Large-scale efficient extraction of 3D roof segments from aerial stereo imagery

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TU Delft:
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Readaar:
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READAAR

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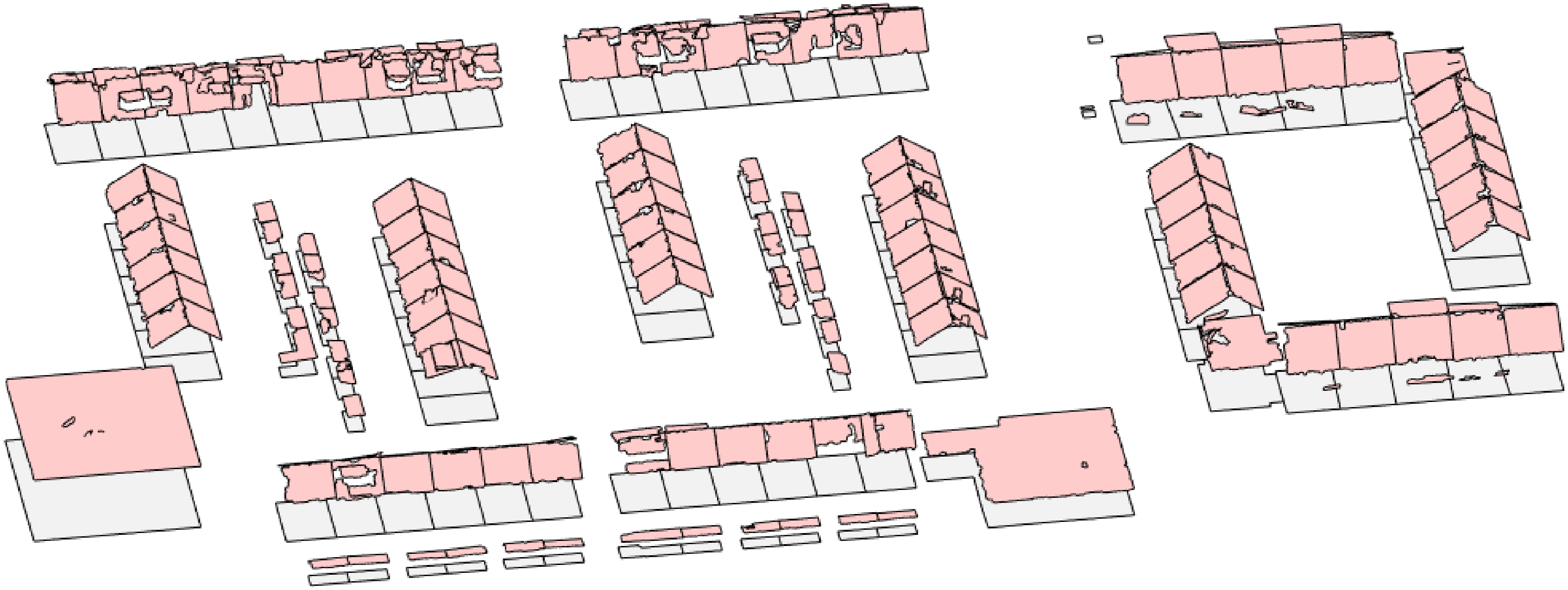
From: Aerial stereo imagery

To: 3D roof segments



- For large area: Municipalities & Provinces

Relevance: PV potential & Asbestos

READAAR:

- Photovoltaic potential
  - Number of panels and orientation
  - Solar panel yield
- Detection of asbestos
  - Asbestos illegal in 2024
  - Estimated 120km^2
  - 1000 asbestos related deaths yearly

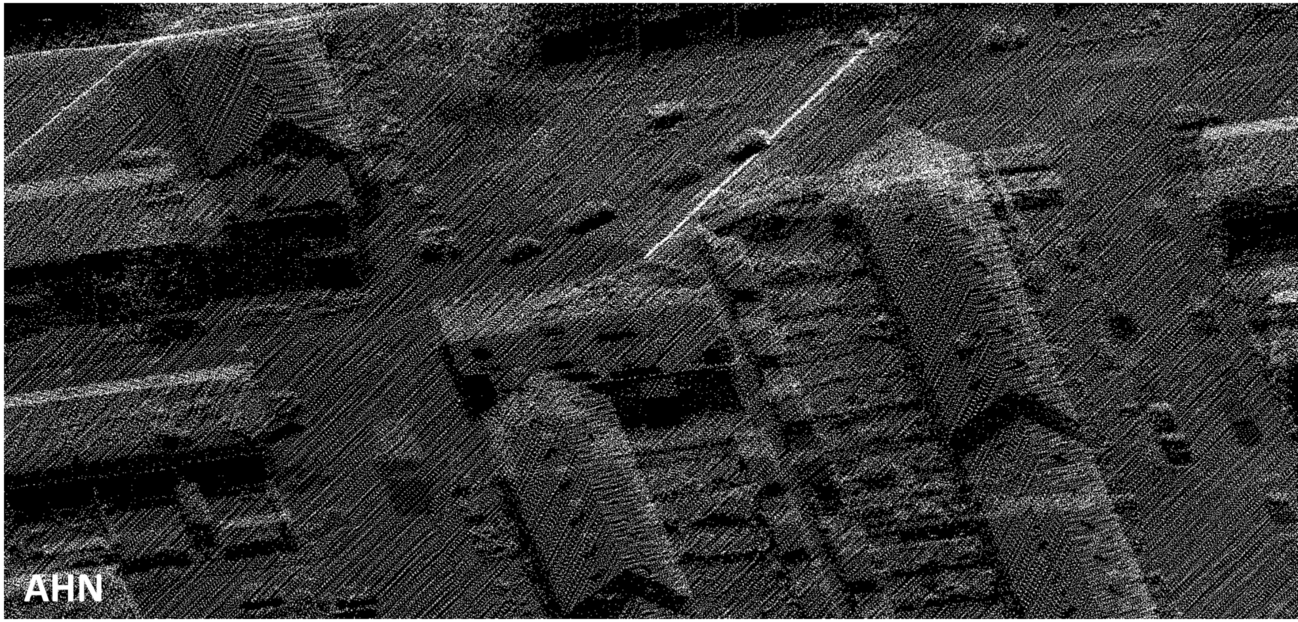
Current method READAAR has its limitations

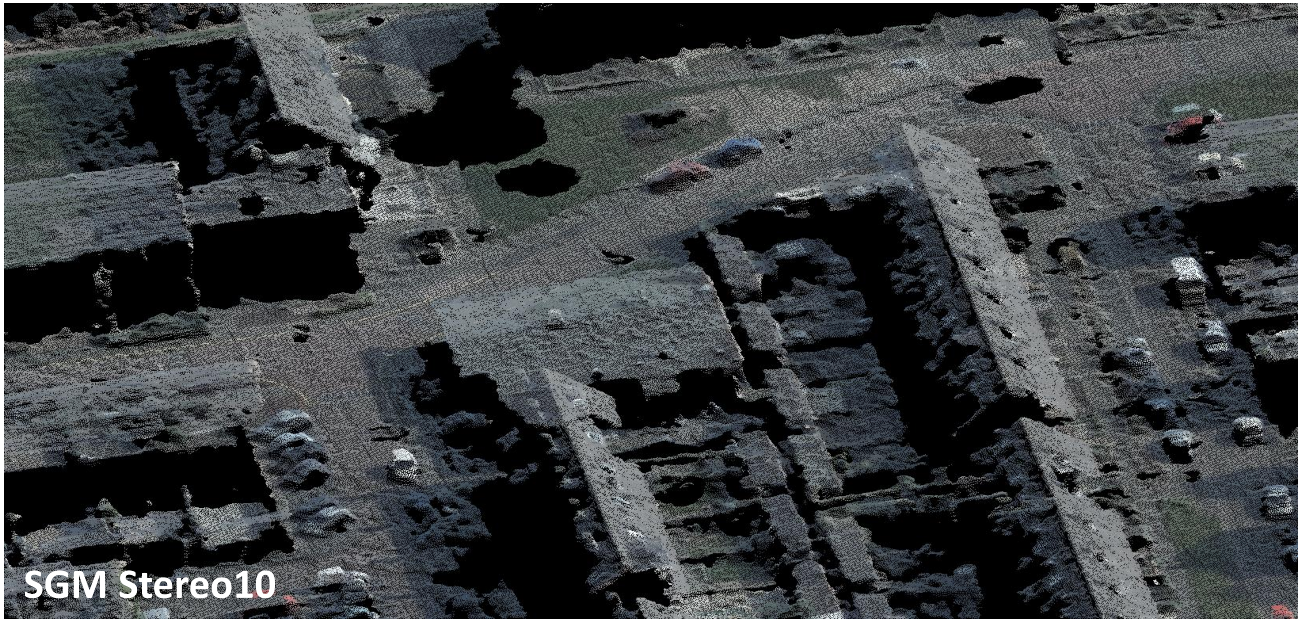
- Based on gridded LiDAR
  - Not always available outside NL
  - Expensive to gather

- Potential improvement using aerial stereo imagery

LiDAR vs stereo

- Color
- Density
- Gaps/noise





LiDAR vs stereo

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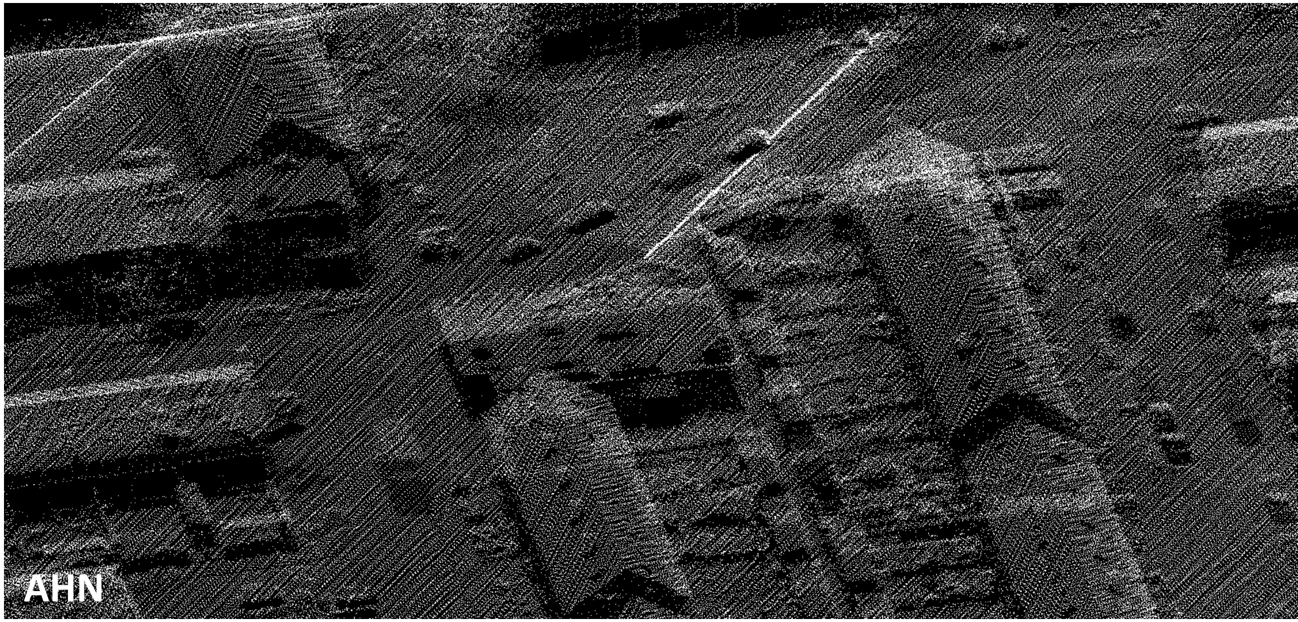

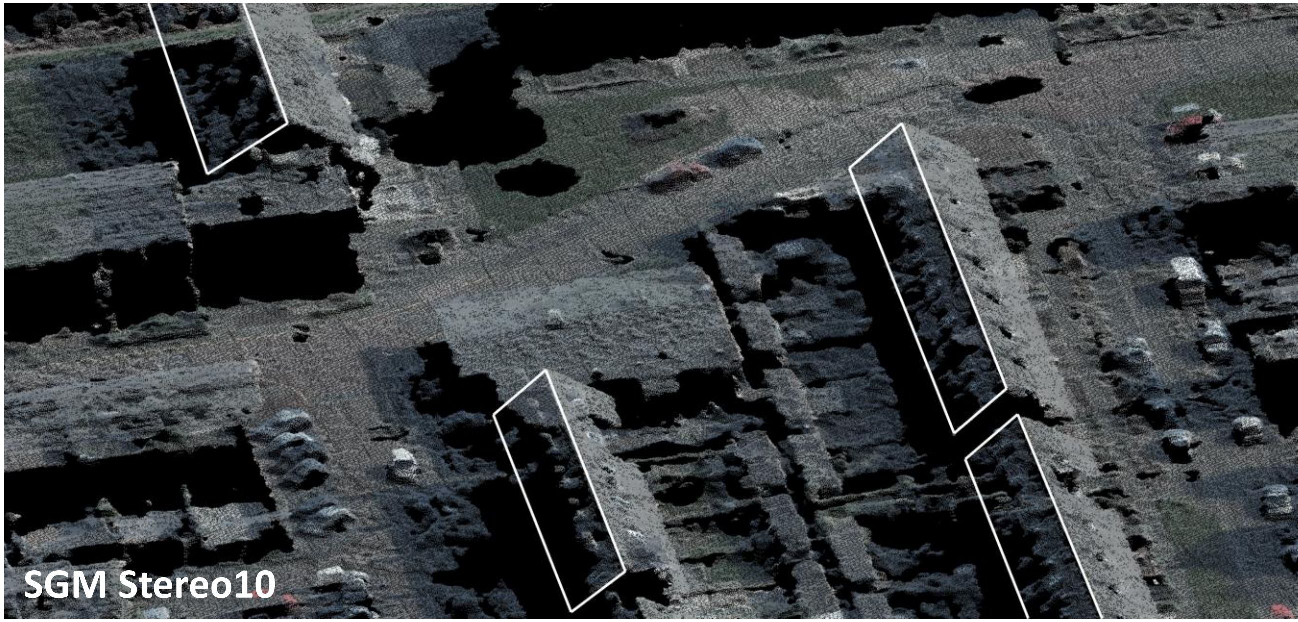

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Goal: Large-scale efficient extraction of 3D roof segments using only aerial stereo imagery

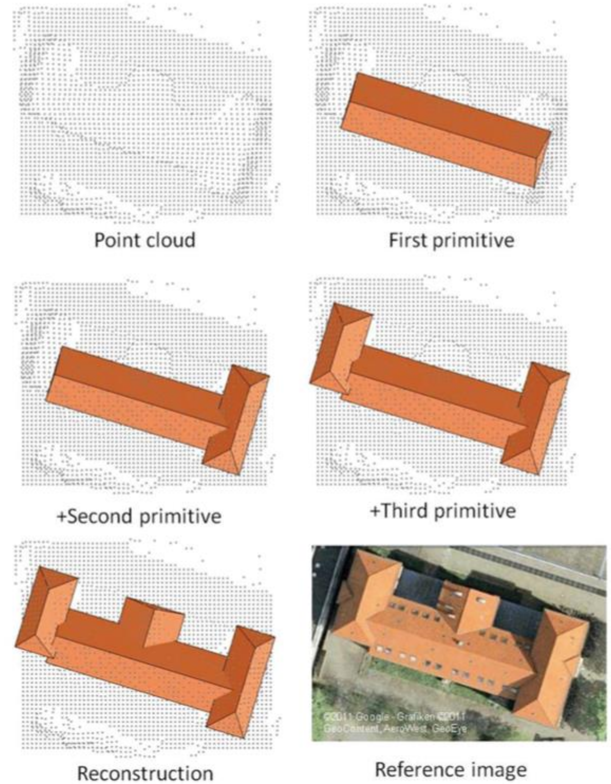
1. Scalability & Efficiency:
   - Municipalities/provinces
   - Fully automatic
   - Within reasonable time

2. 3D roof segments:
   - Watertight building models not required

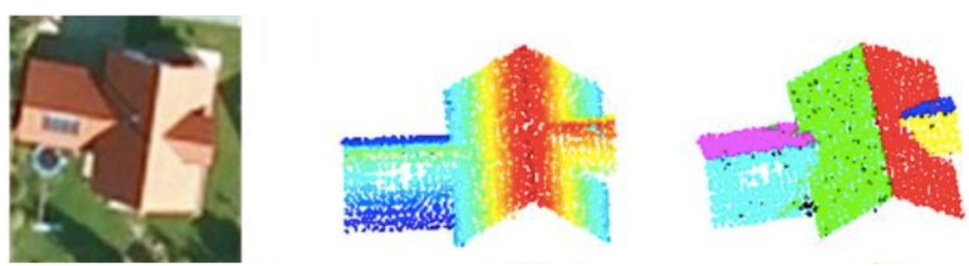
3. Aerial stereo imagery
   - Not dependent on LiDAR data

Related work: Model vs data driven

- Model-driven (Fitting primitives from library)
  - Watertight roofs
  - Limited to shapes in library



- Data-driven (Segmentation of pointcloud/image)
  - Roofs of any shape
  - Not watertight



Related work: Segmentation

- Directly searching planes
  - RANSAC
  - Hough transform

- Image segmentation based on color/normals
  - Thresholding
  - Region growing
  - Watershed

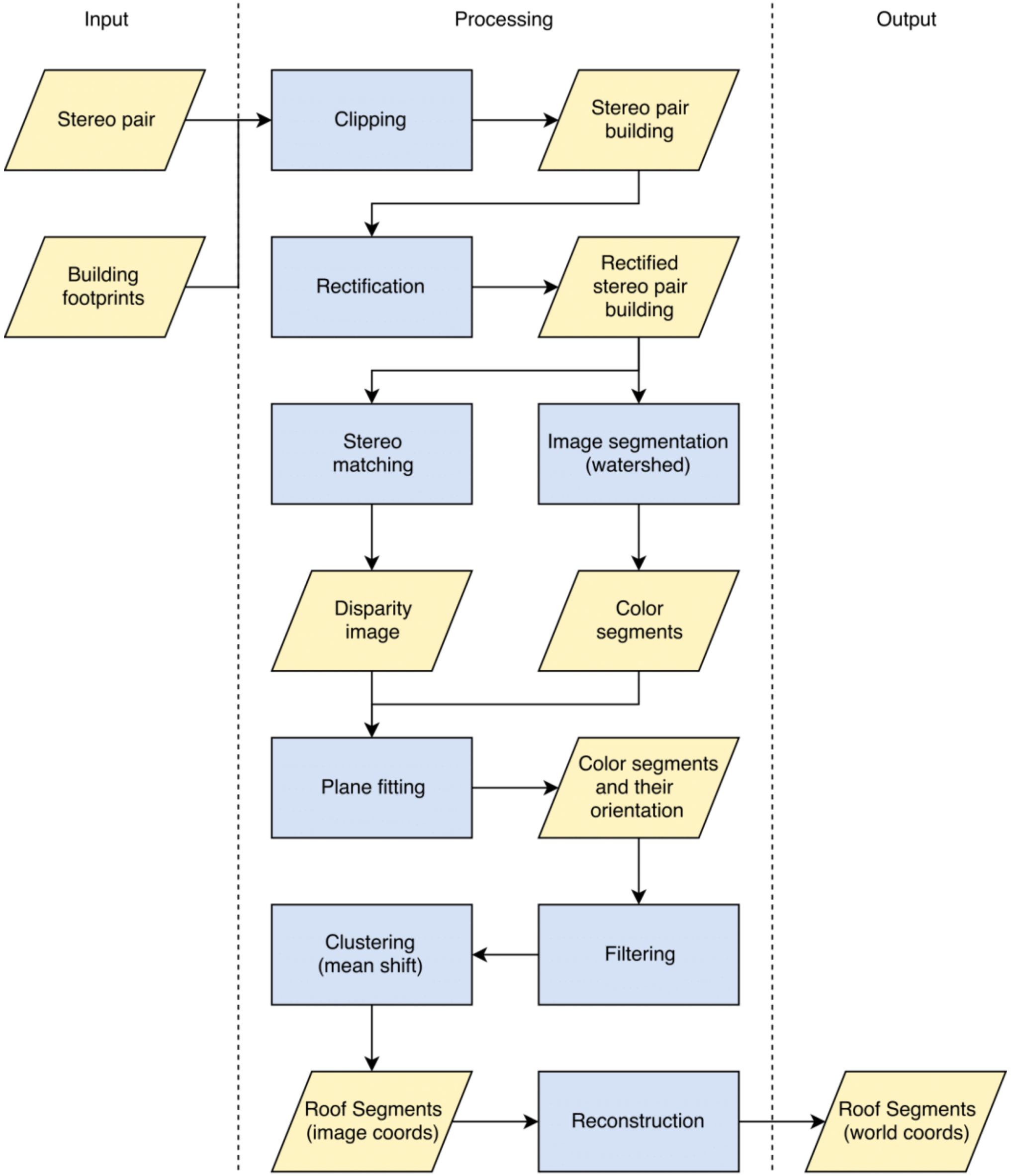
- Clustering normals
  - K-means
  - Mean-shift

Literature study conclusions

1. Data-driven approach
   - Any shape
   - Watertight building models not required
2. Potentially useful algorithms for large-scale applications
   - Thresholding
   - Watershed
   - Mean-shift
3. Two step segmentation approach (first color than orientation)
   - Exploiting color
   - Dealing with gaps/noise
   - Efficient

Methods:

- All processing steps are per building
- This Ensures scalability



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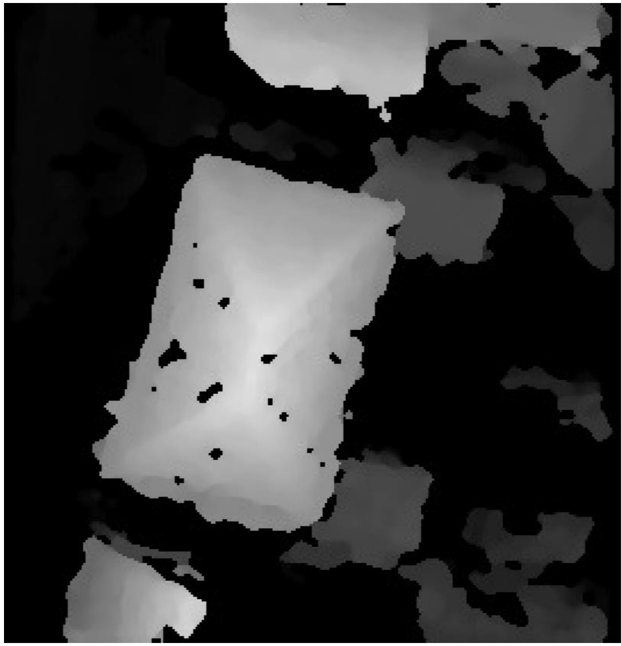
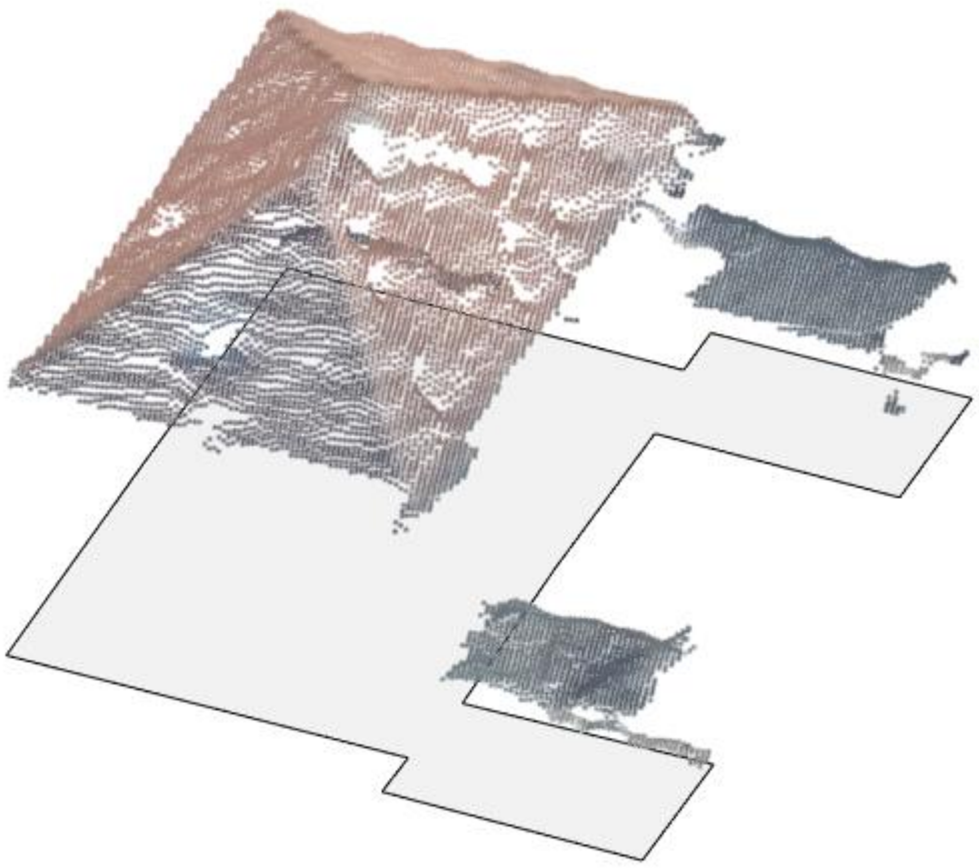
Methods: Clip, rectify & match


Left View


Right View


Disparity

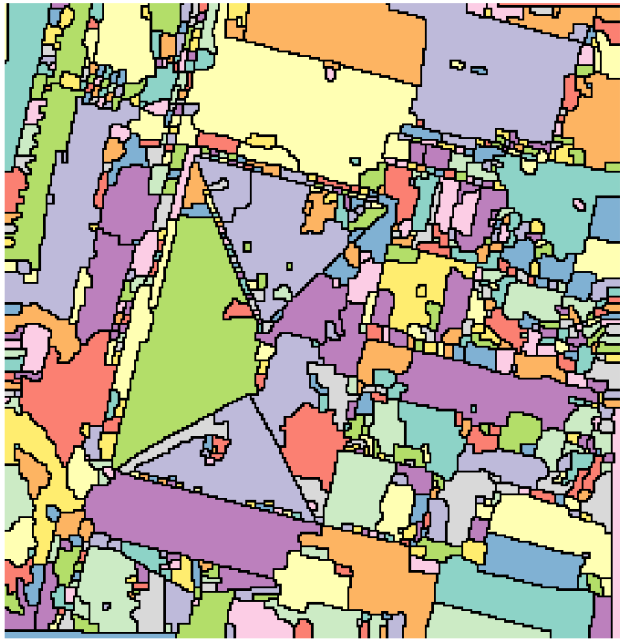
Method: Conversion to pointcloud



Methods: Color segmentation

Left View

Gradient Magnitude



Watershed

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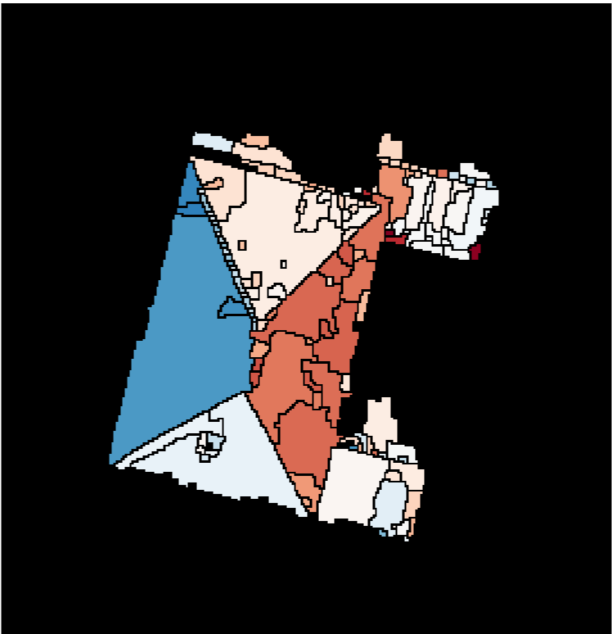
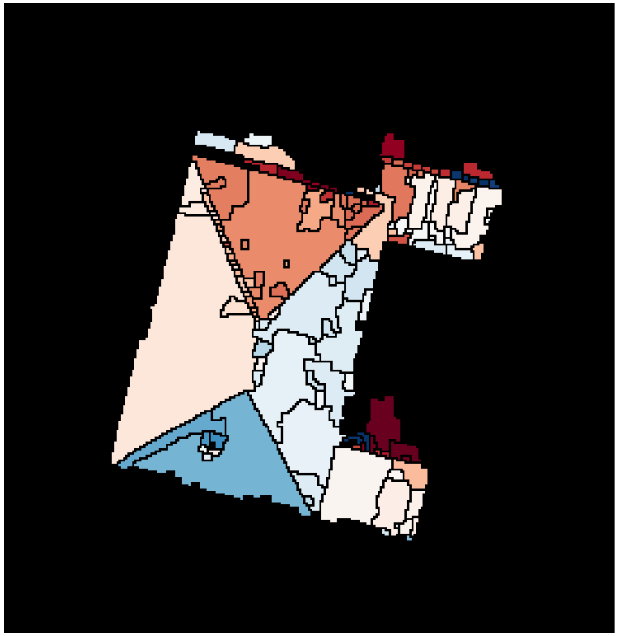
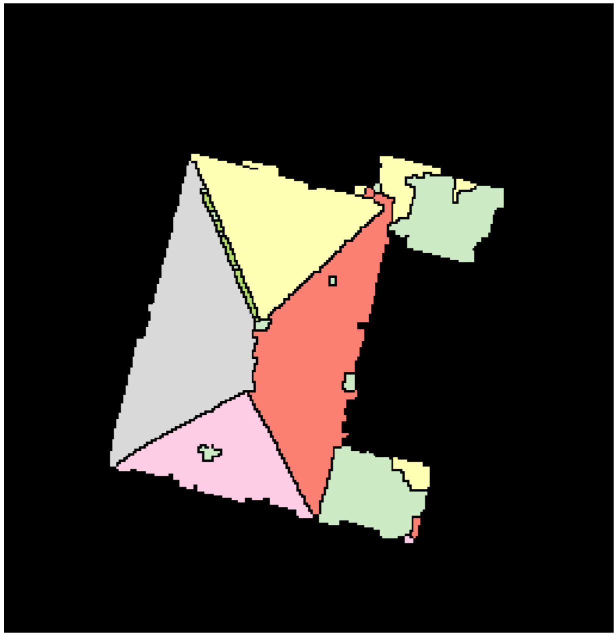
Methods: Cluster color segments



Normal *x* component

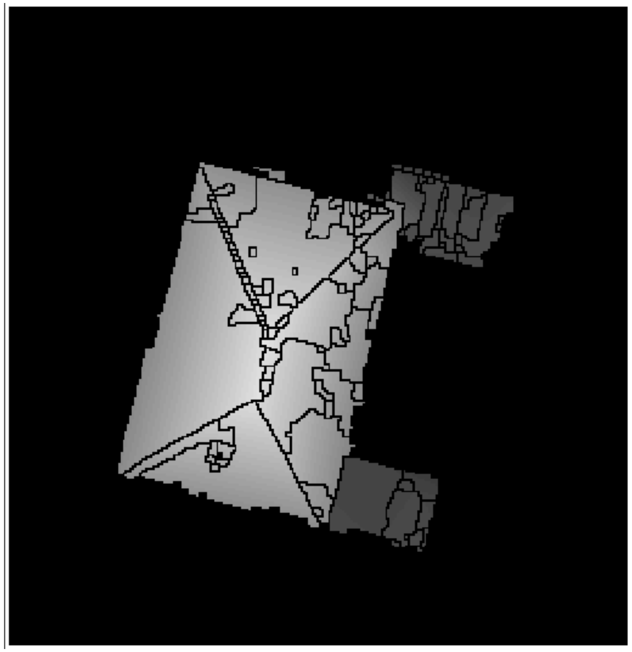


Normal *y* component

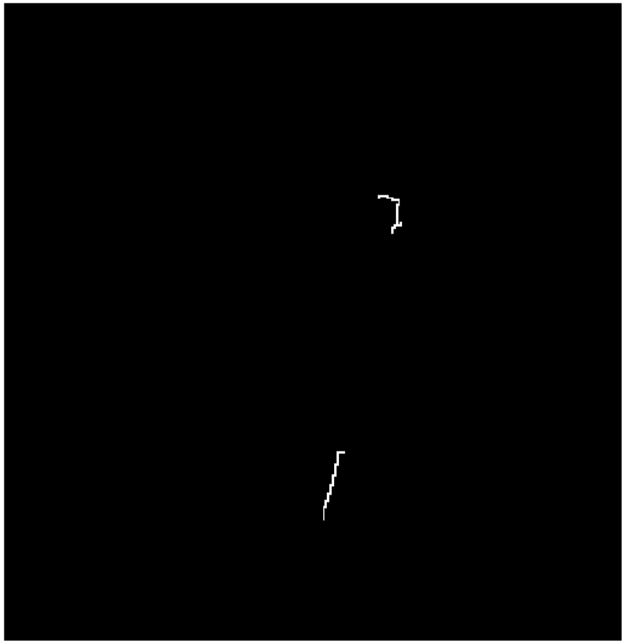


Mean-Shift clustering of color segments based on orientation

Methods: Height jumps



Disparity based on plane models



Height Jumps

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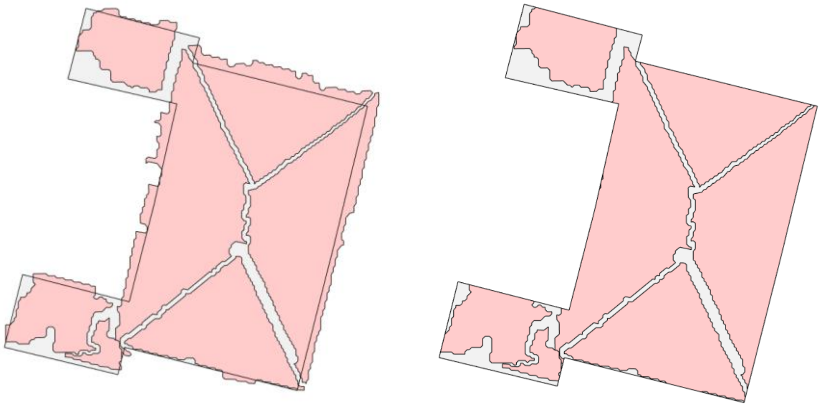
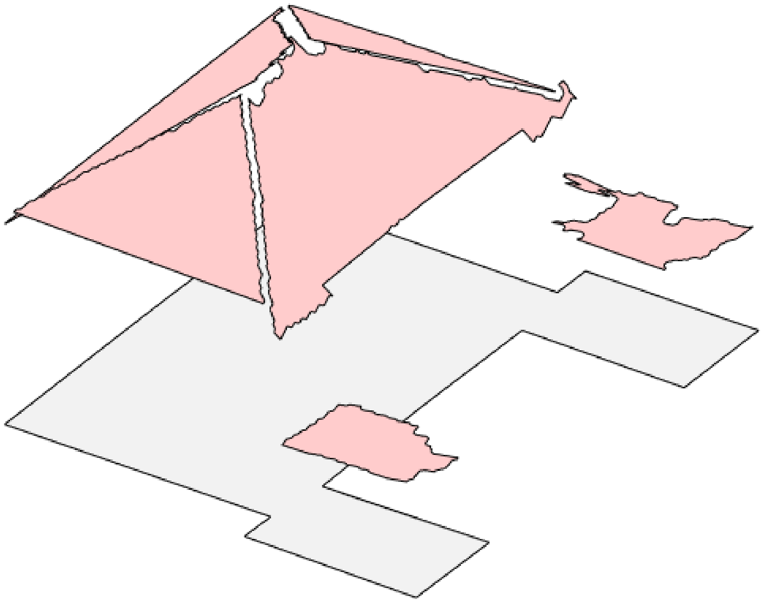
Methods: Reconstruction



Vectorize & Cut with Footprint



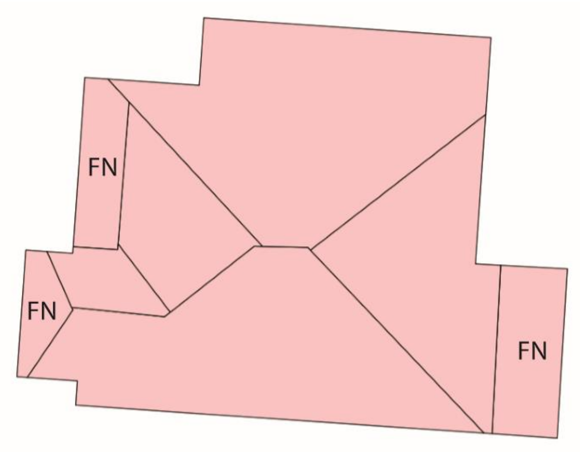
3D roof segments

Quality assessment:

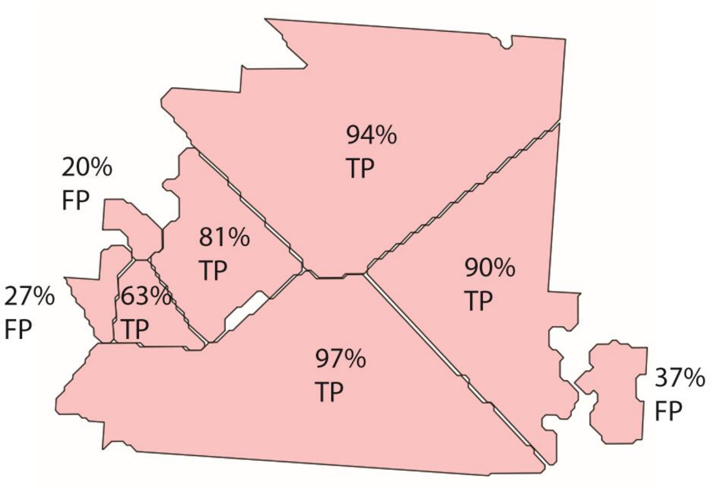
- True Positive (TP):
  >50% overlap

- False Positive (FP):
  <50% overlap

- False Negative (FN):
  Not detected



Ground Truth



Extracted Segments

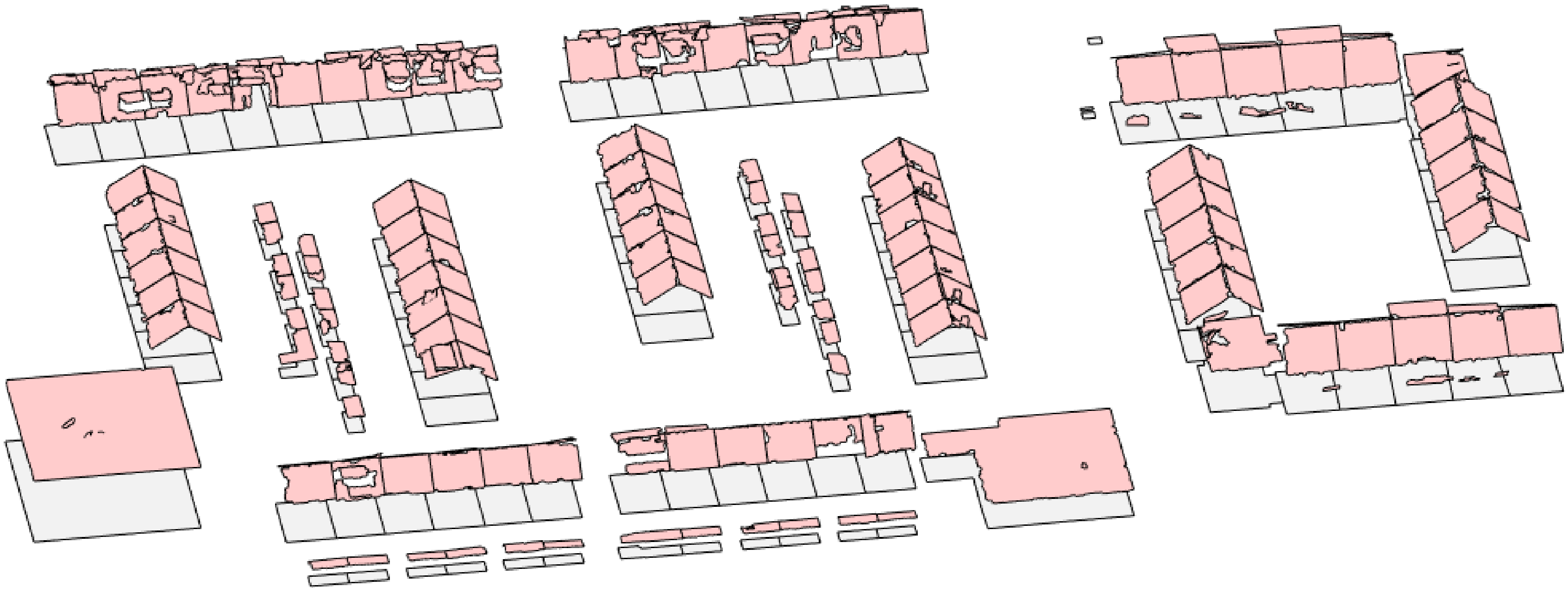
Quality assessment:

- $Completeness = \frac{|TP|}{|TP|+|FN|}$

- $Correctness = \frac{|TP|}{|TP|+|FP|}$

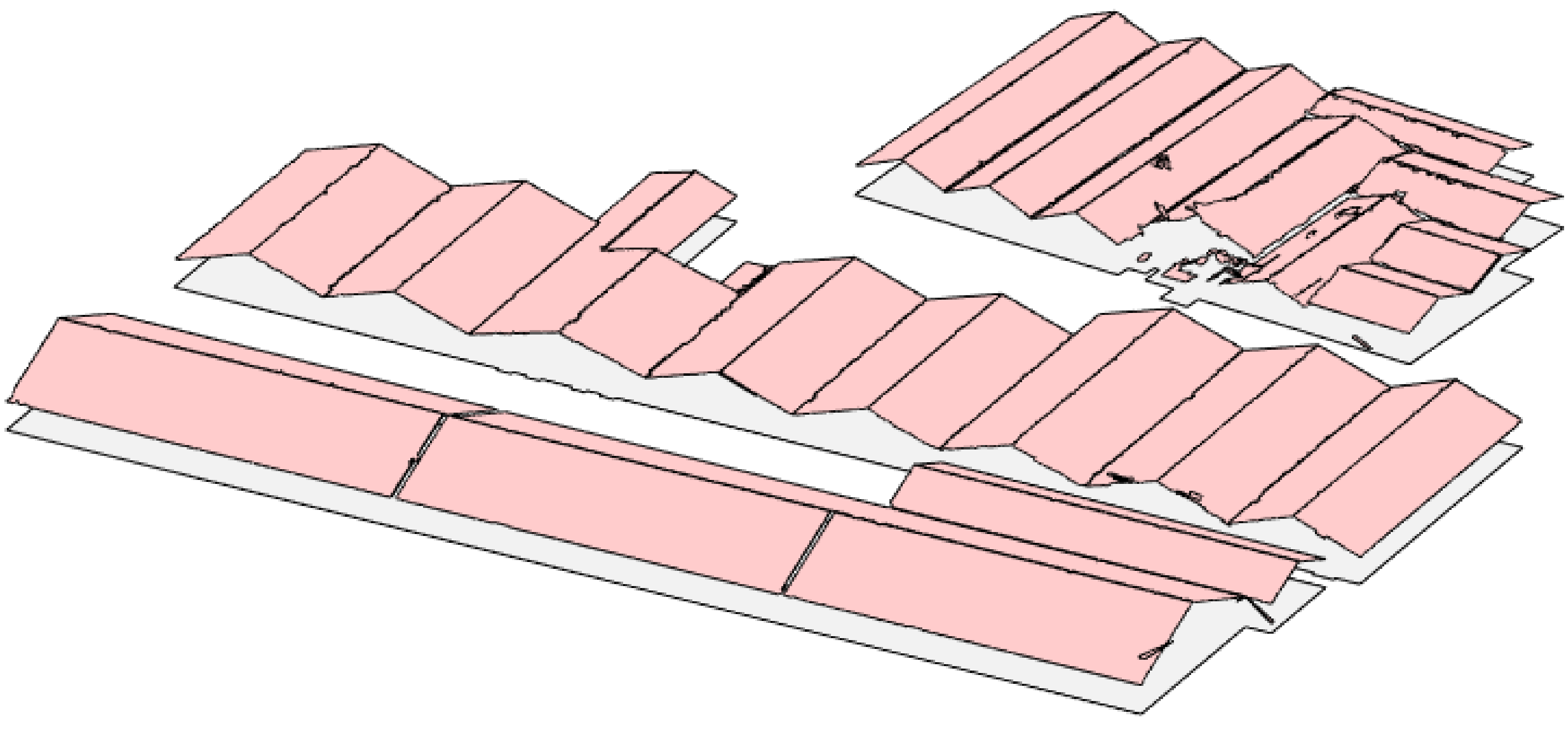
- $Quality = \frac{|TP|}{|TP|+|FP|+|FN|}$

Results: Terraced



Results: Free-standing

Results: Industry

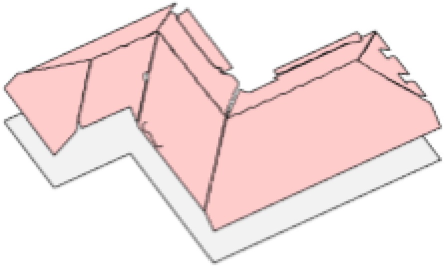


Results: Segmentation quality

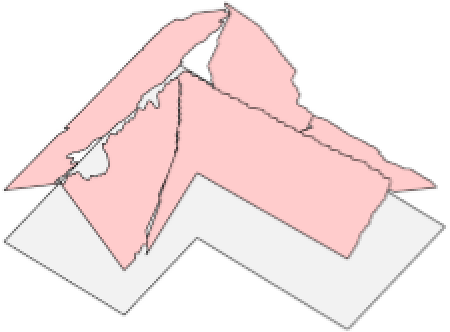
Stereo		*Comp*	*Corr*	*Q*
Terraced		92.9	86.4	81.0
	$>10m^2$	96.7	98.6	95.4
Free-standing		64.5	76.2	53.7
	$>10m^2$	86.1	96.3	83.3
Industry		88.2	48.9	45.9
	$>10m^2$	95.7	90.0	86.5

Results: Problems

Overhanging roofs

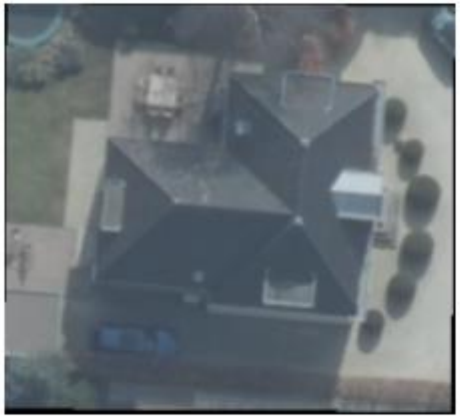


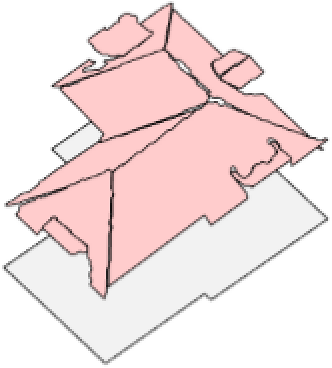
Shadowing effects



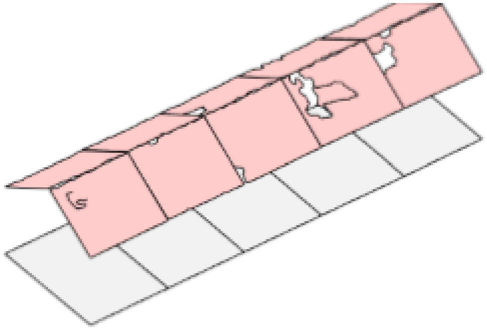
Results: Problems

Dormers





Roof objects
(Chimneys)

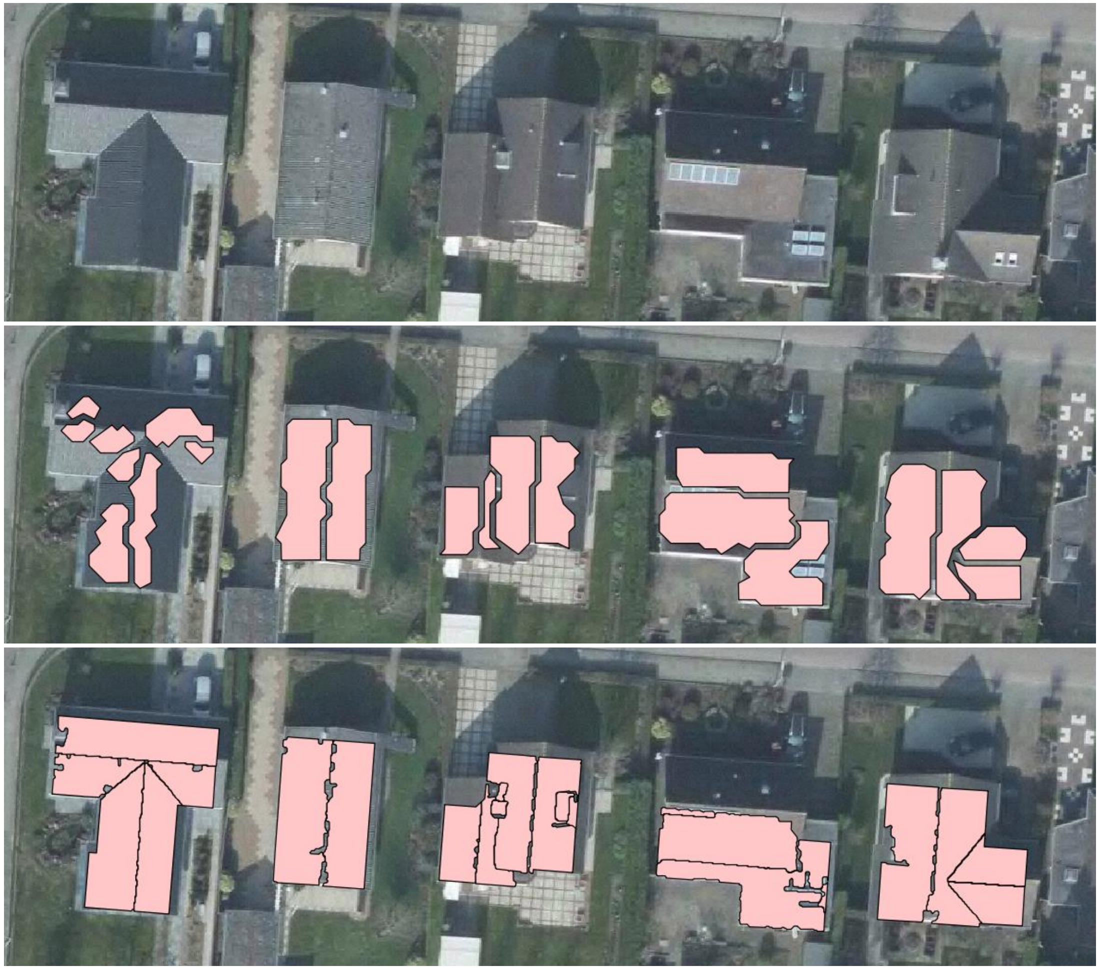


Results: Computation time

- Without loading times
- Roughly 14400 buildings/hour
- Average municipality in The Netherlands has 25000 buildings

Process	Time (s)
Rectification	0.069
Matching	0.027
Watershed	0.018
BAG_Filter	0.033
Plane fitting	0.036
Height Jumps	0.004
Clustering	0.039
Reconstruction	0.031
Total	0.257

Results: Comparison



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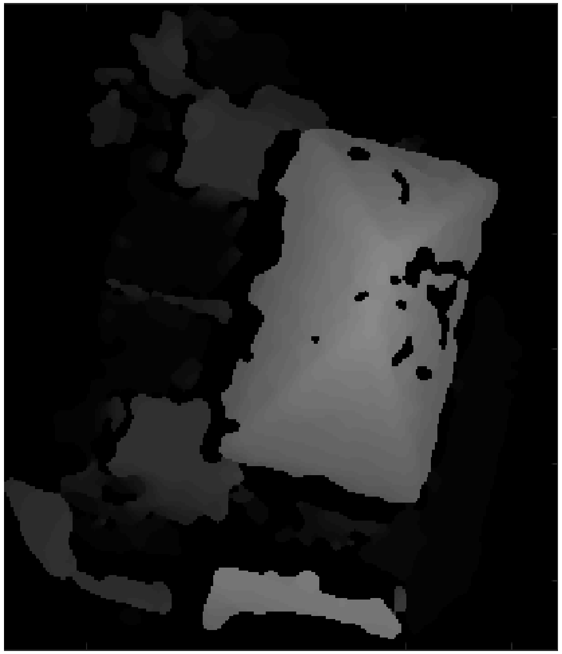
Industry		88.2	48.9	45.9
	$>10m^2$	95.7	90.0	86.5
LiDAR				
Terraced		85.7	88.0	76.8
	$>10m^2$	89.7	97.0	87.2
Free-standing		34.3	49.7	25.5
	$>10m^2$	58.2	79.8	50.7
Industry		74.5	47.5	40.9
	$>10m^2$	80.9	92.7	76.0

Conclusions/contributions

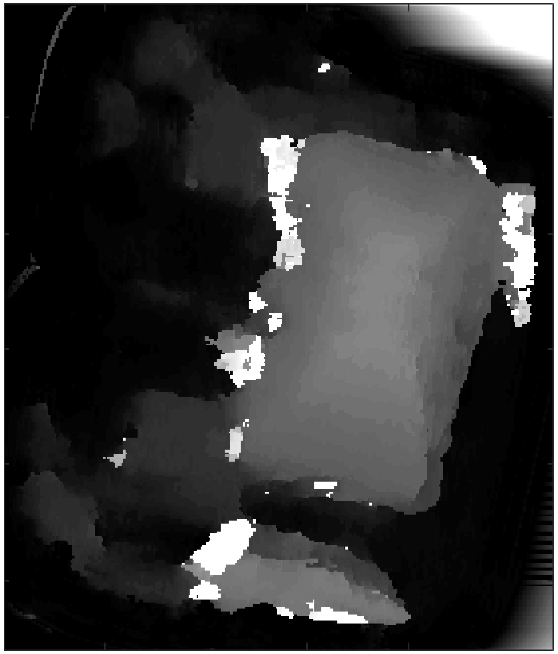
- Integration of stereo matching and roof segment extraction (scalable)
- Efficient method for extraction of 3D roof segments from aerial stereo images only
- Higher quality than the current LiDAR-based method
- Problems with shaded areas, overhanging roofs, roof objects and complicated roof shapes

Future work: Matching with neural network

- Promising results
  - Network trained with traffic situations only
  - Train network with aerial stereo images and disparity from AHN



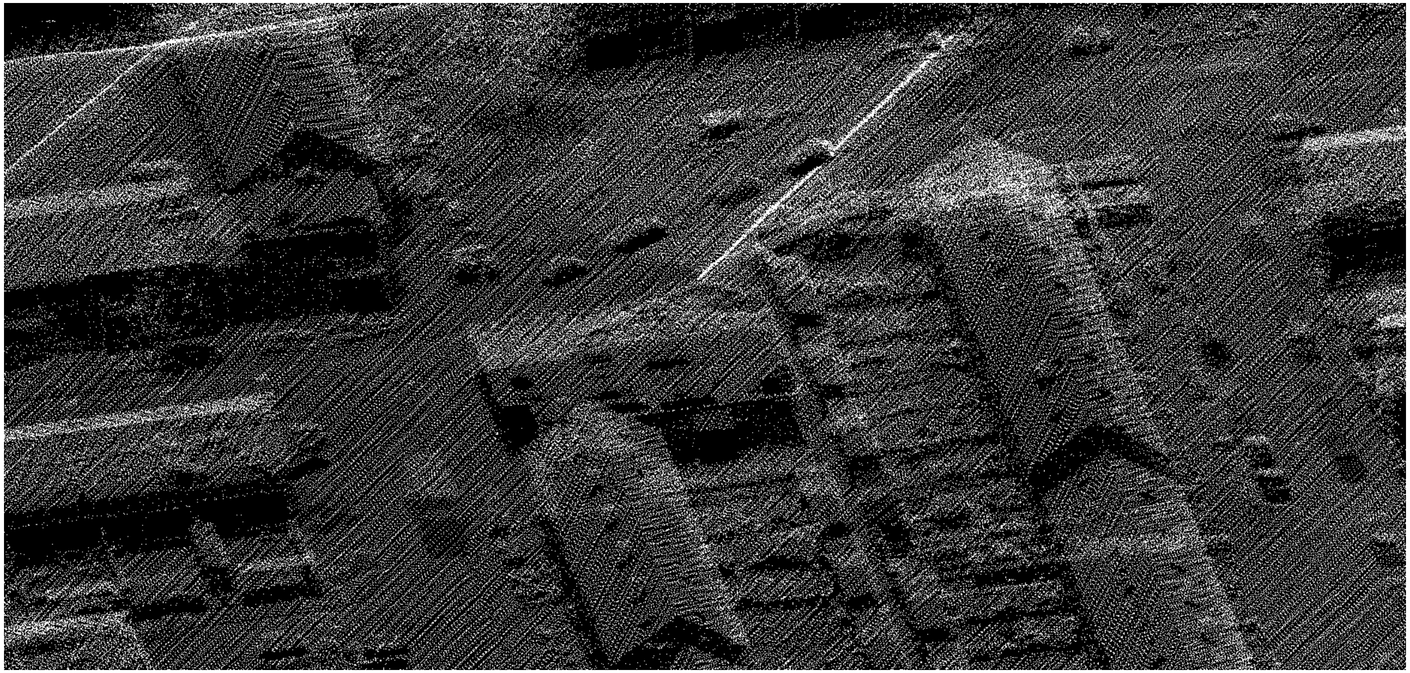
SGM



Neural network (Luo, 2016)

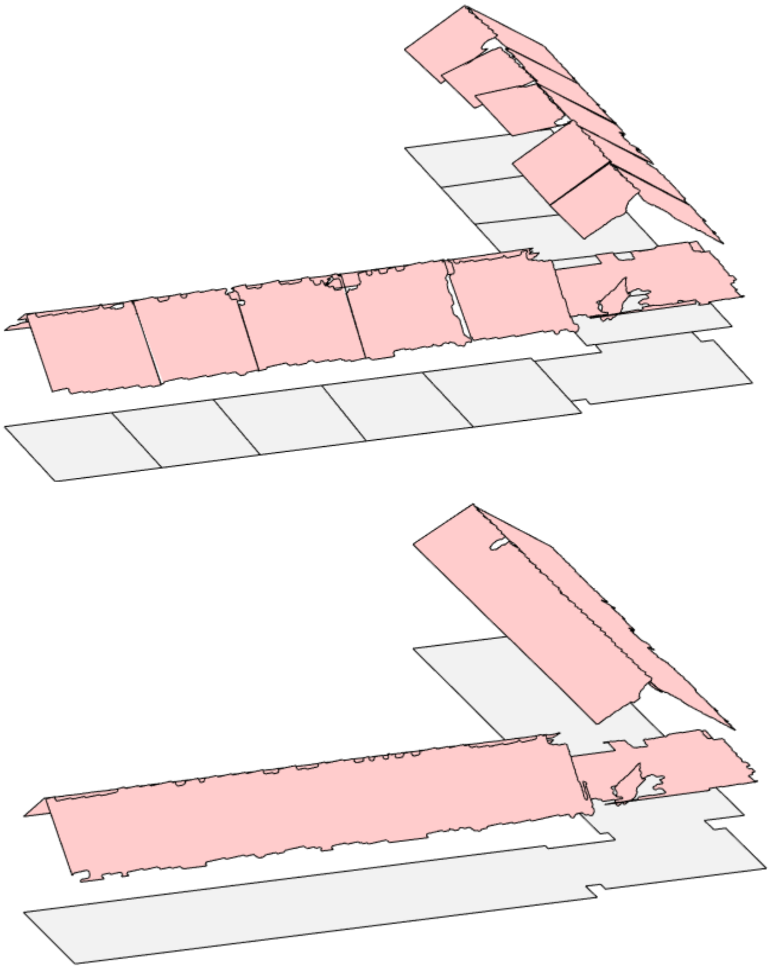
Future work: Integrate LiDAR

- Improve results in shaded areas

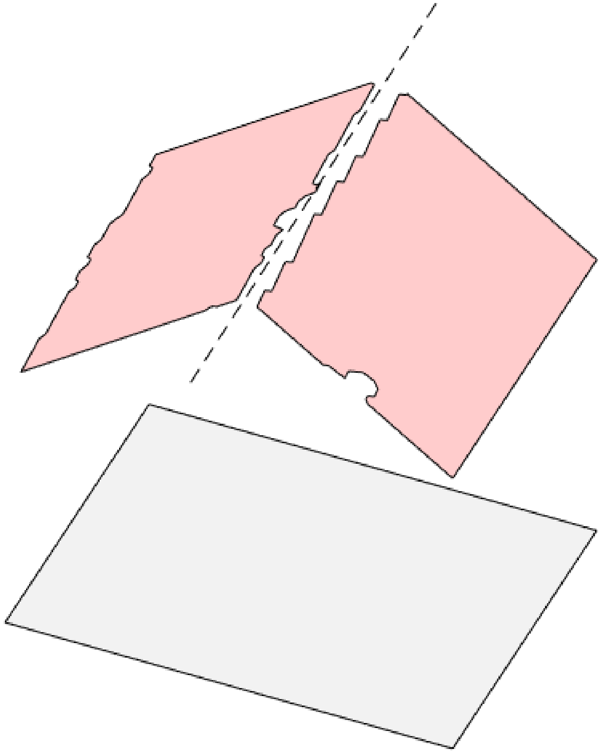


Future work: Process building blocks

- Improve results when roofs within block are similar
- Not possible for blocks with varying roof shapes



Future work: Intersect segments



Thank you for your attention