Extraction of 3D building models from airborne laser scanning data

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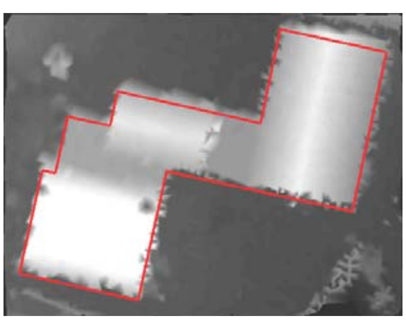
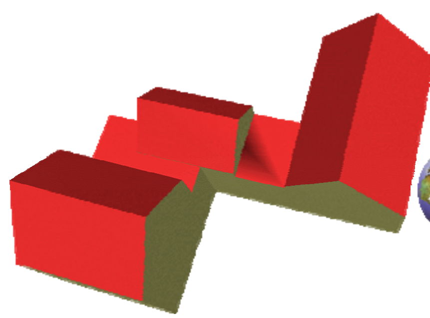
Building model reconstruction





Model, data and map driven approaches

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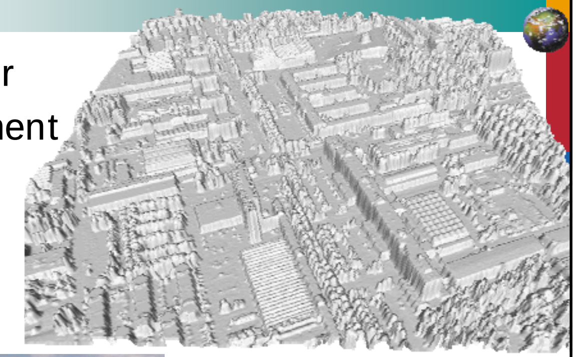
3D city modelling

Modelling required for

- accuracy improvement
- data reduction



Christo’s
wrapped
Reichstag

Building reconstruction from laser data

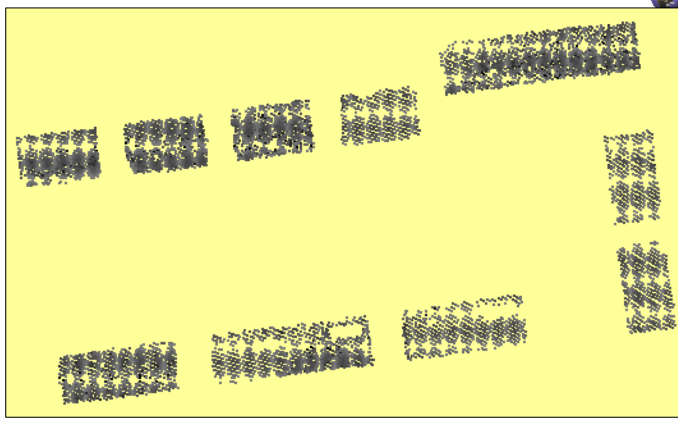
- Reliable 3D coordinates
- High point density required
- Assumptions on building shapes needed
- Usage of building ground plans

Case studies

- Model based approach using moments
- Data driven approach
- Map guided reconstruction
  - Data driven
  - Model driven

Model based approach using invariant moments

Invariance of
- shift
- scale
- rotation

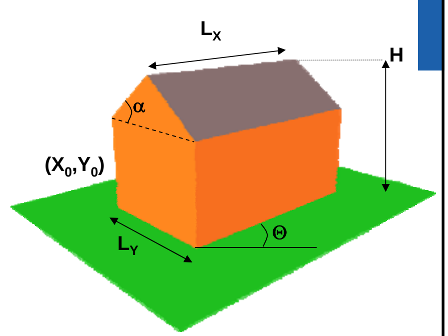


Irregularly distributed point data

$$M_{ij} = \sum_{P=P_1}^{P_n} X_P{}^i \cdot Y_P{}^j \cdot H_P$$

Building reconstruction using moments

- 7 building parameters for gable roof
- 1st and 2nd order invariant moments as a function of building parameters
- solve equation system (express building parameters as function of moments)



Building reconstruction using moments

- segmented point cloud $(X,Y,H)_l$
- binarized moments m_{ij} (with H = 1) for ground plan, position and orientation
- height-weighted moments M_{ij} for roof model model

Position: $X_0 = \frac{m_{10}}{m_{00}}, \; Y_0 = \frac{m_{01}}{m_{00}}$

Shift invariance: $\overline{M}_{ij} = \sum_{P=P_1}^{P_n} (X_P - \overline{X})^i \cdot (Y_P - \overline{Y})^j \cdot H_P$

Orientation: $\Theta = \frac{1}{2} \cdot \arctan \frac{2\overline{m}_{11}}{\overline{m}_{20} - \overline{m}_{02}}$

Rotation invariance:

$$M'_{pq} = \sum_{r=0}^{p} \sum_{s=0}^{q} (-1)^{q-s} \cdot \binom{p}{r} \cdot \binom{q}{s} \cdot \Psi \cdot \widetilde{M}_{(p+q-r-s)(r+s)}$$

with $\Psi = (\cos \Theta)^{p-r+s} \cdot (\sin \Theta)^{q+r-s}$

Length: $L_X = \sqrt{\frac{12 \cdot m'_{20}}{m'_{00}}}$

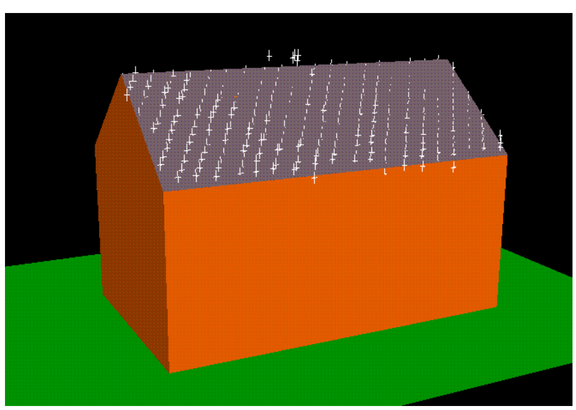
Width: $L_Y = \sqrt{\frac{12 \cdot m'_{02}}{m'_{00}}}$

Roof inclination: $\alpha = \arctan(8 \cdot \frac{M'_{00} \cdot (\frac{M'_{20} / M'_{02}}{m'_{20} / m'_{02}} - 1)}{\frac{M'_{20} / M'_{02}}{m'_{20} / m'_{02}} \cdot L_Y})$

Height: $H = M'_{00} + \frac{L_Y}{2} \cdot \tan \alpha$

Data-driven model refinement

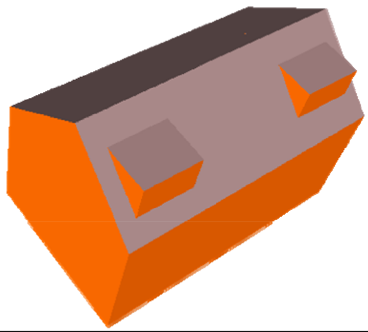
- Detection of regions with outliers
- Generation of refining hypotheses



Modelling of dorms - example

Potential:

- minimum of 8-10 points per dorm needed
- dorms must be smaller than ~40% of roof surface



Point density

Simulations with reduced point densities

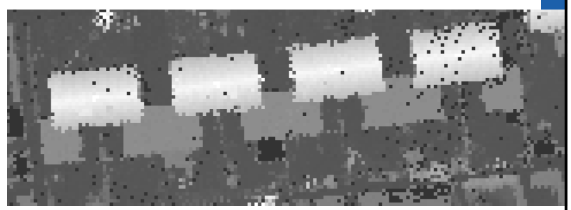
RMS derivations to parameters from high density

pts/m²	centroid		Θ	length	width	height	slope
2.6	0.03	0.01	0.2	0.09	0.03	0.03	0.3
1.3	0.10	0.06	0.4	0.19	0.08	0.04	0.5
0.65	0.23	0.14	1.0	0.28	0.16	0.07	1.5
0.33	0.40	0.20	1.9	0.57	0.20	0.19	3.2
0.17	0.95	0.39	2.9	0.85	0.50	0.41	6.9
0.08	1.32	0.61	6.0	1.13	0.68	0.73	12.1

Data driven approach

Assumptions:

- Roof described by planar faces
- Height jump edges parallel or perpendicular to main building orientation

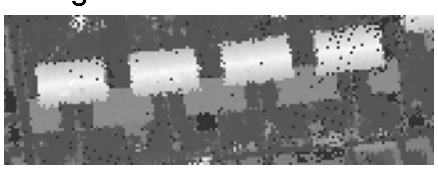


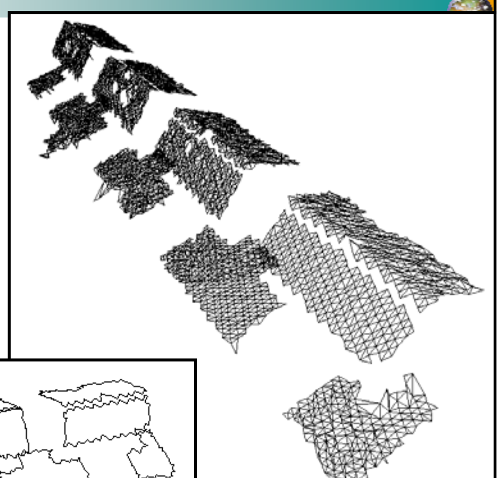
Steps:

- Plane detection
- Initial face outlining in TIN
- Reconstruction of building outline
- Reconstruction of roof face edges

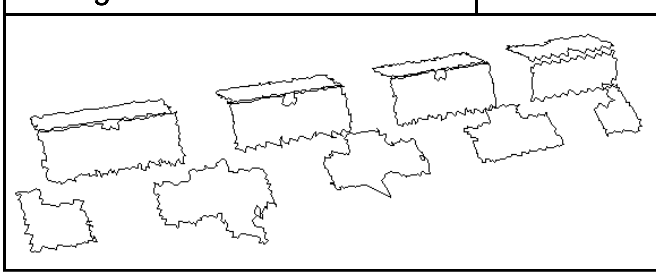
Initial roof faces

Height data





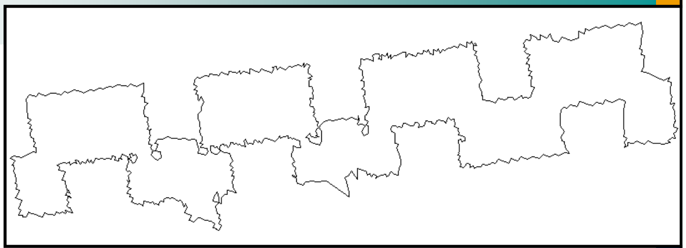
Rough face outlines



Connected components

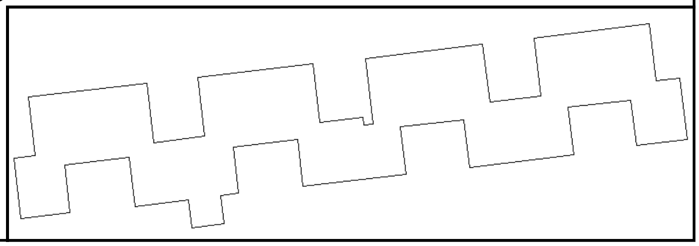
Reconstruction of roof outline

Union of faces



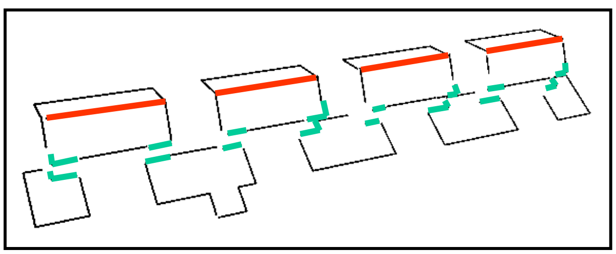
Approximation by straight lines

- main building direction
- minimum edge size
- most points inside building



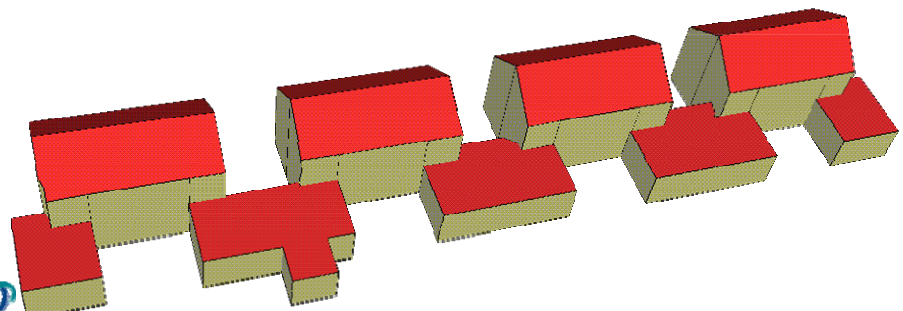
Reconstruction of face edges

- Ridges and valleys
  Intersection of planes of adjacent roof faces
- Roof outline
  Intersection of planes with adjacent walls
- Height jumps inside roof surface
  Straight lines aligned to main building directions



Reconstruction of 3D building

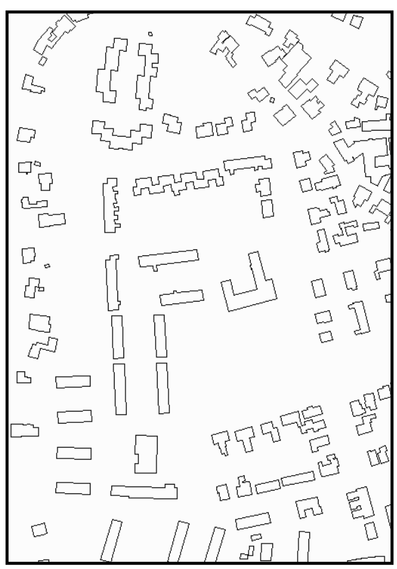
- Merging edges to faces
  - Joining parallel edges
  - Intersection of other edges
- Extraction of terrain height



Using ground plans

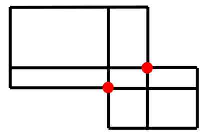
Benefits:

- Easy building location problem
  - Map and data inaccuracy
  - Roof extensions
- Constraints on roof plane orientations
- Indication of building composition

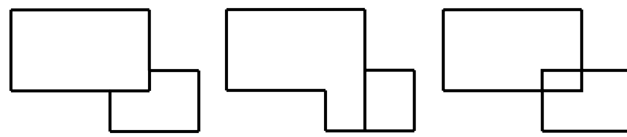


Decomposition of ground plans

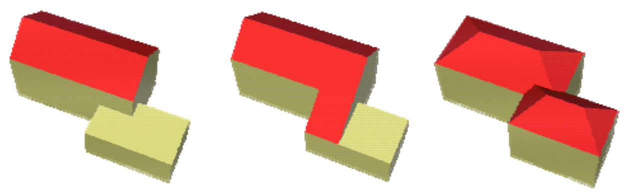
Ground plan



Decompositions

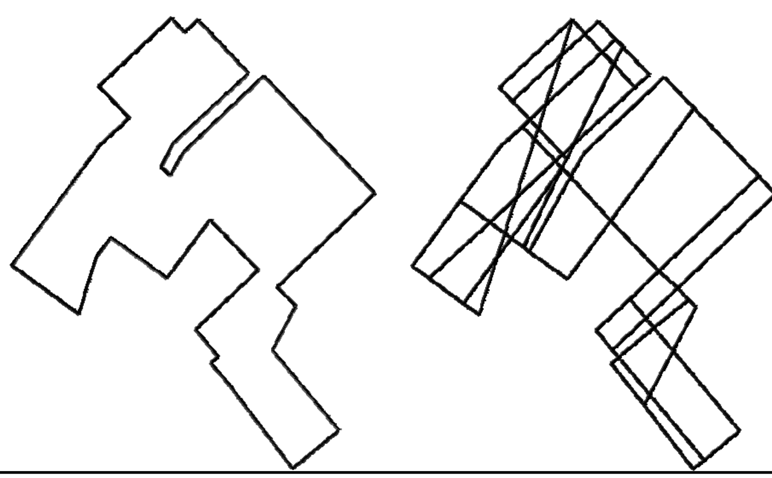


Building primitives on partitions



Decompositions of ground plans (II)

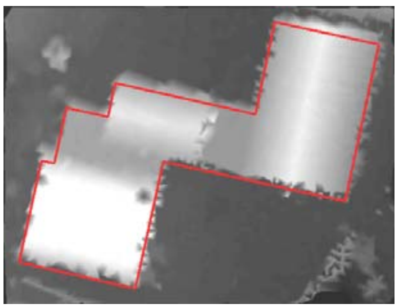
Extending edge segments at concave corners

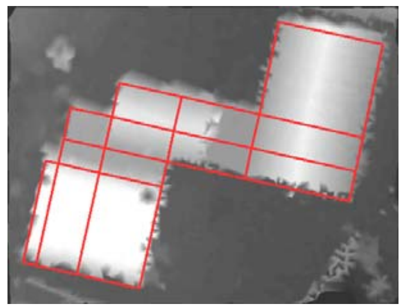


Combining maps with laser data

Processing steps:

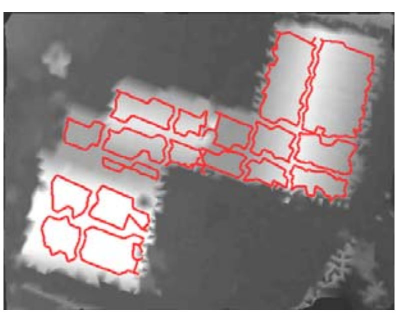
- Detection of planar faces
- Ground plan refinement
- Roof face reconstruction
- Initial 3D model
- Model refinement

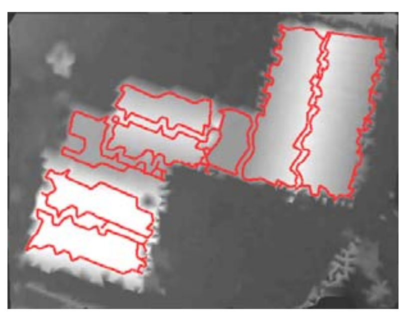




Detection of planar faces (II)

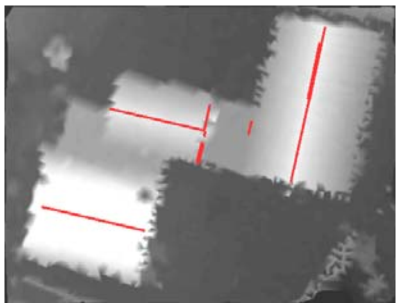
- 3D Hough transform in each ground plan segment
- Growing and merging of initial planar faces

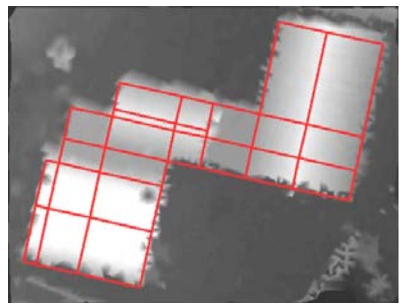




Refinement of ground plan segmentation

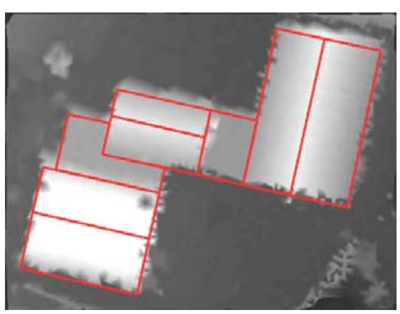
- One plane per segment
- Detection of intersection lines
- Detection of height jump lines
  - Constrained to segment orientation
  - Not near segment edge

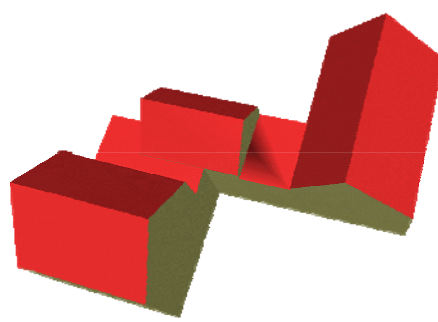




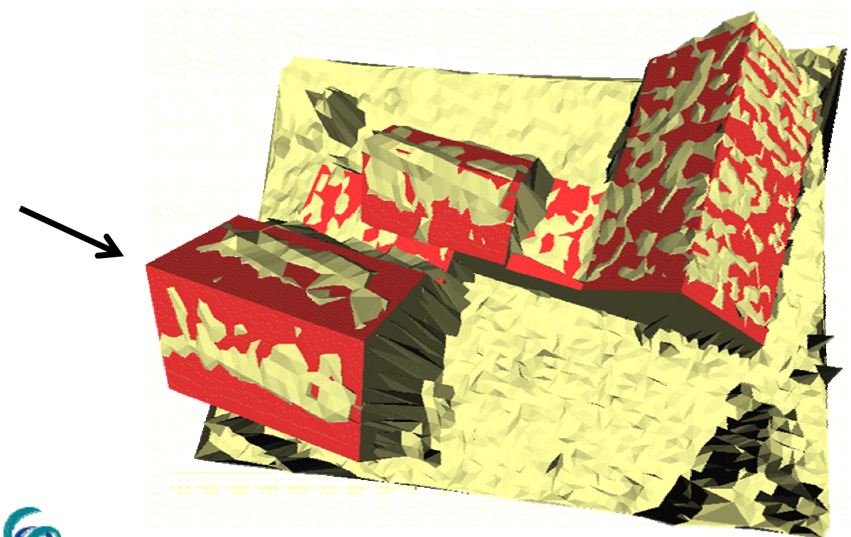
Reconstruction of roof face outlines

- Best fitting plane per segment
- Merging of segments of same plane

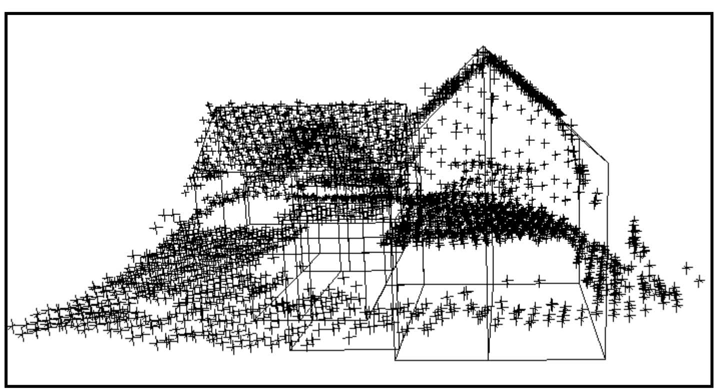




Difference to TIN



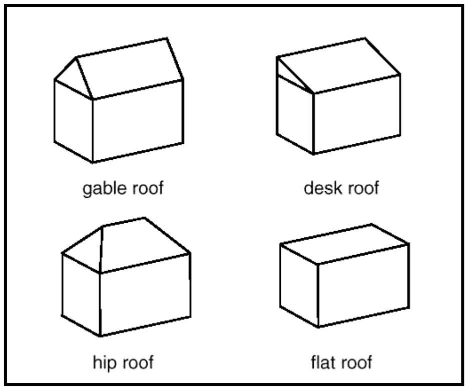
Point cloud view



Steep roof parts near edge with few points

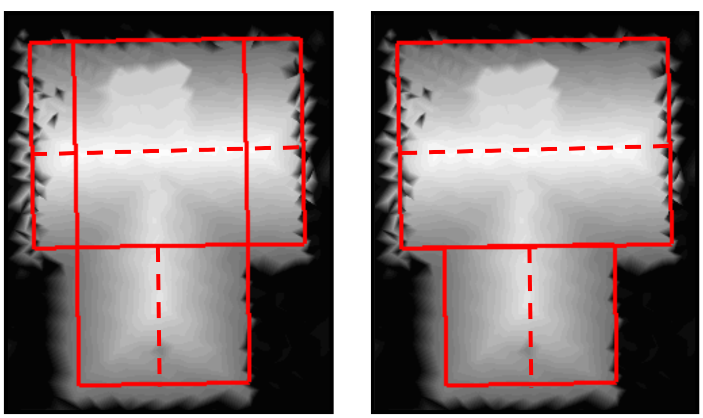
Model library

Best model per segment (flat, slanted, gable)



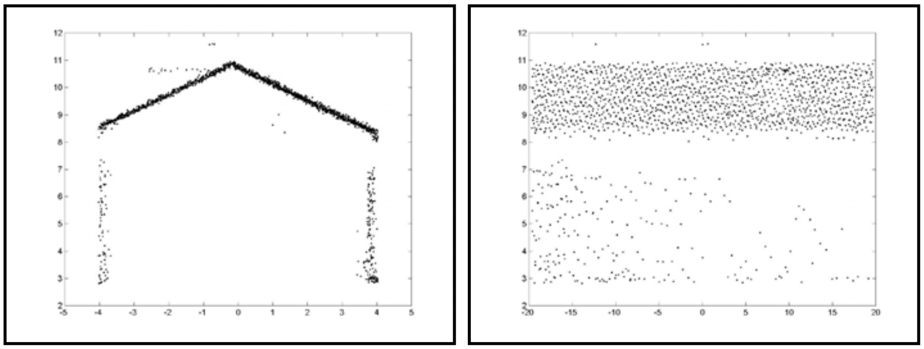
Initial 3D model

Merge similar models in adjacent segments



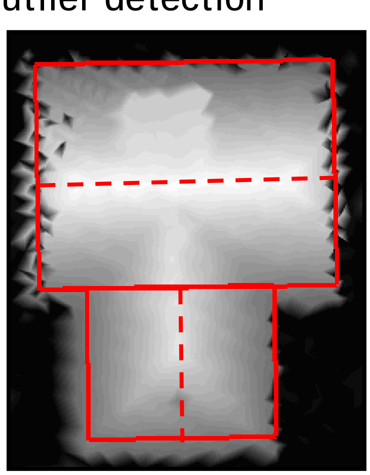
Reduction of Hough transform to 2D

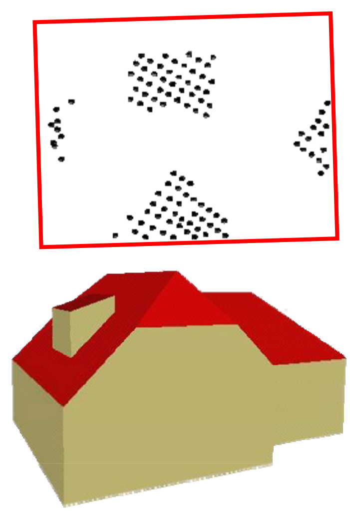
Point clouds projected onto walls



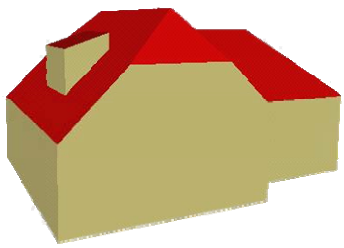
Refinement of 3D model

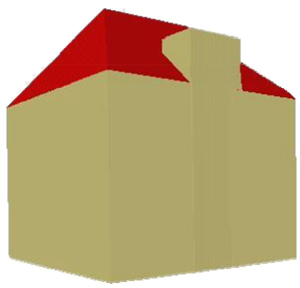
Outlier detection

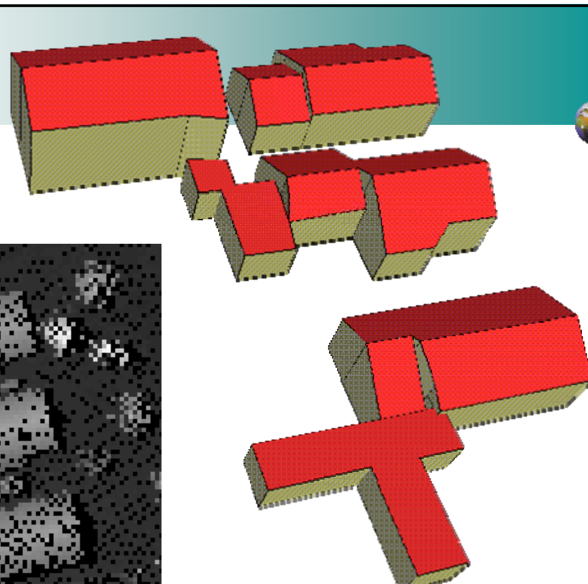


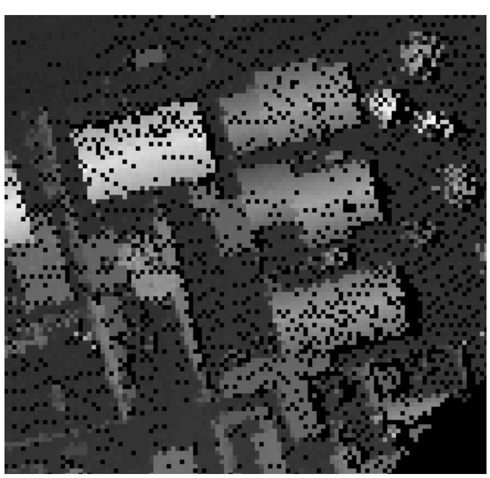


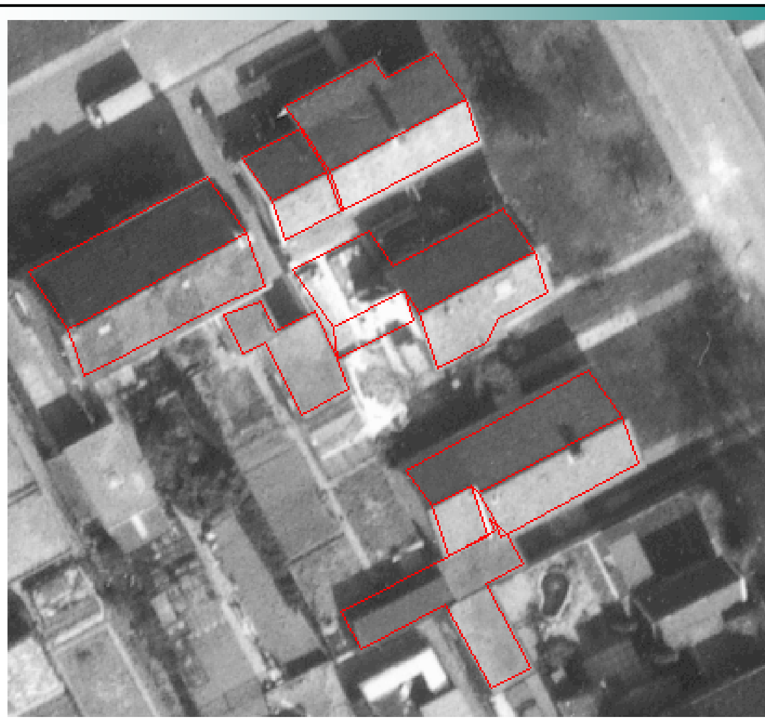
Comparison to photographs



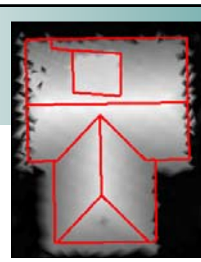


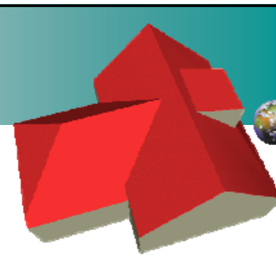


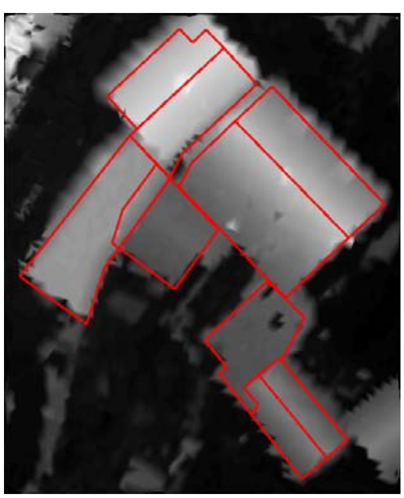


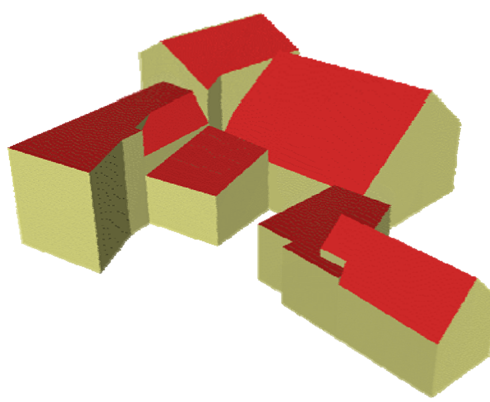


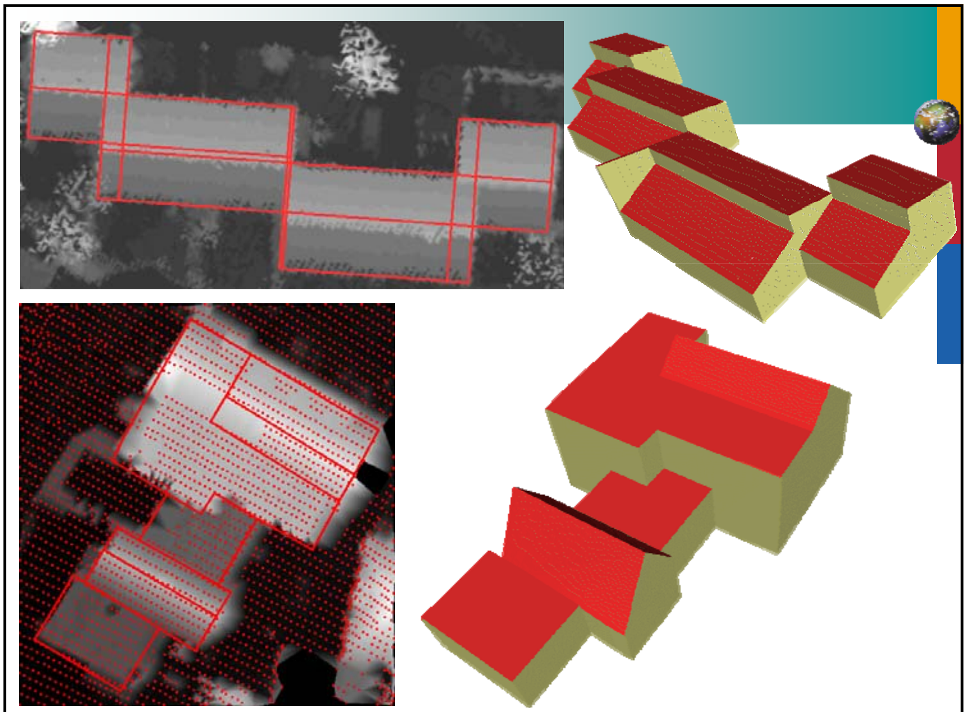
Some more results







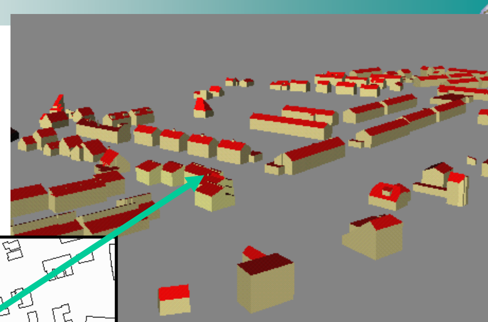


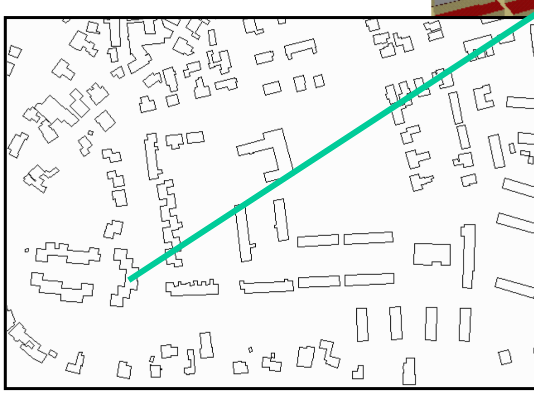


Overall results

Out of 106 buildings

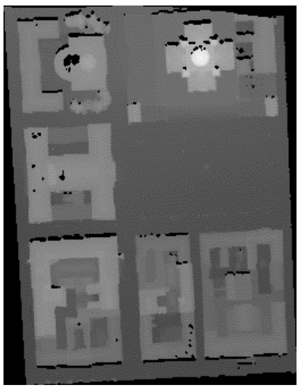
- 12 not suitable
- 11 failed
- 83 reconstructed

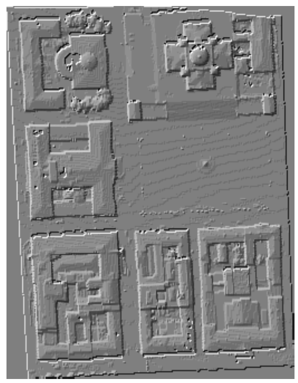




EuroSDR test on building extraction

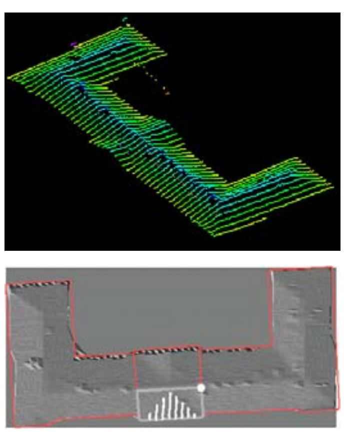
Comparison of different building extraction techniques using laser scanner data and/or aerial photographs and maps.

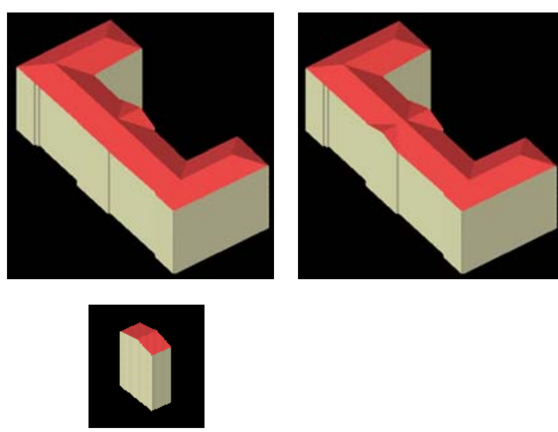




Semi-automatic building reconstruction

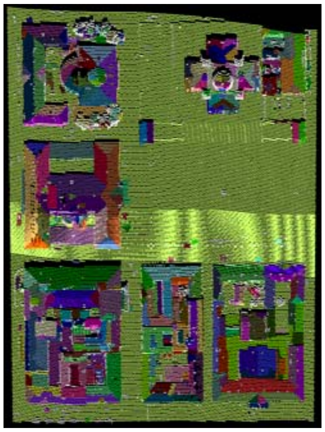
- Automatic reconstruction
- Interactive correction and extension of models

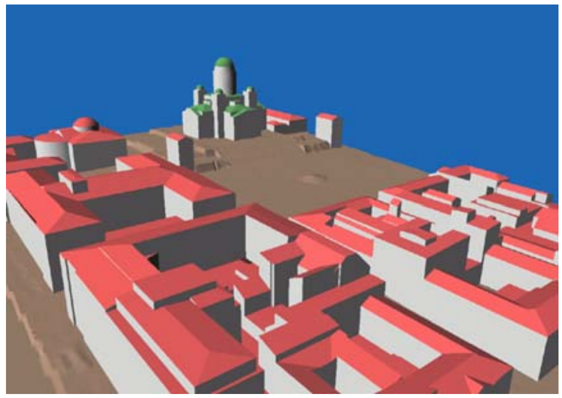




Semi-automatic terrain reconstruction

- Automatic extraction of smooth surfaces
- Interactive selection of terrain patches





Data integration

- Building ground plans
- Laser data
- Terrestrial imagery
- Aerial colour infrared image
- Computer graphics

Conclusions

- Map provides useful information on building composition.
- Planar faces are detected reliably in laser data.
- Data driven refinement of segmentation needed → high point density required, depending on application.
- Errors in reconstruction from laser data usually related to the number of points in a segment
  - small segment of ground plan
  - bad reflection properties (water on roof, slate roofs)

Outlook

- Sensor characteristics are still improving.
- Laser scanning data and photographs have complementary characteristics.
- Modelling tools for combined measurement processes in laser scanning data and imagery are to be developed.