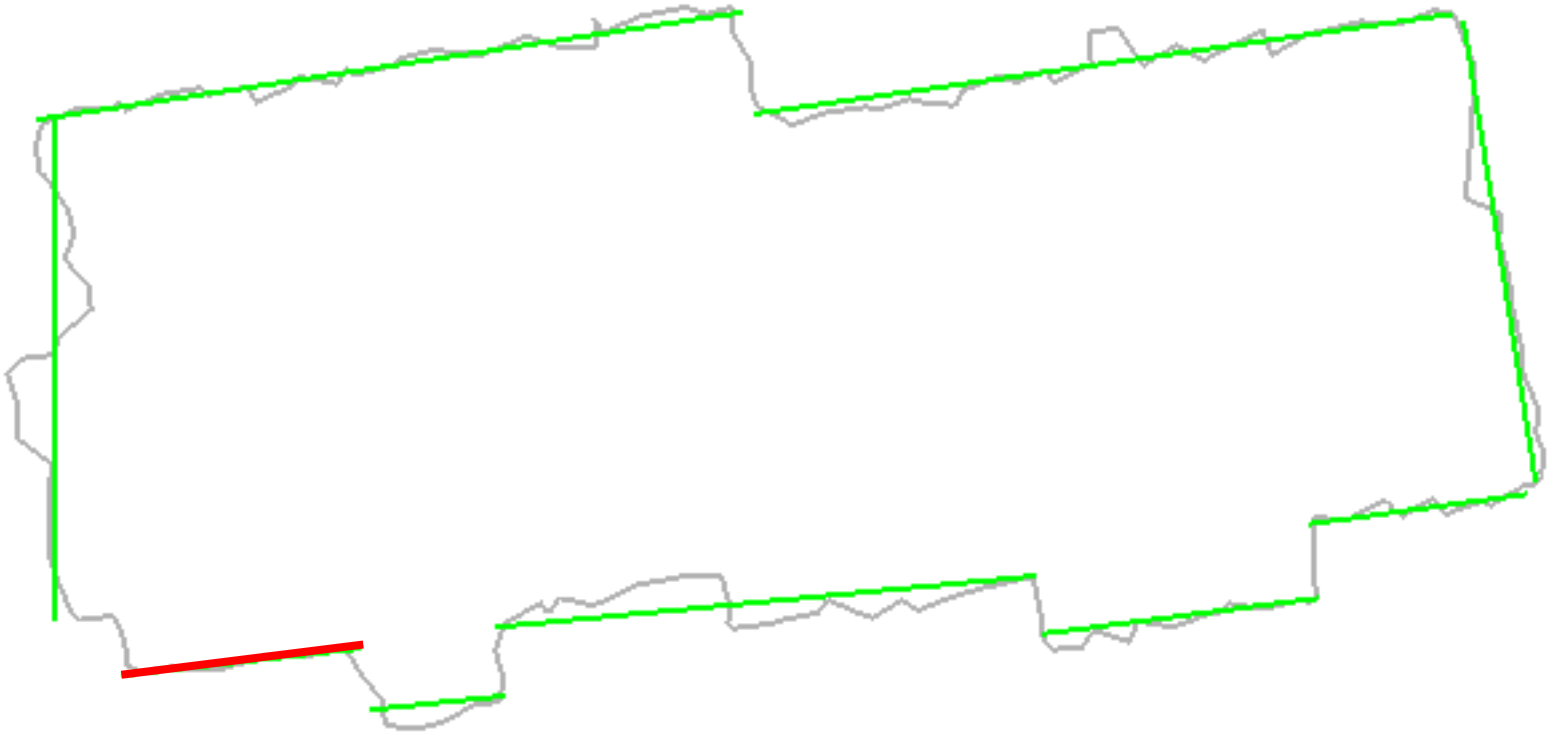
After iteration 1



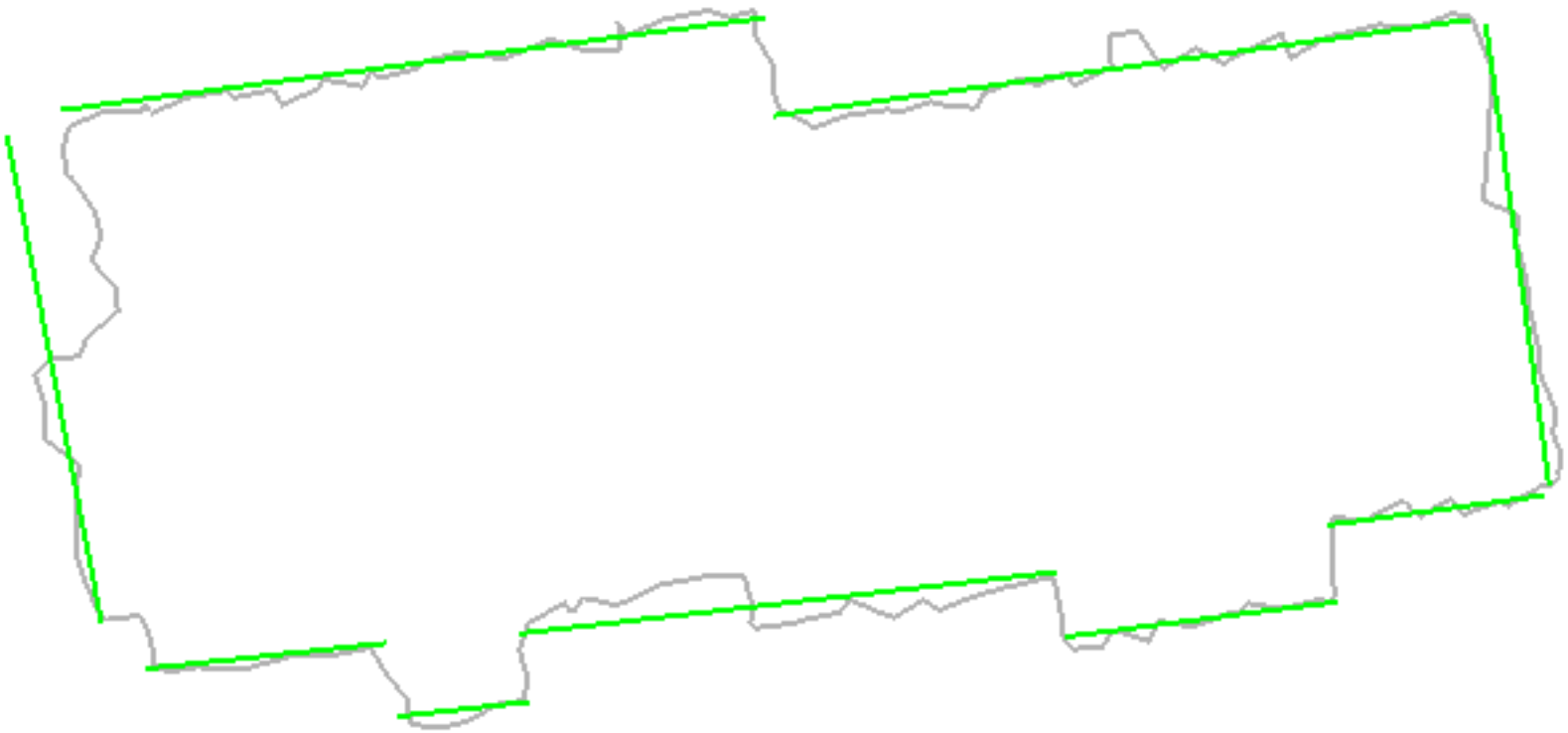
After iteration 2



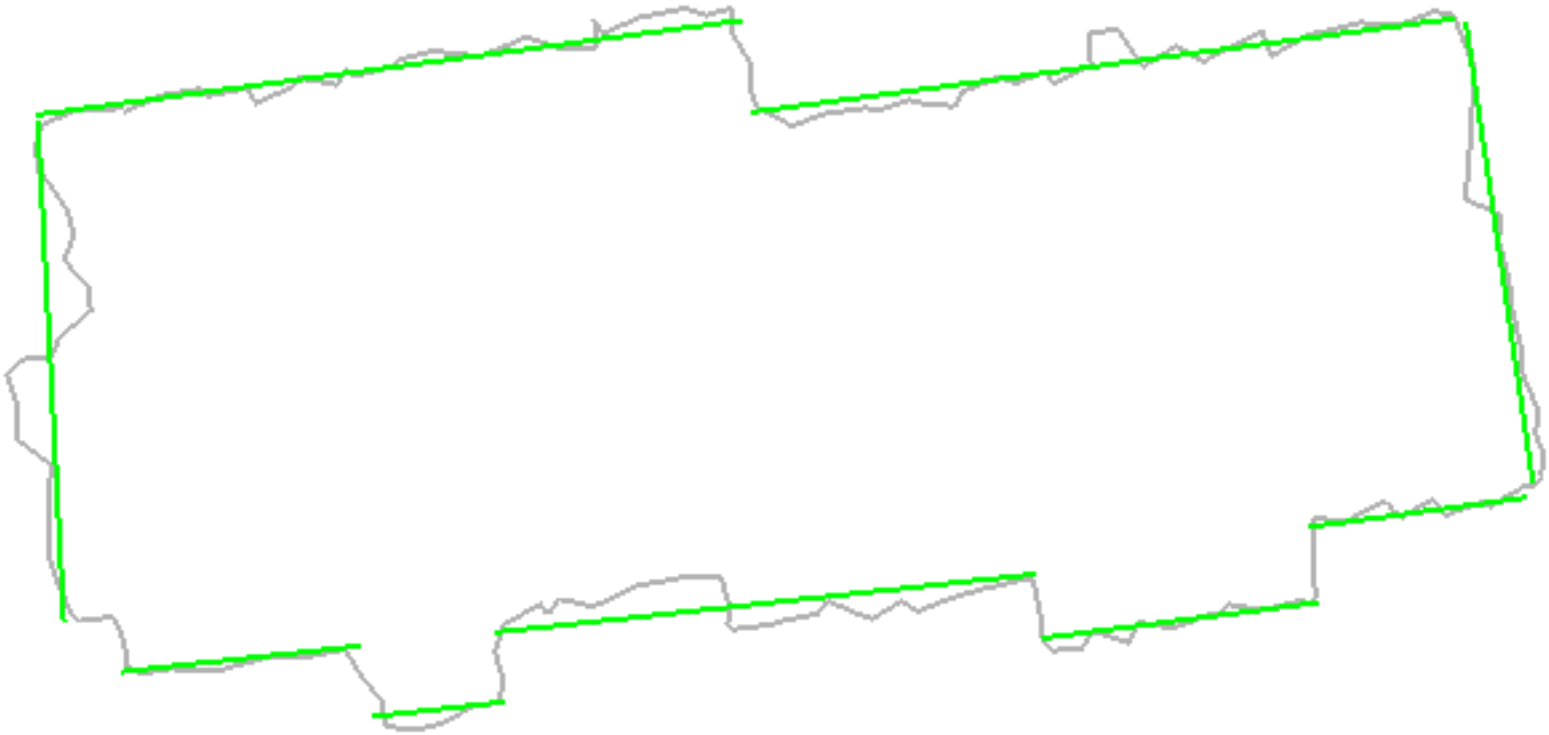
After iteration 3: A new Segment



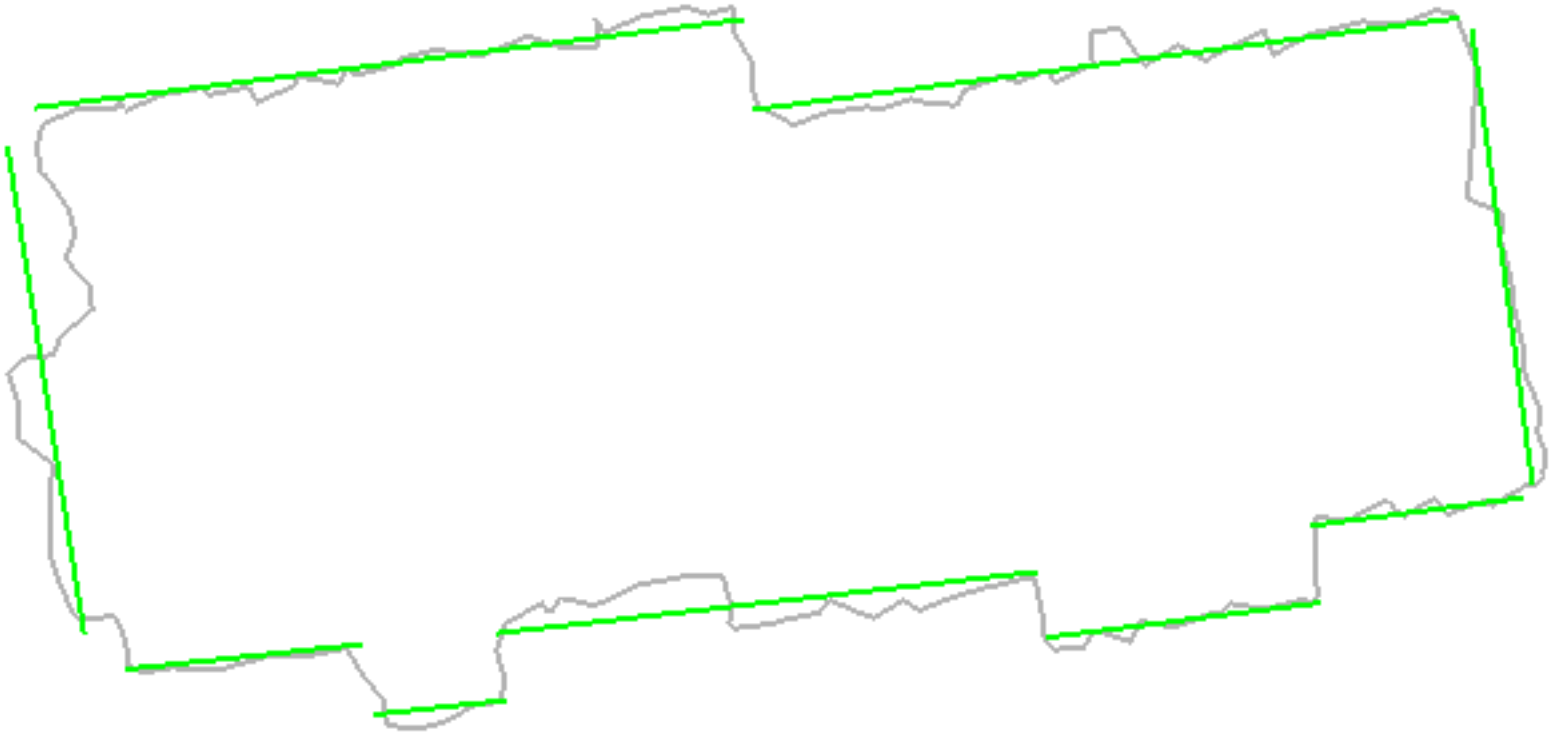
After iteration 4



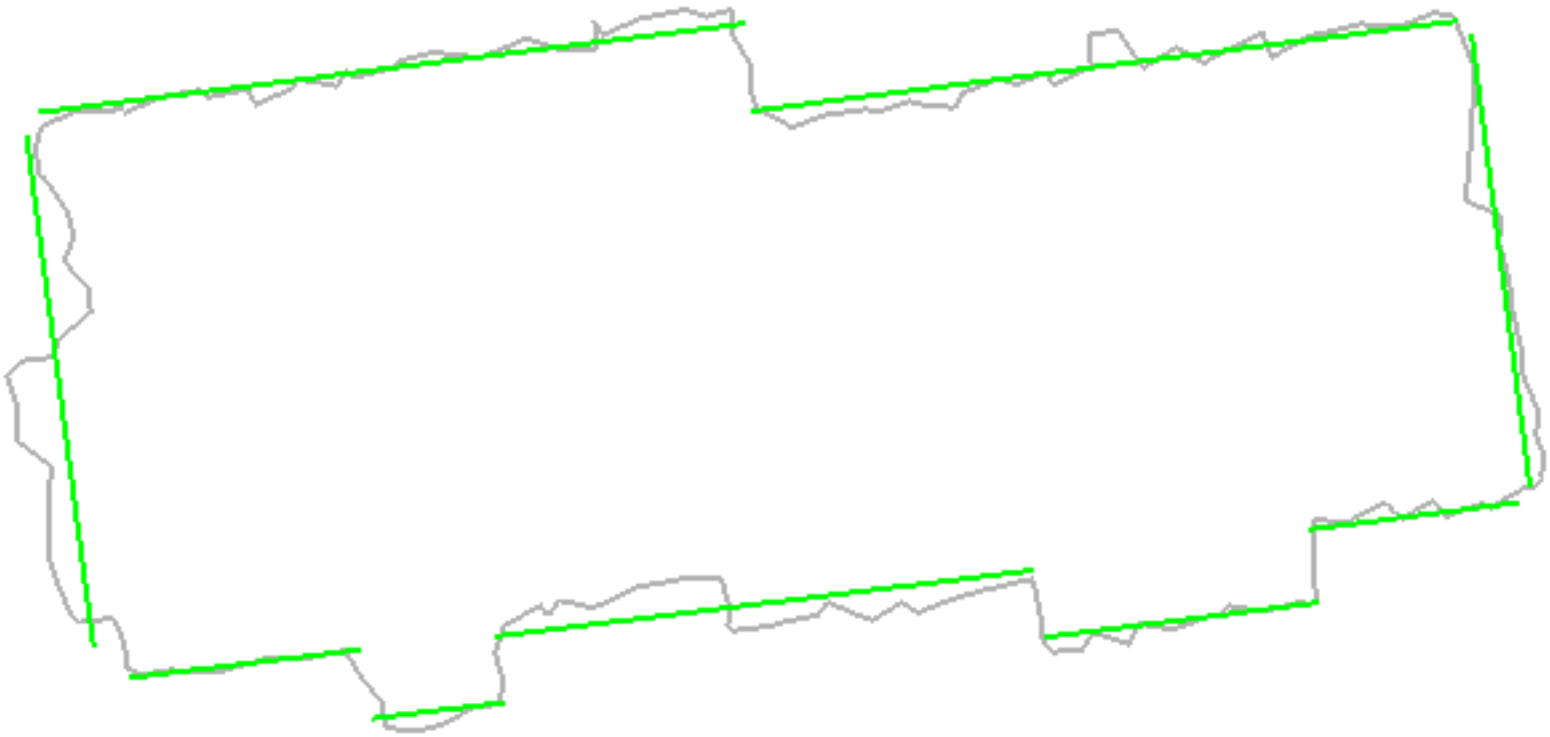
After iteration 5



After iteration 6

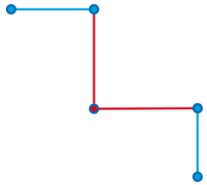
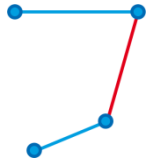


After iteration 20

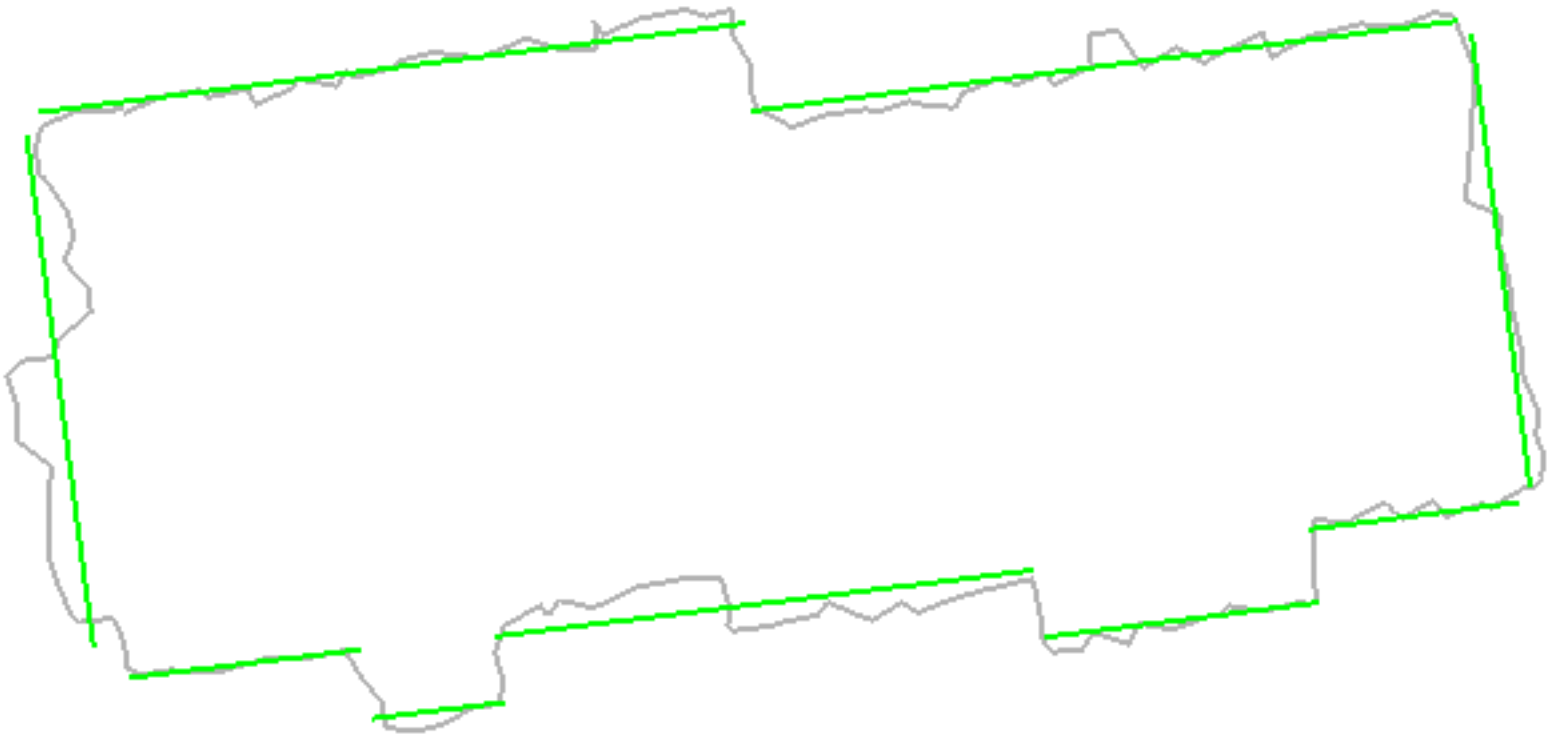


Joining the Line Fragments

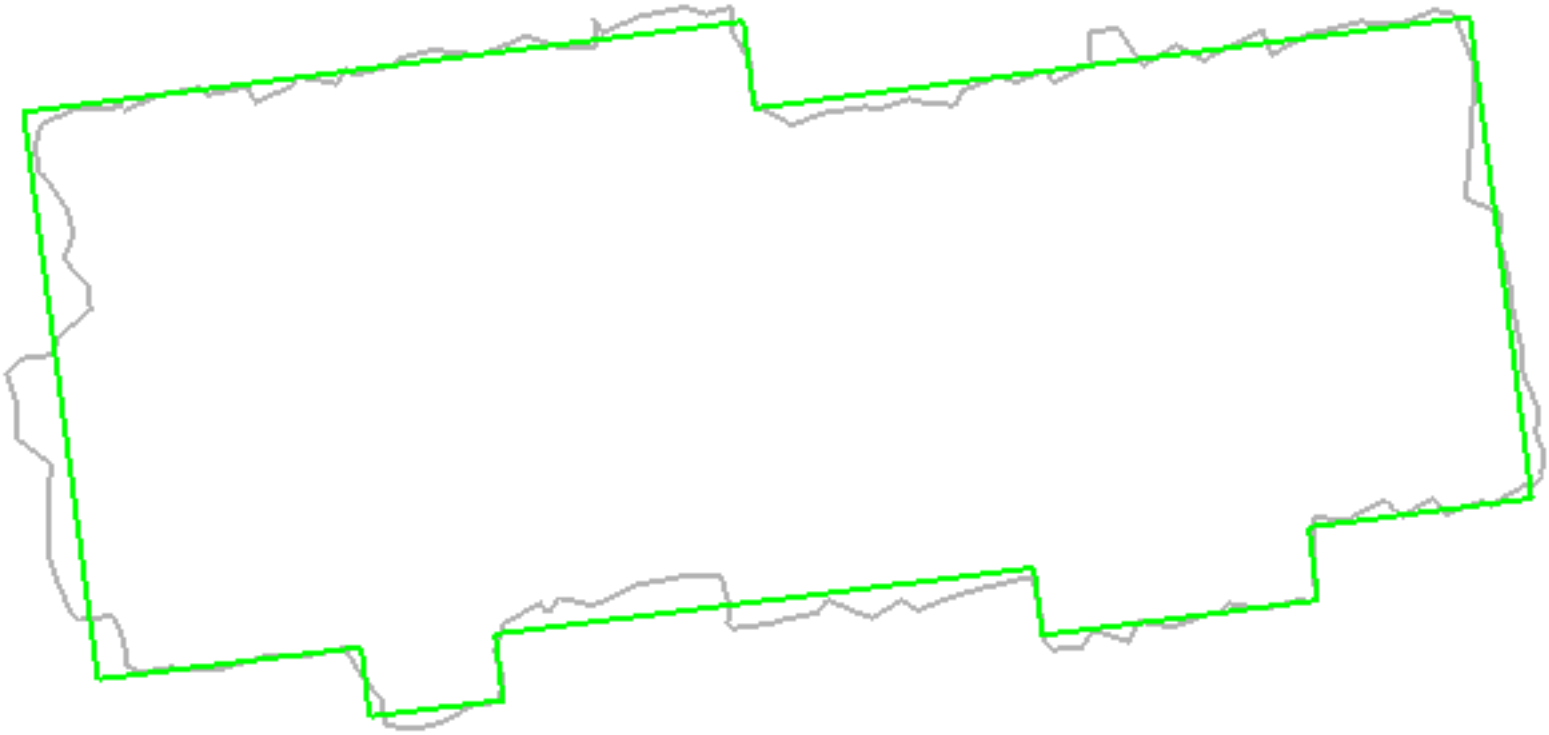
Fragment join: 4 cases

			
(a) Intersection within ε_{line} of segment ends	(b) Parallel segments (intersection → ∞)	(c) Perpendicular segments (intersection distance > ε_{line})	(d) Any other case
• Join segments at their intersection point	• insert a perpendicular segment halfway between the segment ends	• insert two perpendicular segments	• insert a segment joining the ends of the original segments

Final Fragments after Adjustment



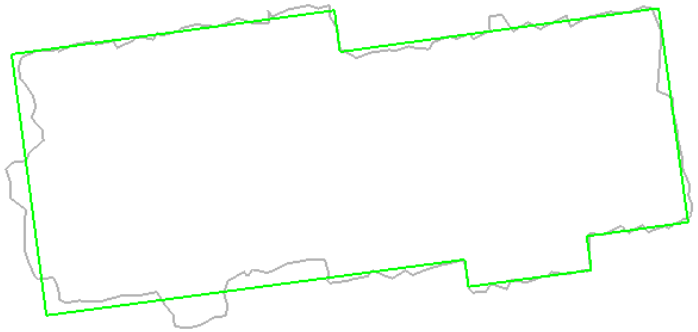
Joined Fragments



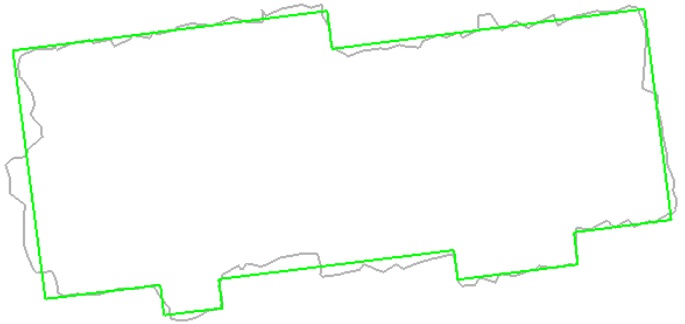
Results & Issues

LOD Series for Building No. 500

Resolution: 2.0m



Resolution: 1.5m



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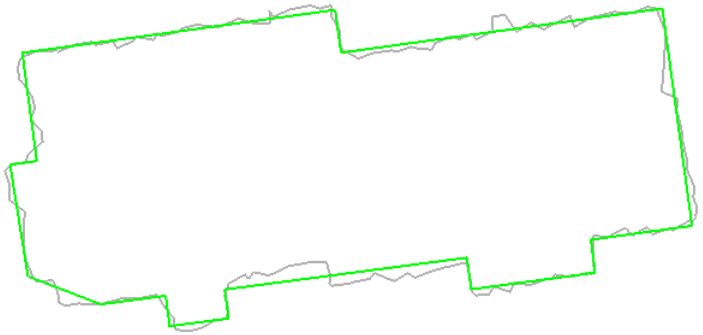
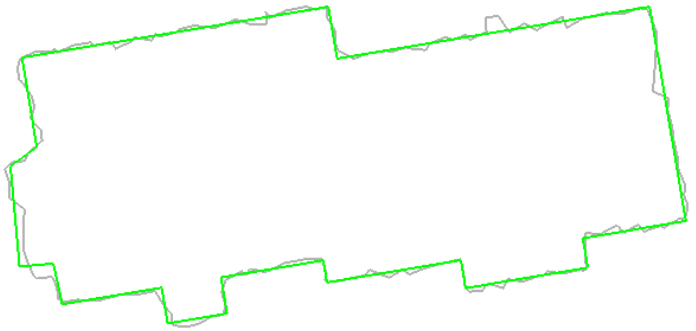
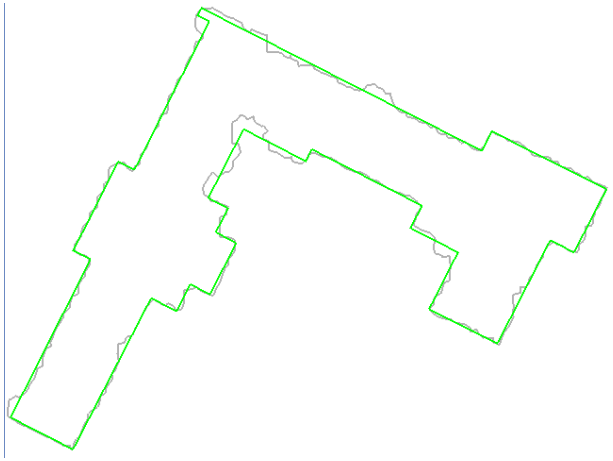


Resolution: 0.7m

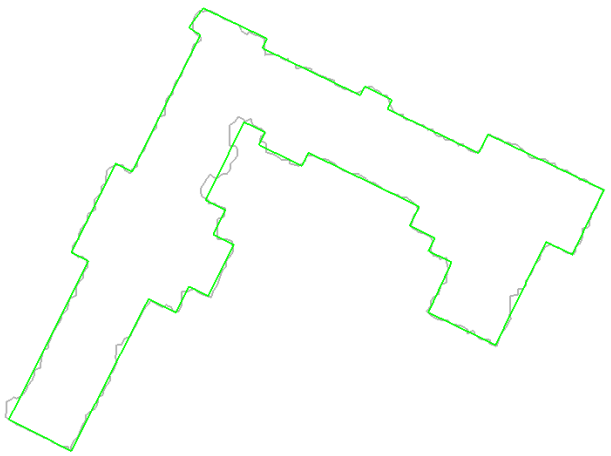


LOD Series for Building No. 1935

Resolution: 2.0m



Resolution: 1.5m



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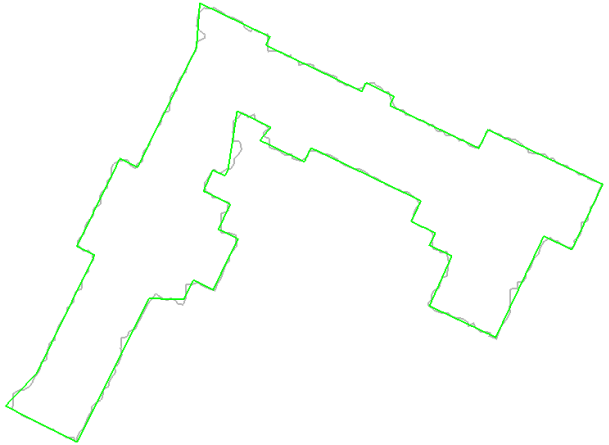
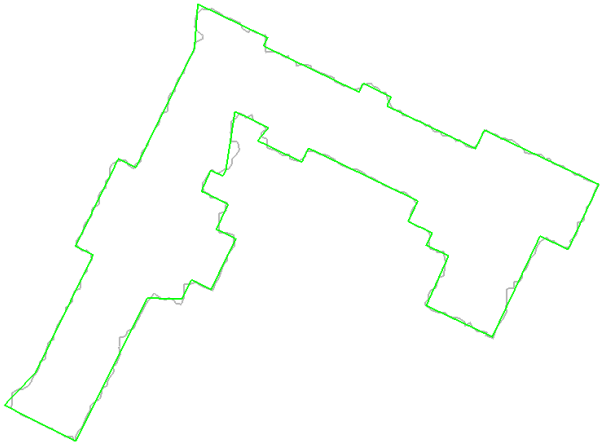
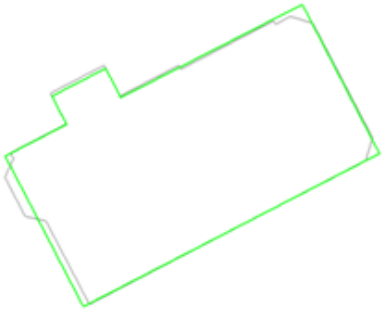
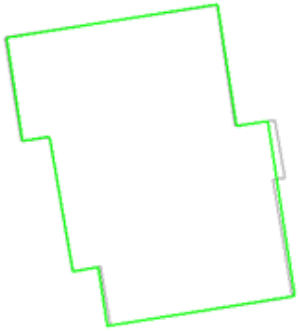
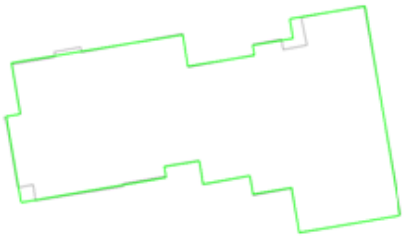
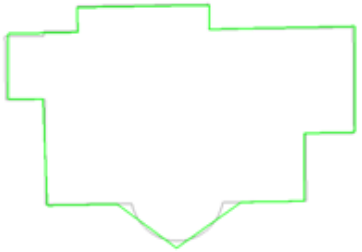
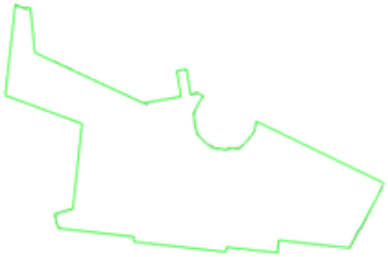
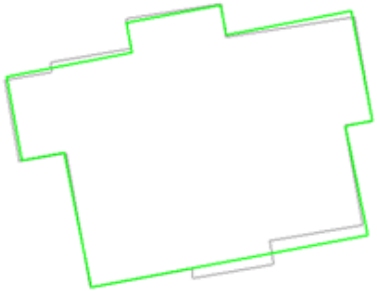
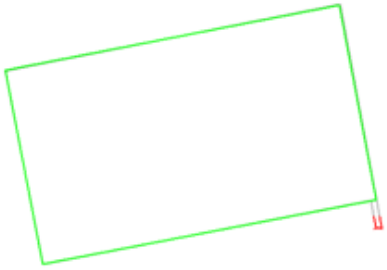
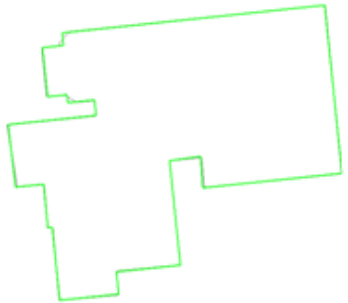


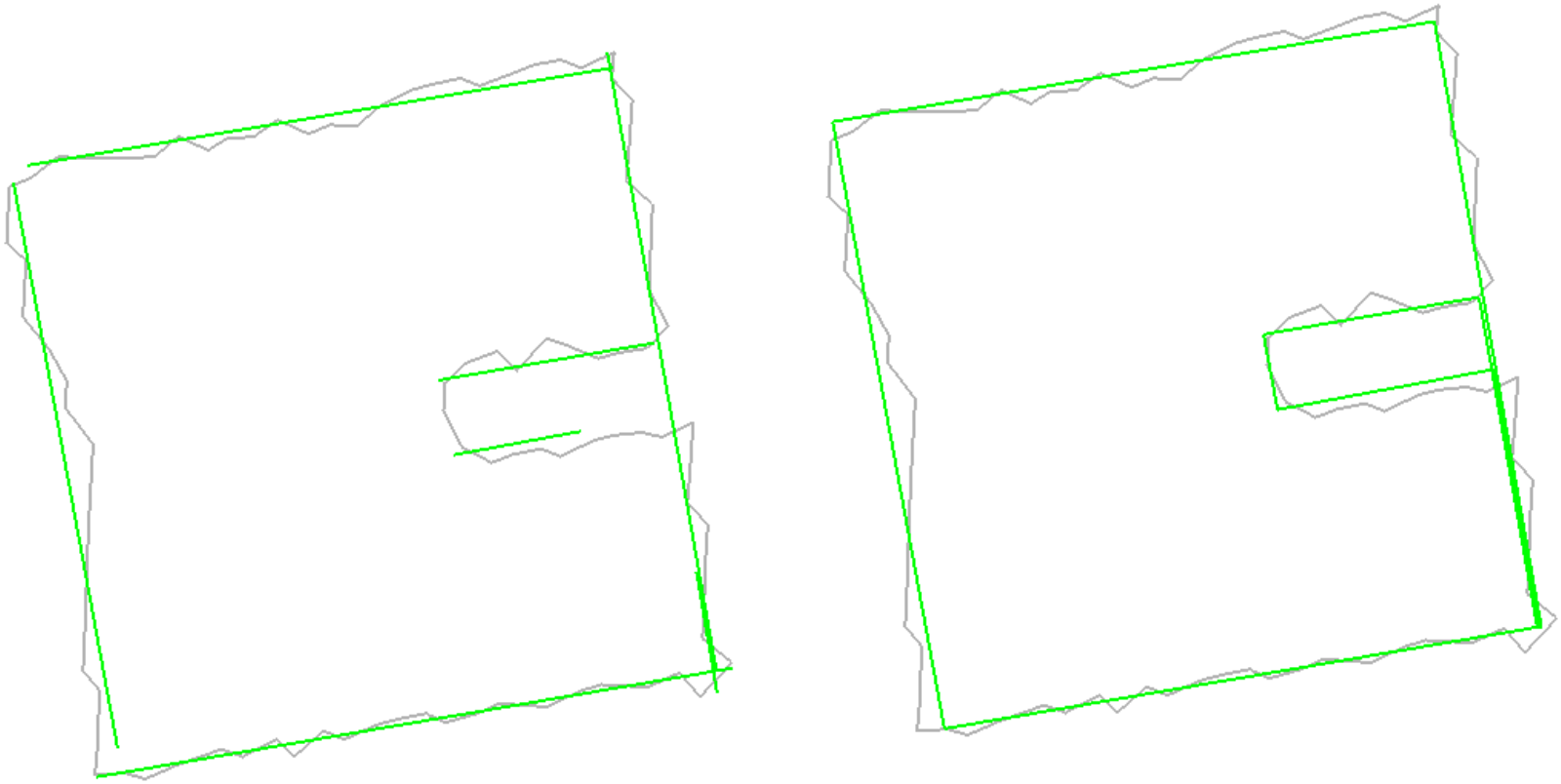
Resolution: 0.7m



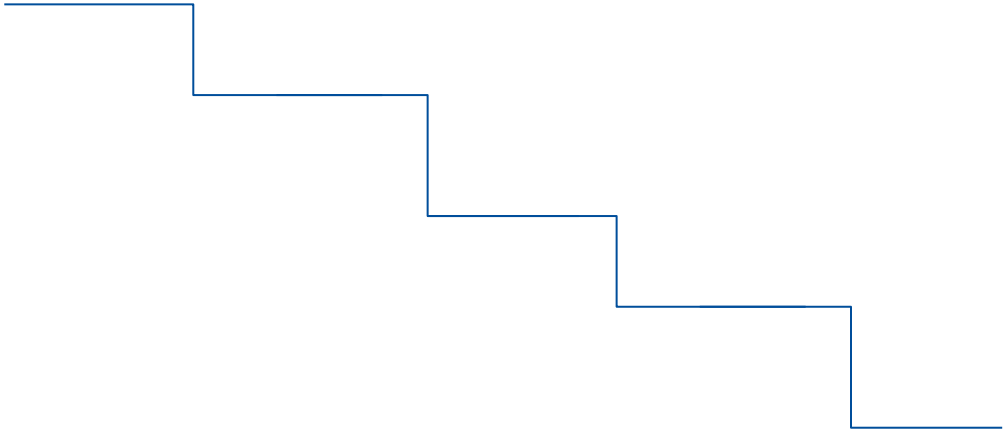
Data reduction: Examples (resolution: 0.7m)

			
21/8	12/10	30/20	175(16)/15(13)
			
394(32)/32(22)	18/12	6/4	25/22

“Cut Segments”



“Stairs”: Ambiguities



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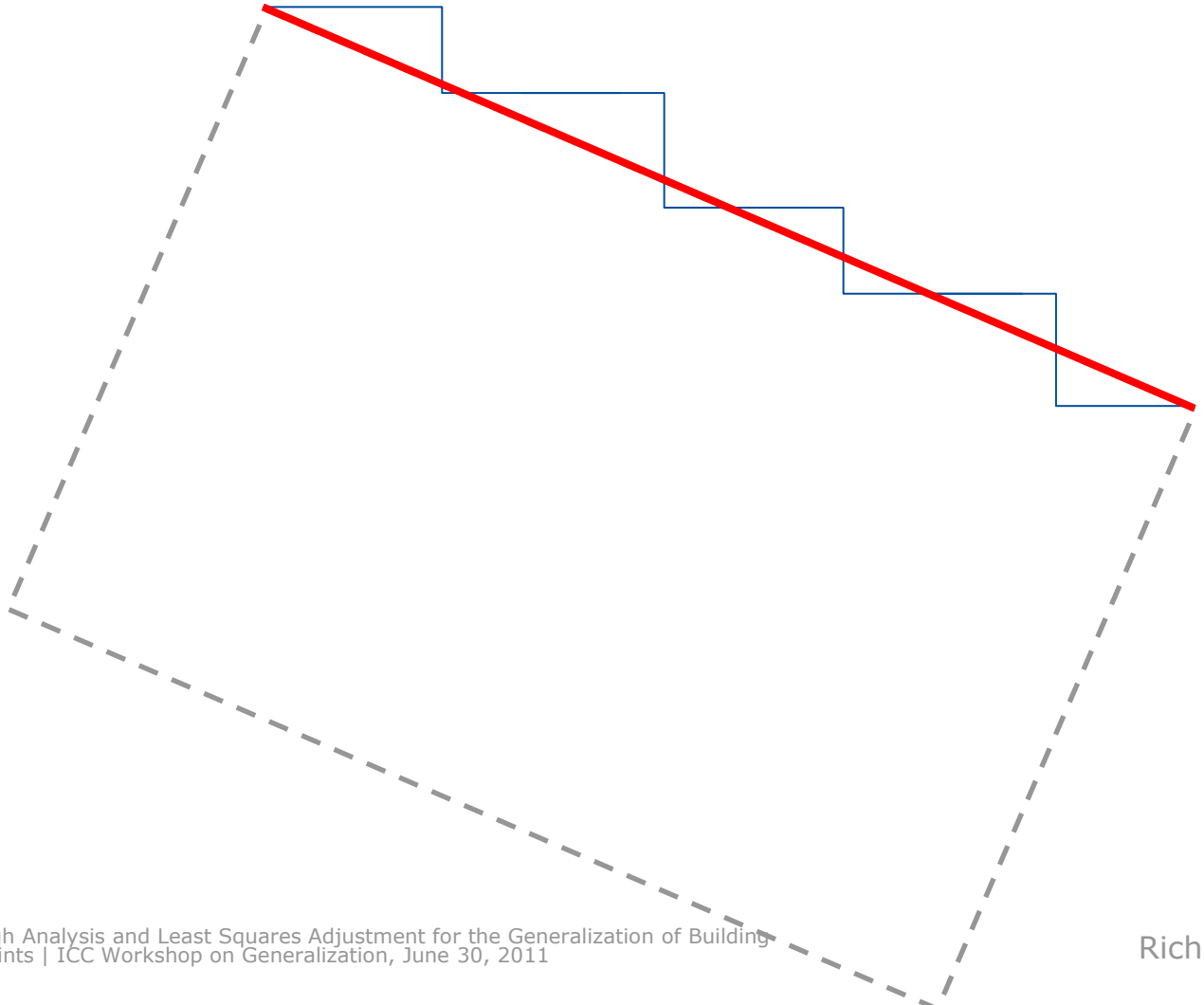

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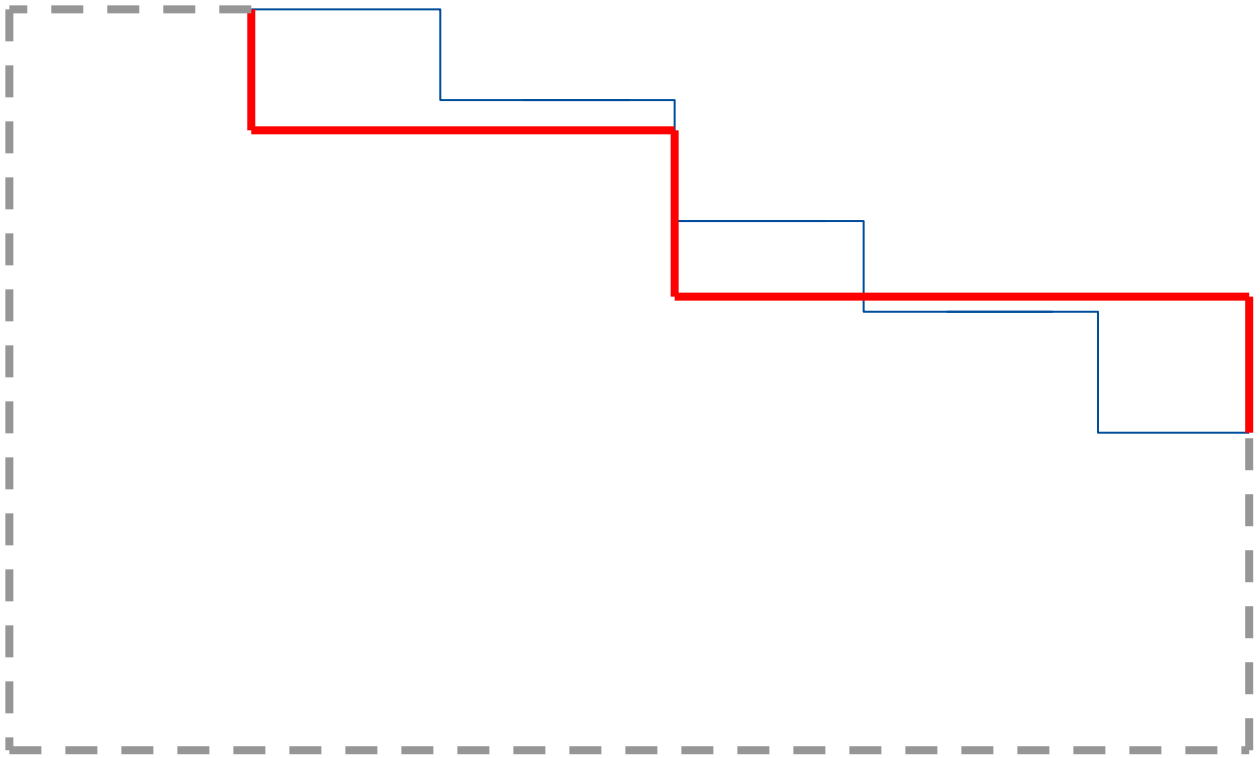

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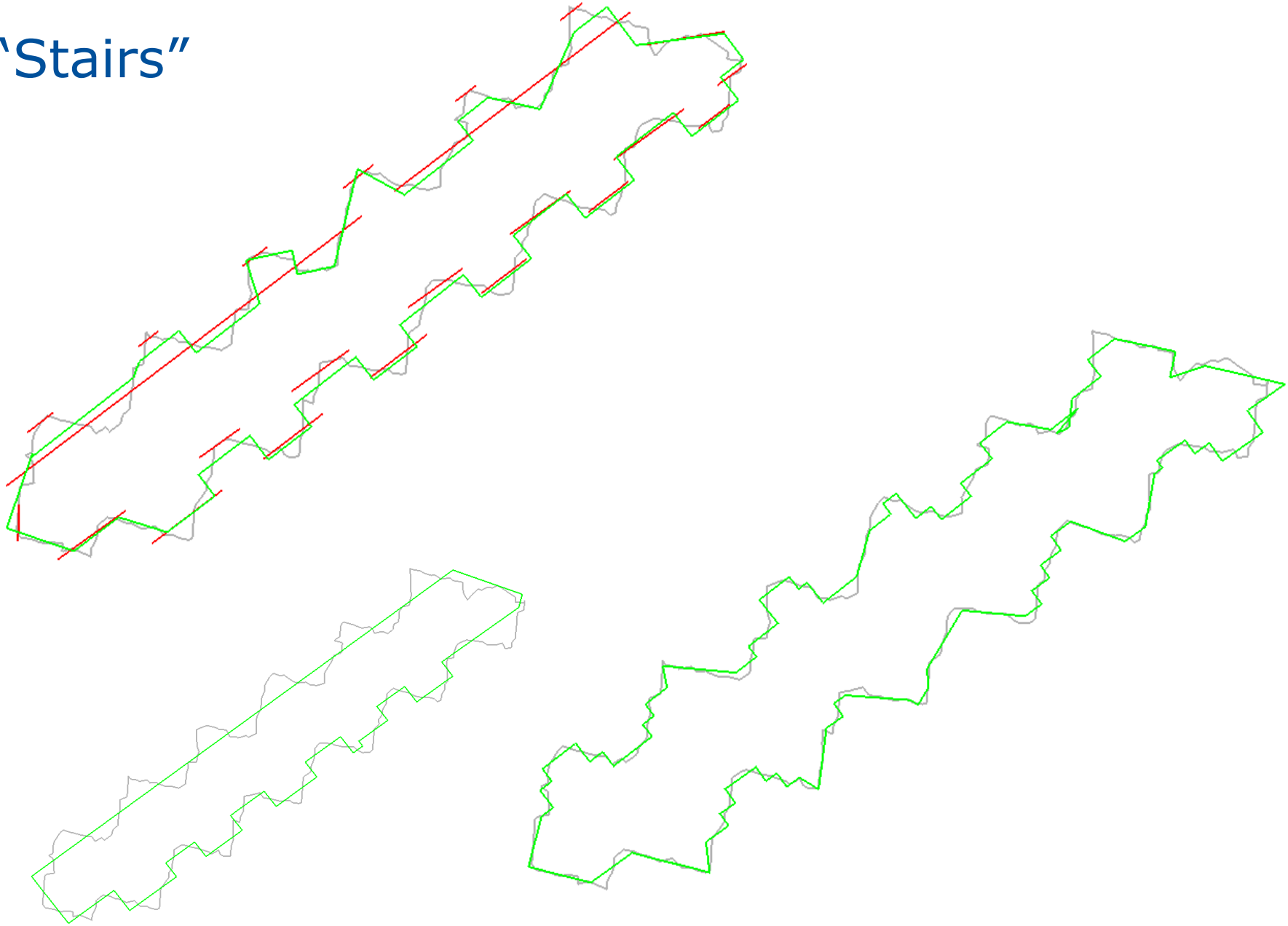

Conclusions & Outlook

Conclusions

- Two use cases of building footprint simplification addressed
  - LOD generation / data reduction for given resolution
  - "De-noising" of fuzzy footprints
- General approach
  - Use a slightly modified Hough transform to find initial line segments
  - Refine the line segments to fit the original shape using LSA
  - Connect the line segments to form a closed polygon
- Results
  - Almost optimal compression rates (sometimes unnecessary steps)

Conclusions

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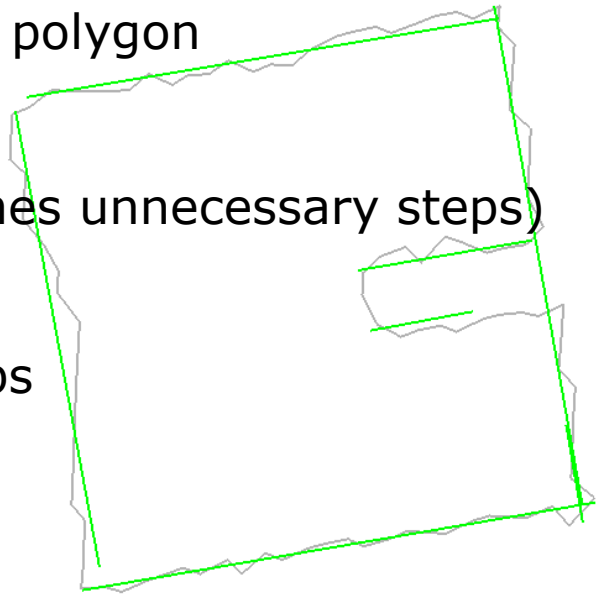

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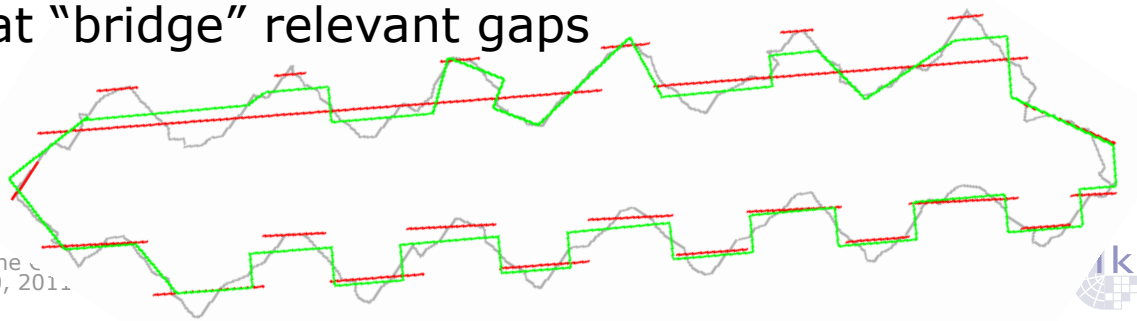

Outlook

- Hough analysis
  - Evaluate different maxima simultaneously
  - Compare to RANSAC
- Resolve “bridged gaps” and “stairs” issues
- Include holes
- Increase stability / ensure convergence
  - Simulated annealing
  - Circular dependencies