UNIVERSITY OF TWENTE.

NATIONWIDE POINT CLOUDS AND 3D GEO-INFORMATION: CREATION AND MAINTENANCE

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ITC

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

OVERVIEW

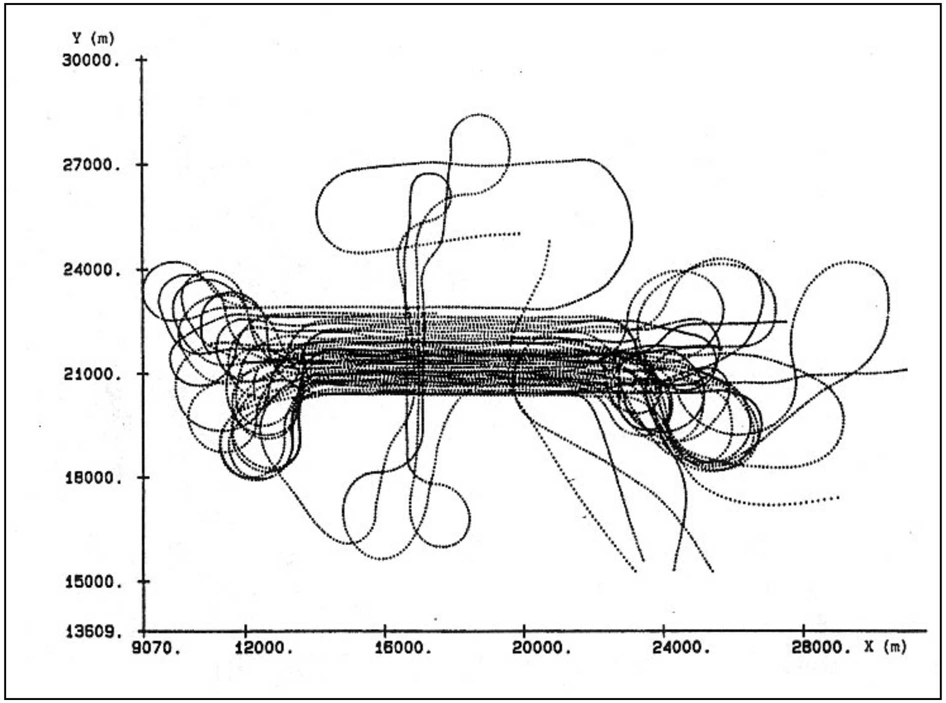
- National point clouds
  - Airborne laser scanning in the Netherlands
  - Quality control
  - Developments in lidar technology
  - Dense matching
  - Maintenance
- National 3D geo-information
  - LOD1
  - LOD2

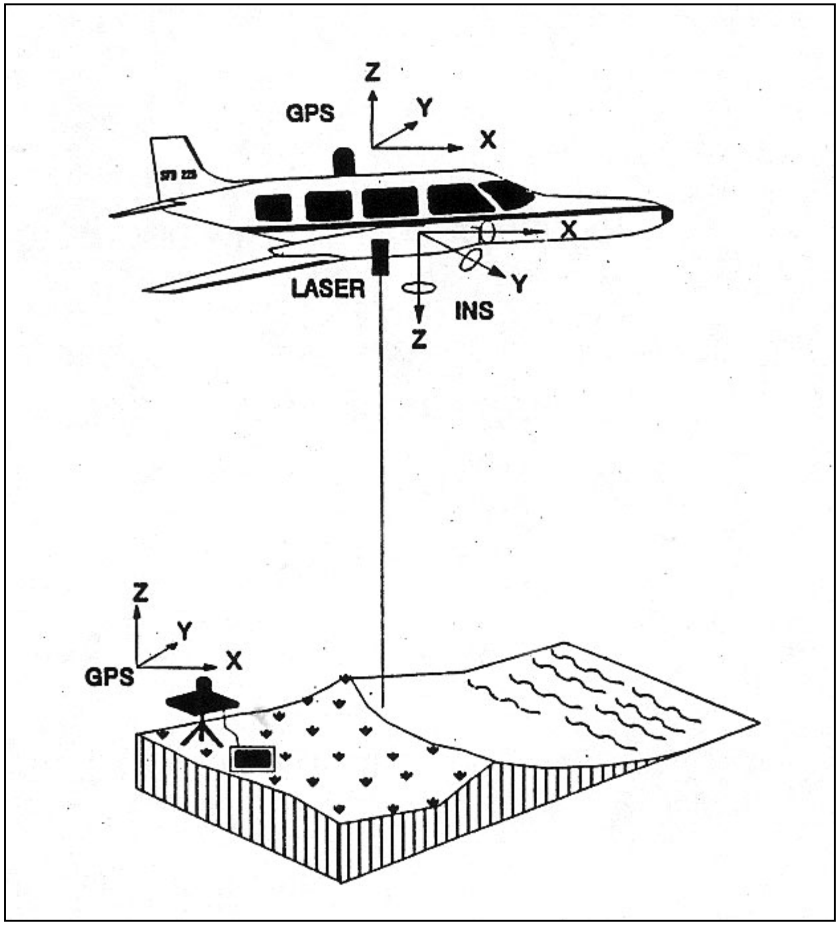
LASER PROFILING

first flights in Europe in 1988

inhomogeneous point density

expensive flights





SPECIFICATIONS OF THE DUTCH NATIONAL ELEVATION MODEL AHN

- AHN-1 (1997-2003)
  - 1 point / 16 m^2
  - 15 cm noise
  - 10 cm systematic error
  - 2.5 billion points

- AHN-2 (2007-2012)
  - 8-10 points / m^2
  - 5 cm noise
  - 5 cm systematic error
  - 640 billion points

QUALITY CONTROL

- Data completeness
- Point density
- Height accuracy
- Planimetric accuracy
- Filtering quality

DATA COMPLETENESS

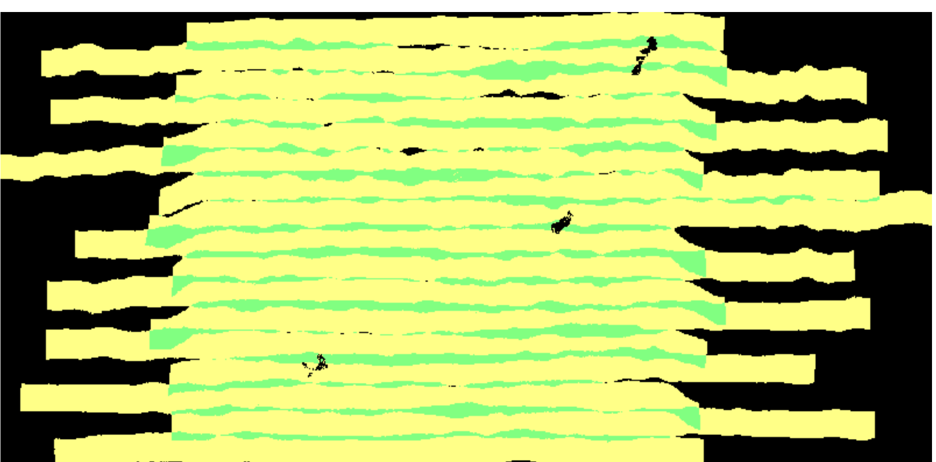
- Binning per strip
- Binary coverage image per strip
- Add strip images

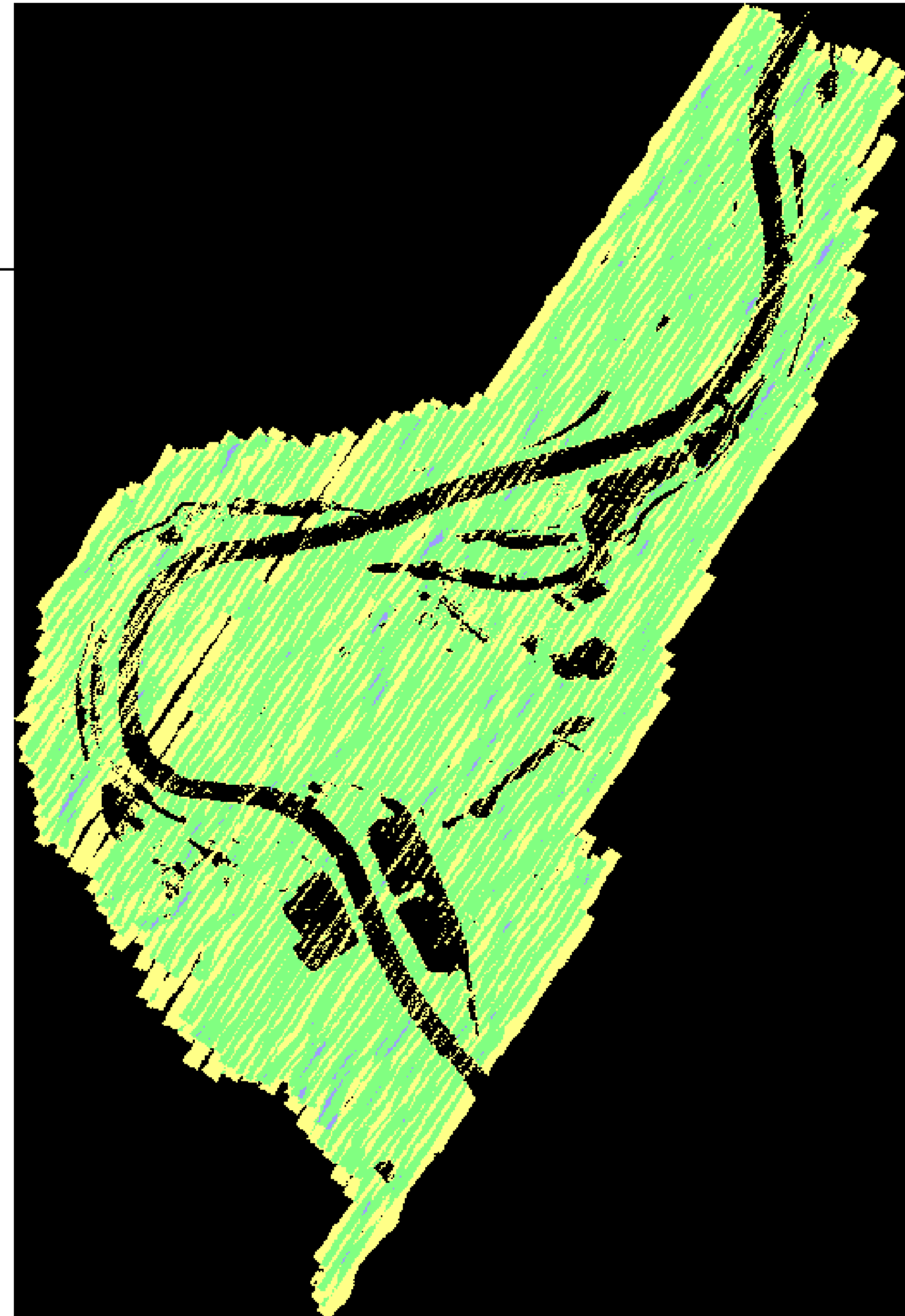
0

2

1

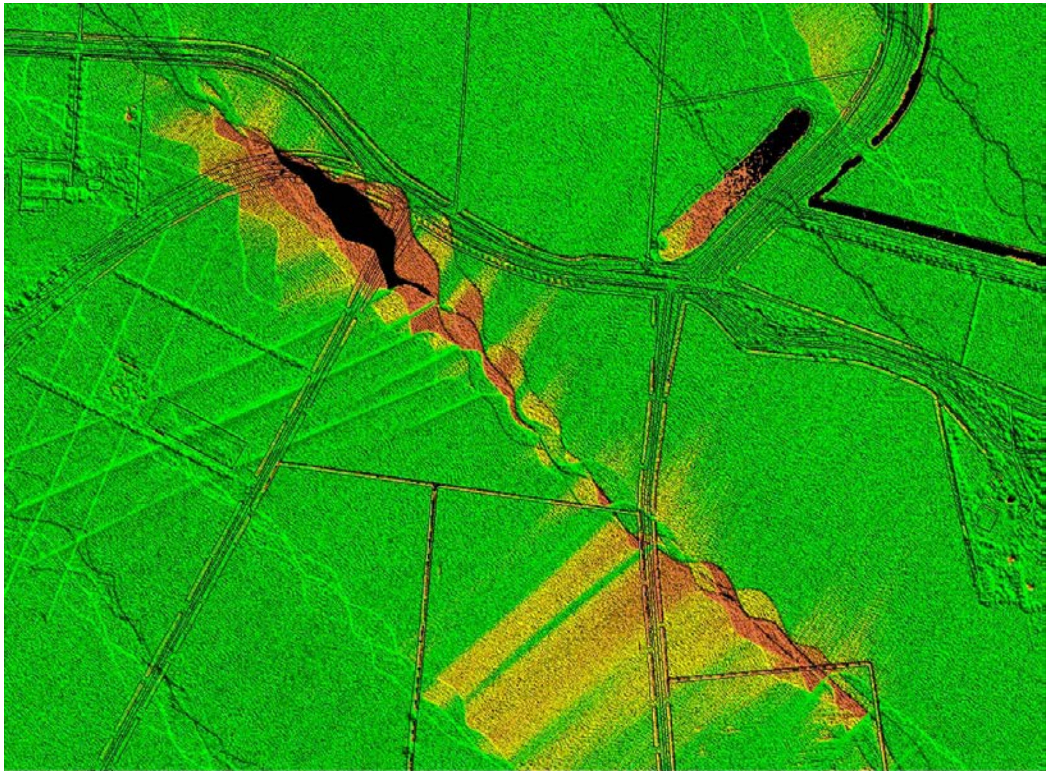
3





POINT DENSITY ANALYSIS

- Local variation in point density



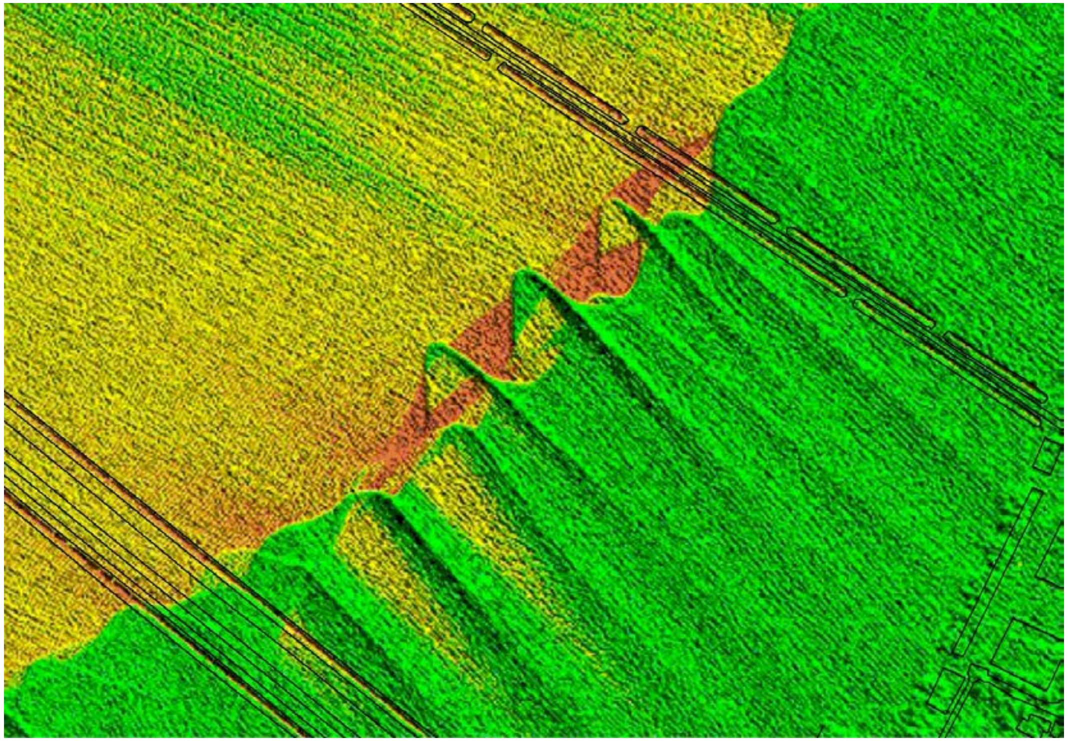
> 6 points/m^2

5-6 points/m^2

< 5 points/m^2

POINT DENSITY ANALYSIS

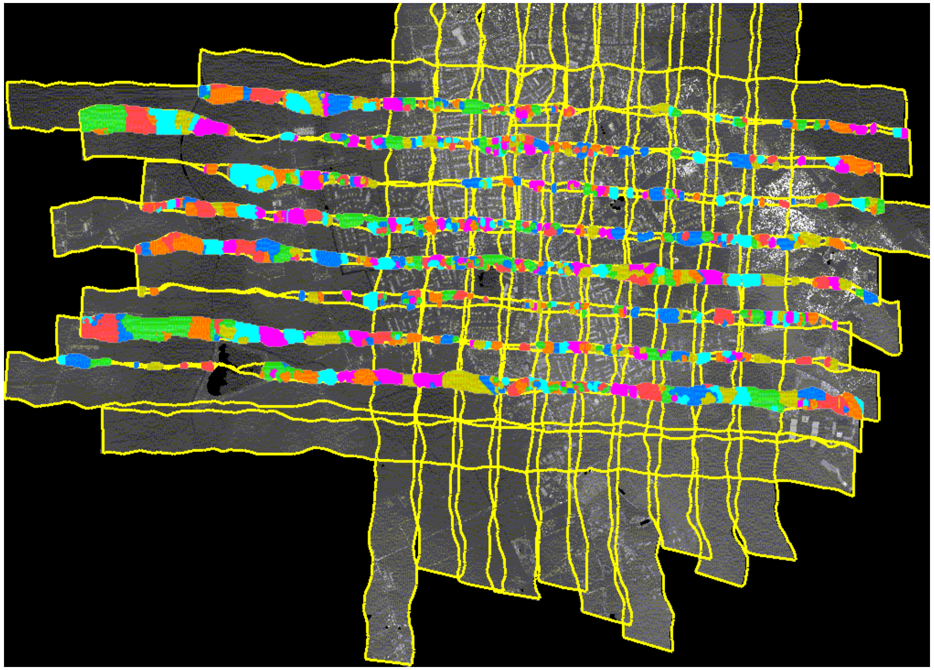
- Variation due to helicopter flight behaviour



- > 6 points/m^2
- 5-6 points/m^2
- < 5 points/m^2

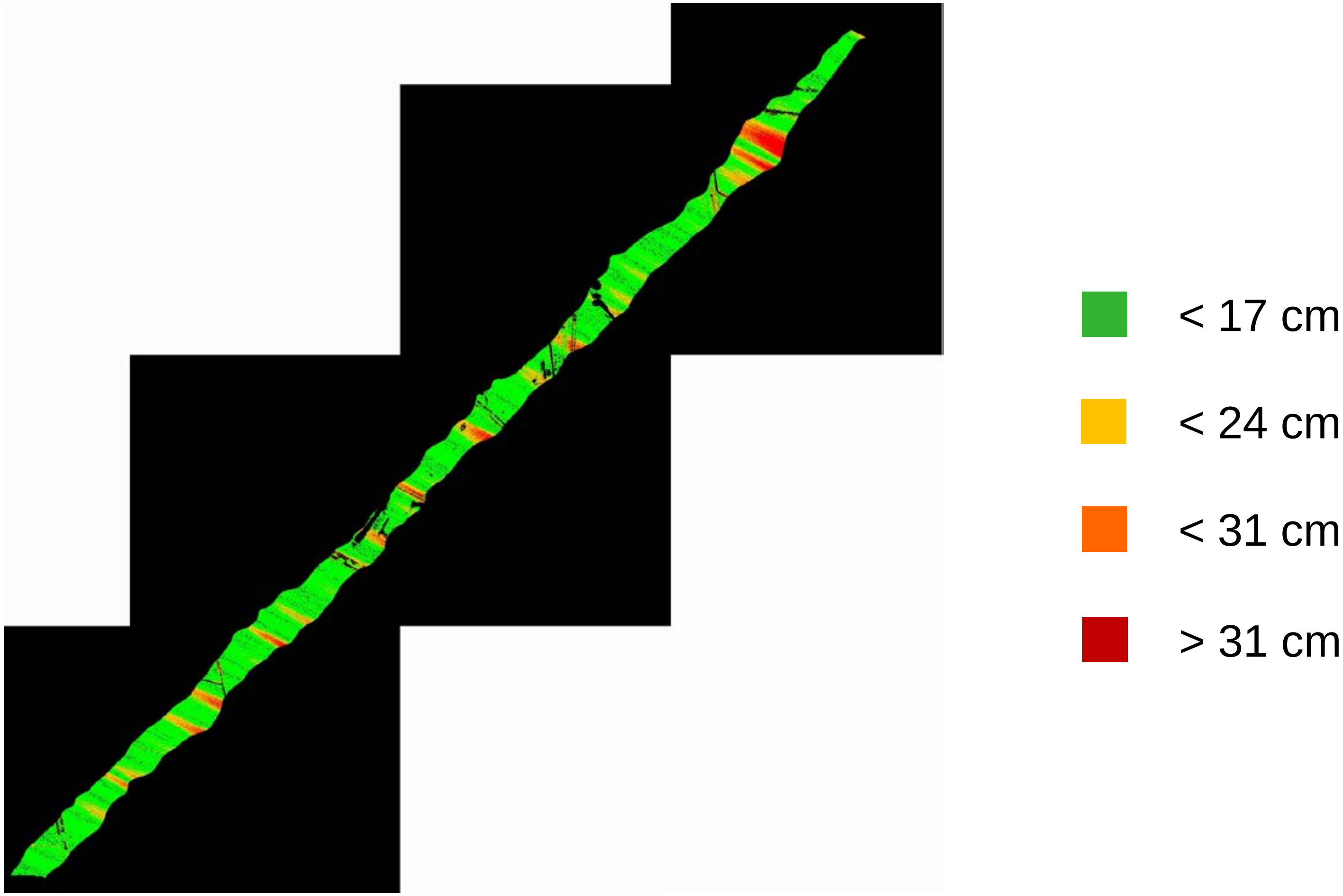
GEOMETRIC ACCURACY EVALUATION

- Relative accuracy
  - Comparisons in overlaps between strips
  - Abundant checks on smooth surfaces or edges

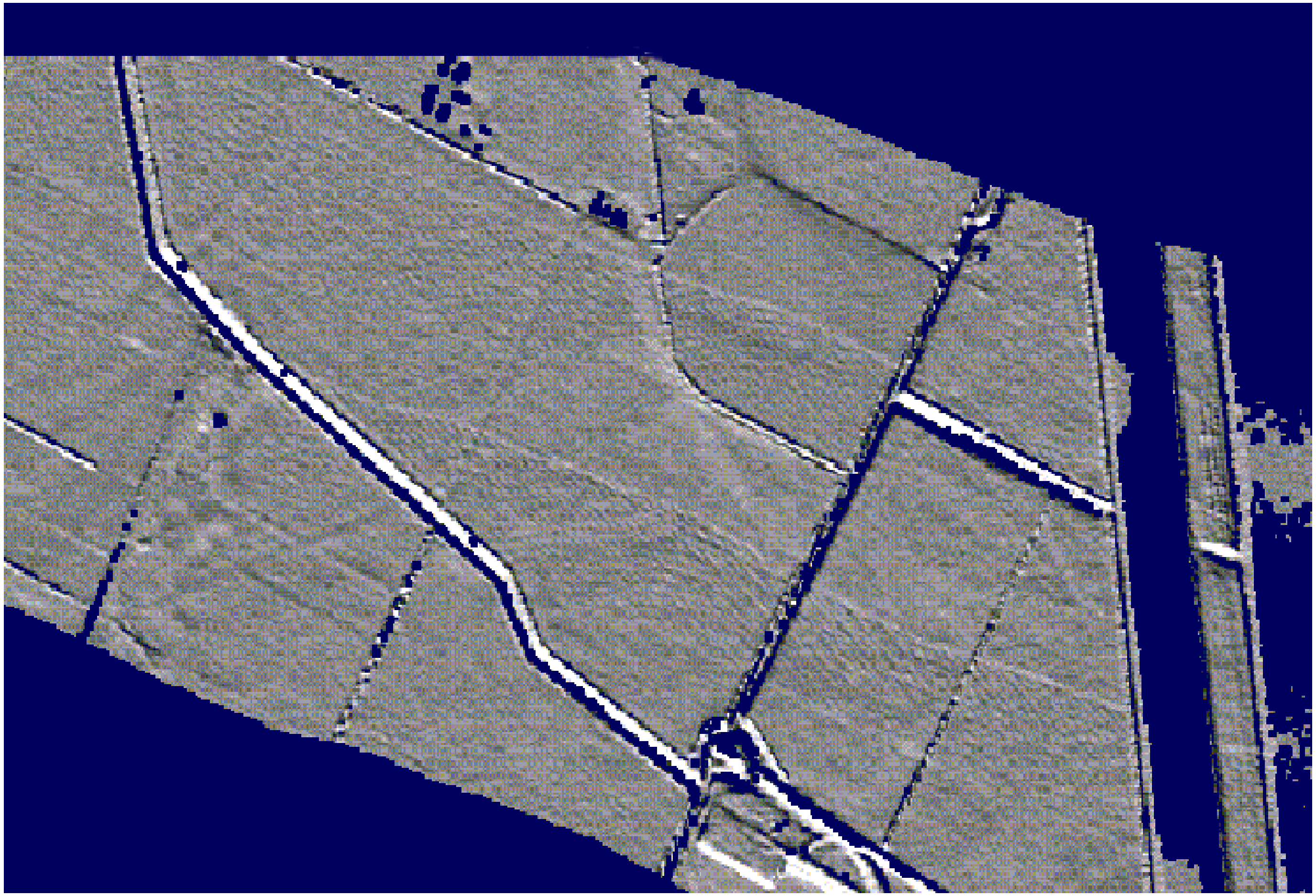


- Absolute accuracy
  - Needed to guarantee quality
  - Requires high quality reference data

COLOUR CODED HEIGHT DIFFERENCES

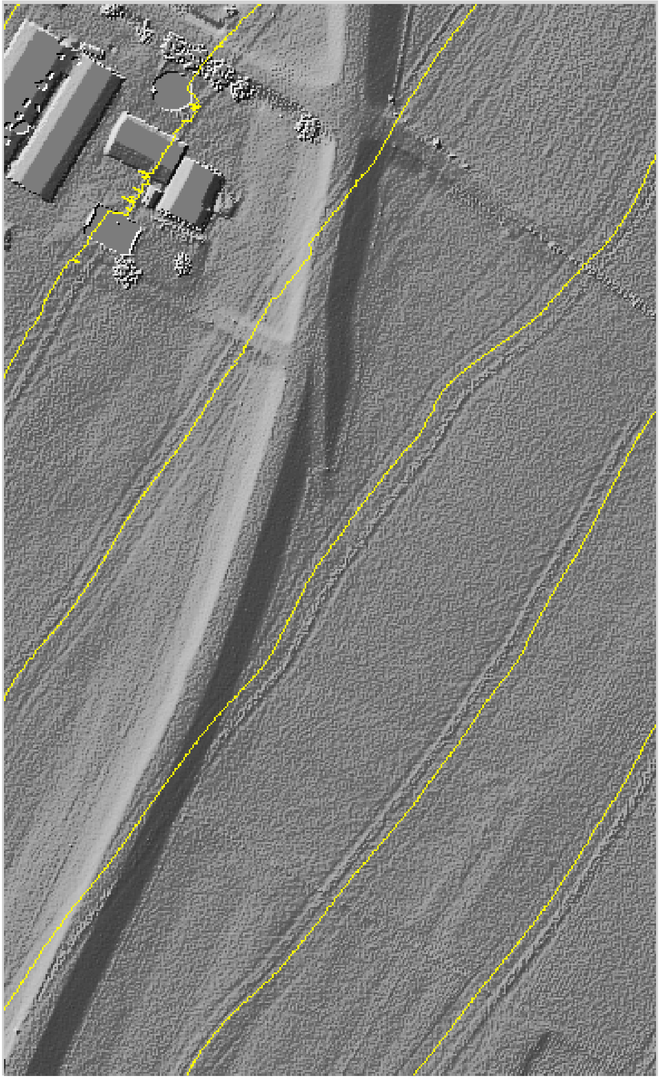


HEIGHT OFFSETS BETWEEN STRIPS



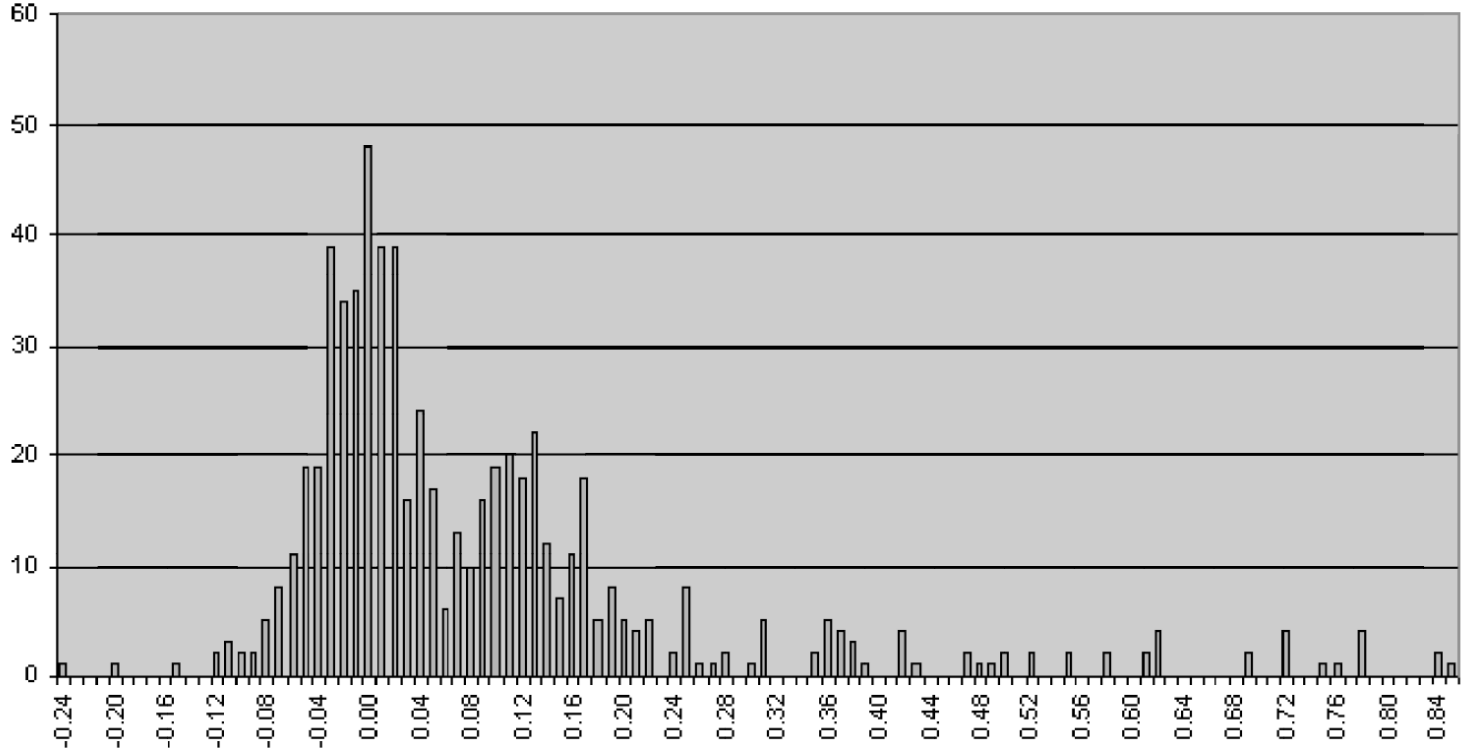
(Survey Department Rijkswaterstaat)

SCANNER ARTEFACTS



ABSOLUTE HEIGHT ERRORS

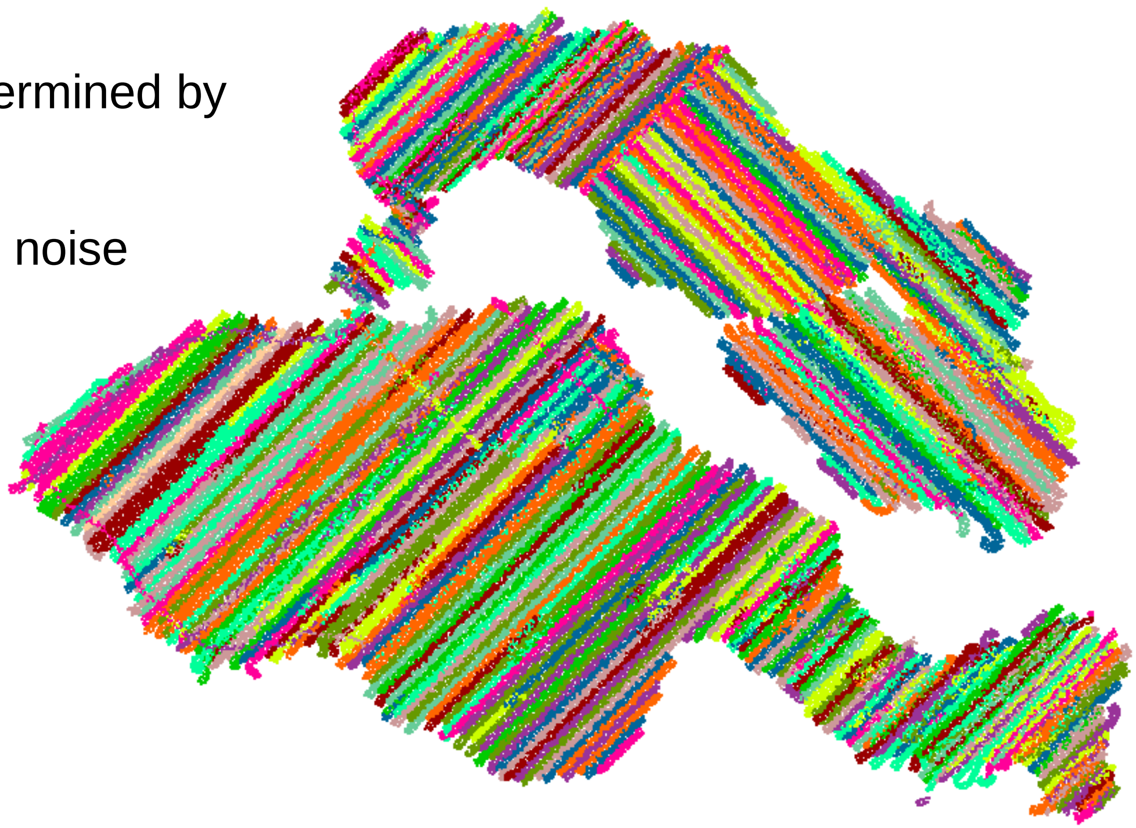
Comparison of point cloud heights against levelled manholes



ANALYSIS OF PLANIMETRIC ACCURACY

- Requirement: An object of 2x2 m can be outlined in the point cloud with a maximum error of 50 cm.

- Mapping accuracy determined by
  - Point spacing
  - Platform positioning noise
  - Systematic errors

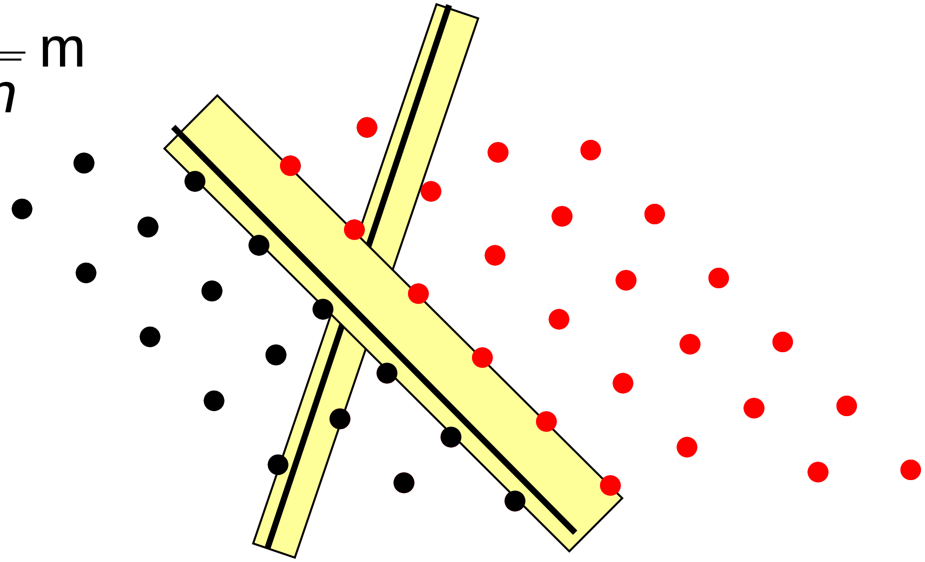


ANALYSIS OF PLANIMETRIC ACCURACY

- Companies are allowed to set the point density for their survey.
- Companies need to demonstrate that the chosen point density, point distribution and their positioning accuracy have been achieved and lead to the desired planimetric accuracy.

ANALYSIS OF PLANIMETRIC ACCURACY

- Outlining uncertainty in a perfect point cloud
  - Assumption: homogeneous point distribution
  - Point density: *n* points / m^2
  - Point spacing: $\frac{1}{\sqrt{n}}$ m
  - Maximum error: $\Delta pd = \frac{1}{2\sqrt{n}}$ m



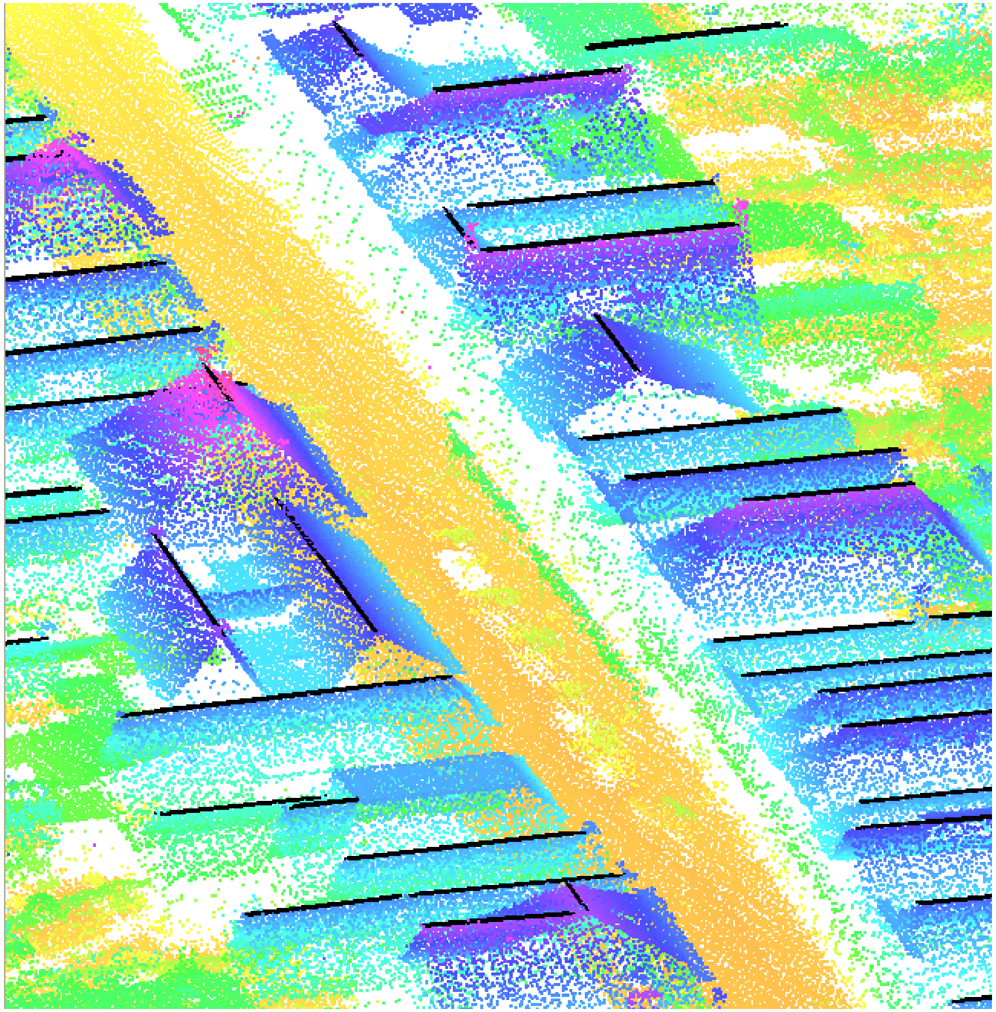
ANALYSIS OF PLANIMETRIC ACCURACY

- Maximum outlining error due to point spacing $\Delta pd = \frac{1}{2\sqrt{n}}$ m
- Systematic offset $\sqrt{\Delta x^2 + \Delta y^2}$
- Standard deviation, including noise and non-constant deformations σ_x
- Planimetric accuracy requirement

$$\Delta pd + \sqrt{\Delta x^2 + \Delta y^2} + 3\sigma_x \leq 50 \text{ cm}$$

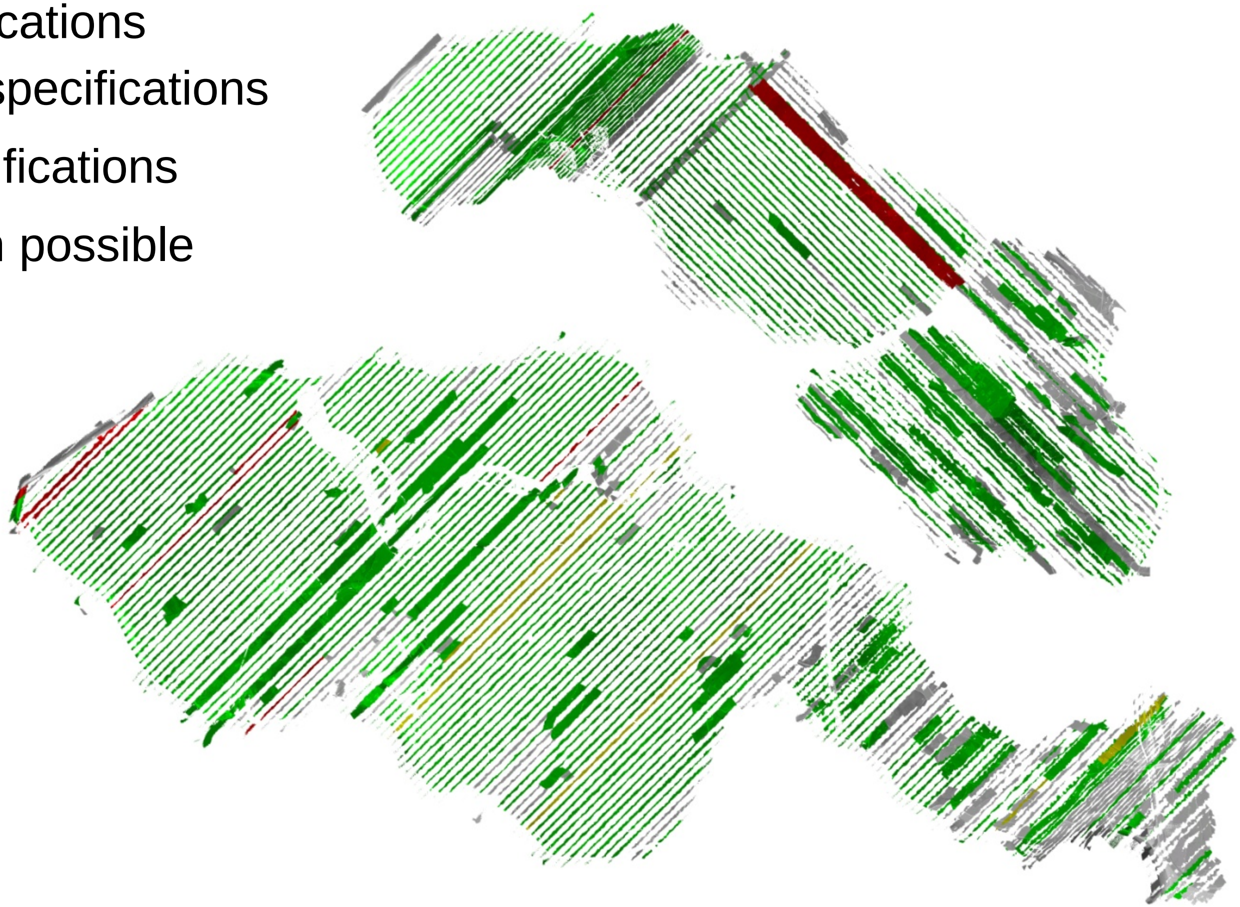
ANALYSIS OF PLANIMETRIC ACCURACY

- Relative check by measuring distances between ridge lines in strip overlaps

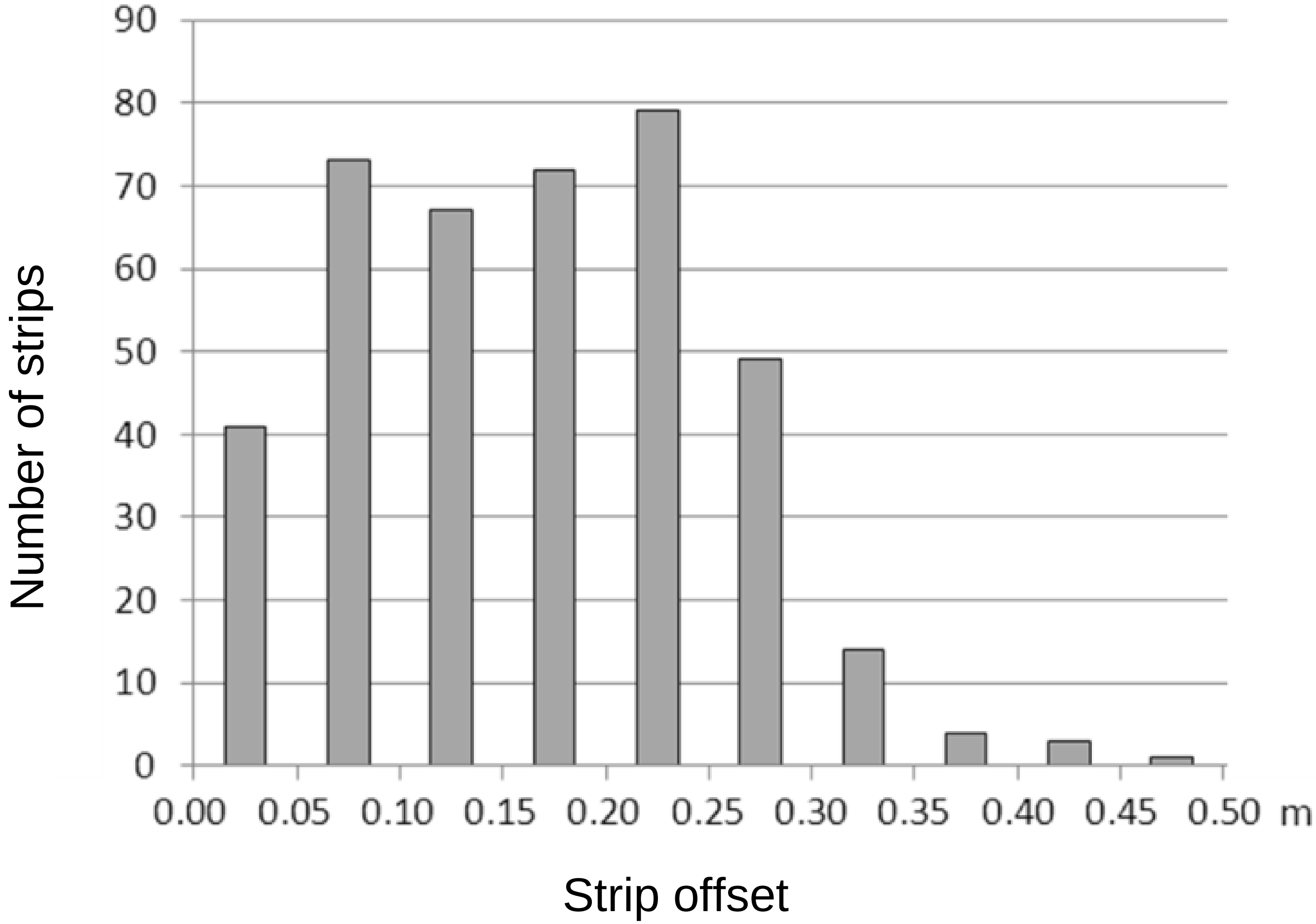


ANALYSIS OF PLANIMETRIC ACCURACY

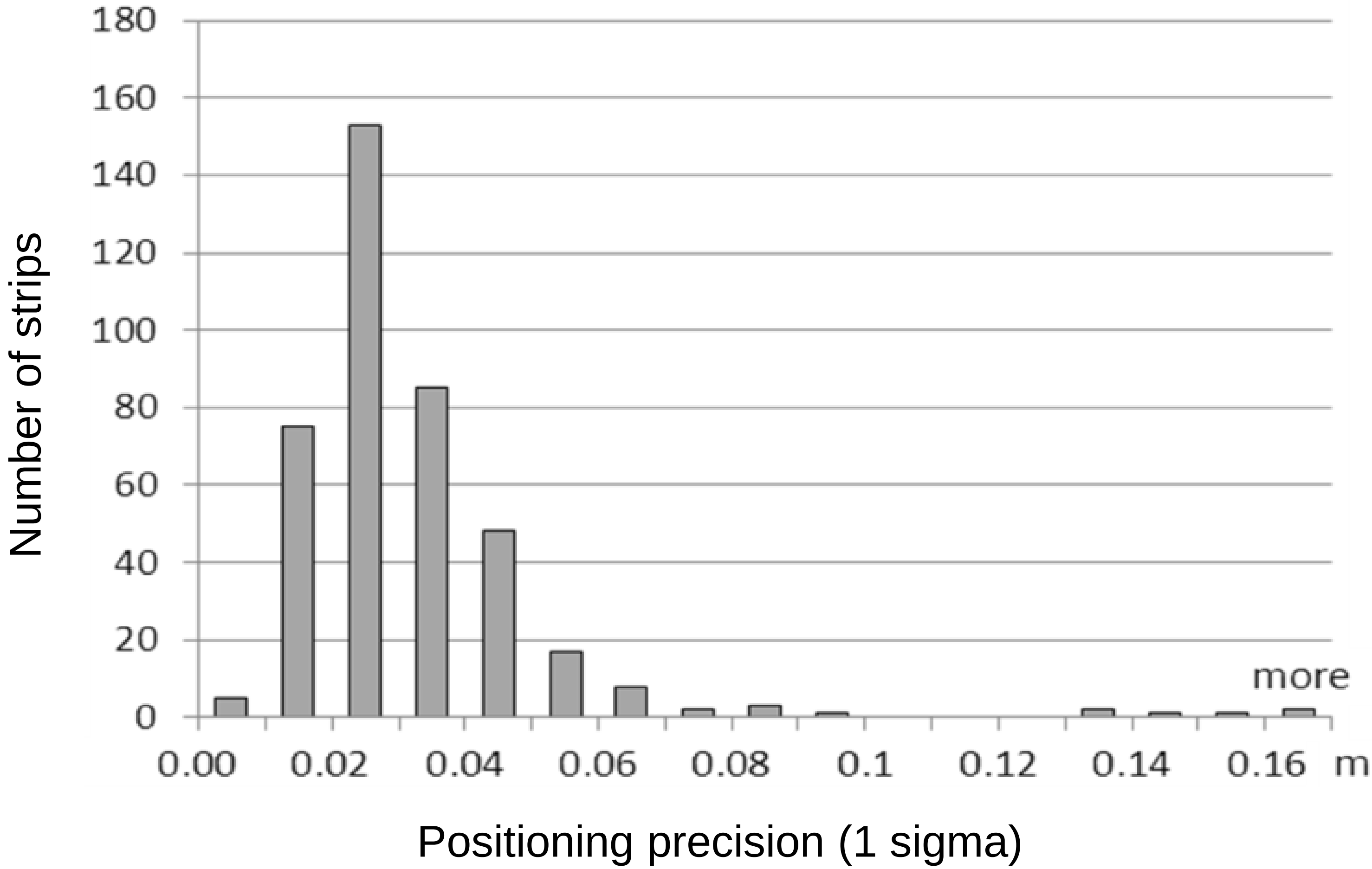
- Analysis per strip overlap based on > 20,000 ridge lines
  - Within specifications
  - Just outside specifications
  - Outside specifications
  - No evaluation possible



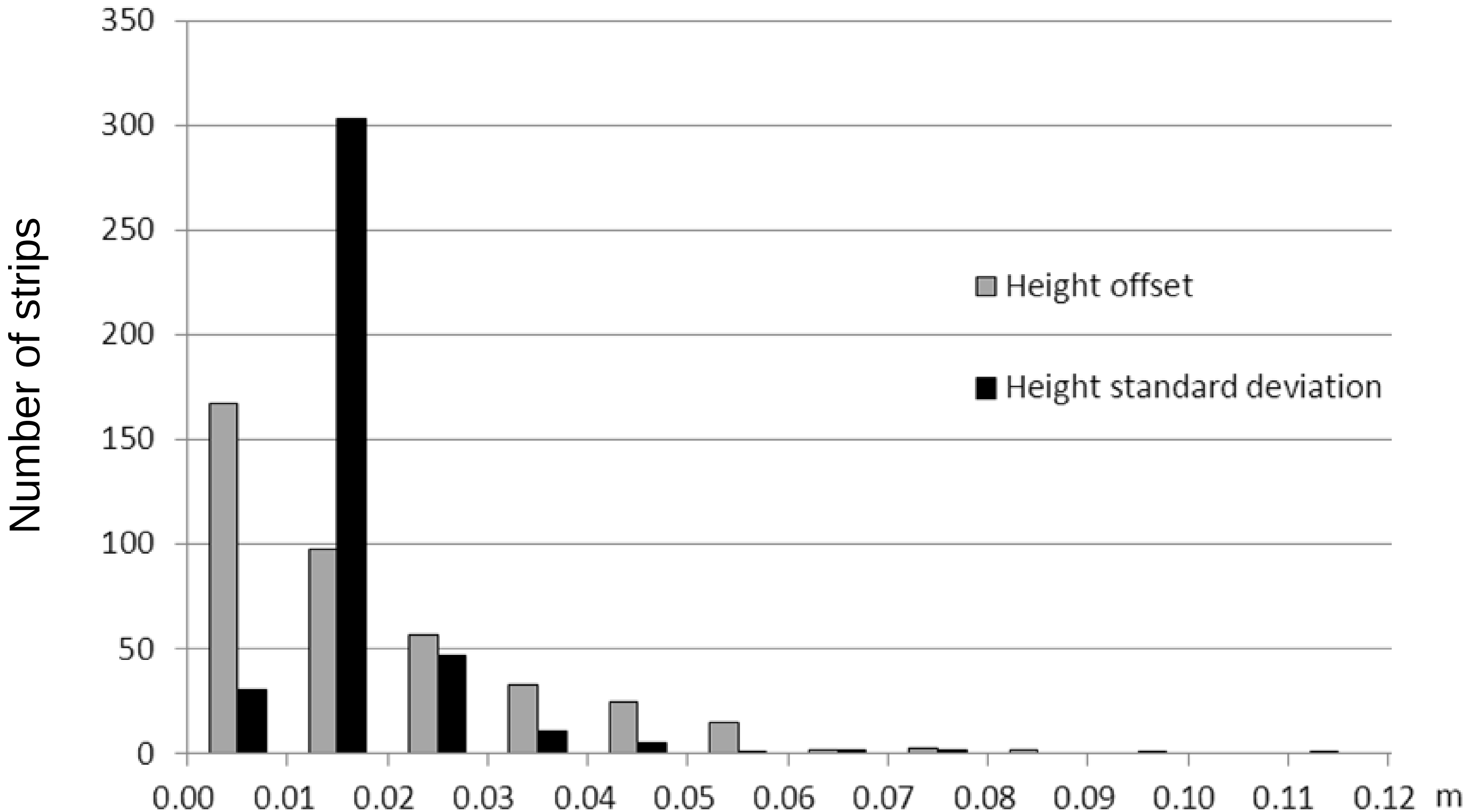
ESTIMATED PLANIMETRIC STRIP OFFSETS



ESTIMATED PLANIMETRIC POSITIONING NOISE

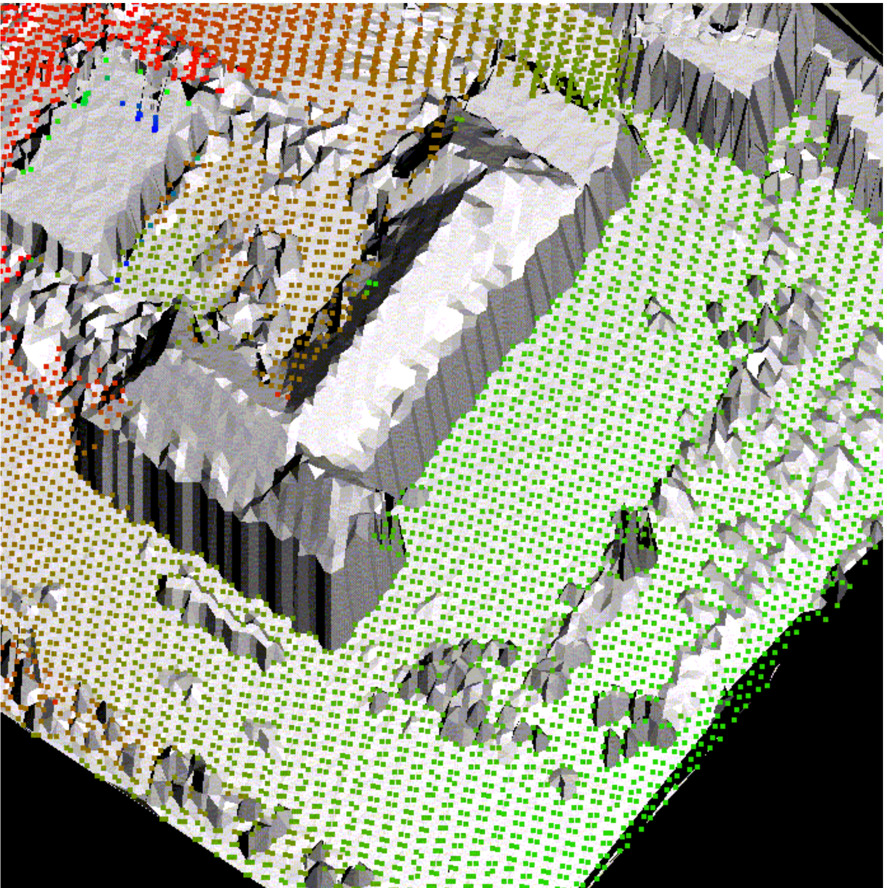


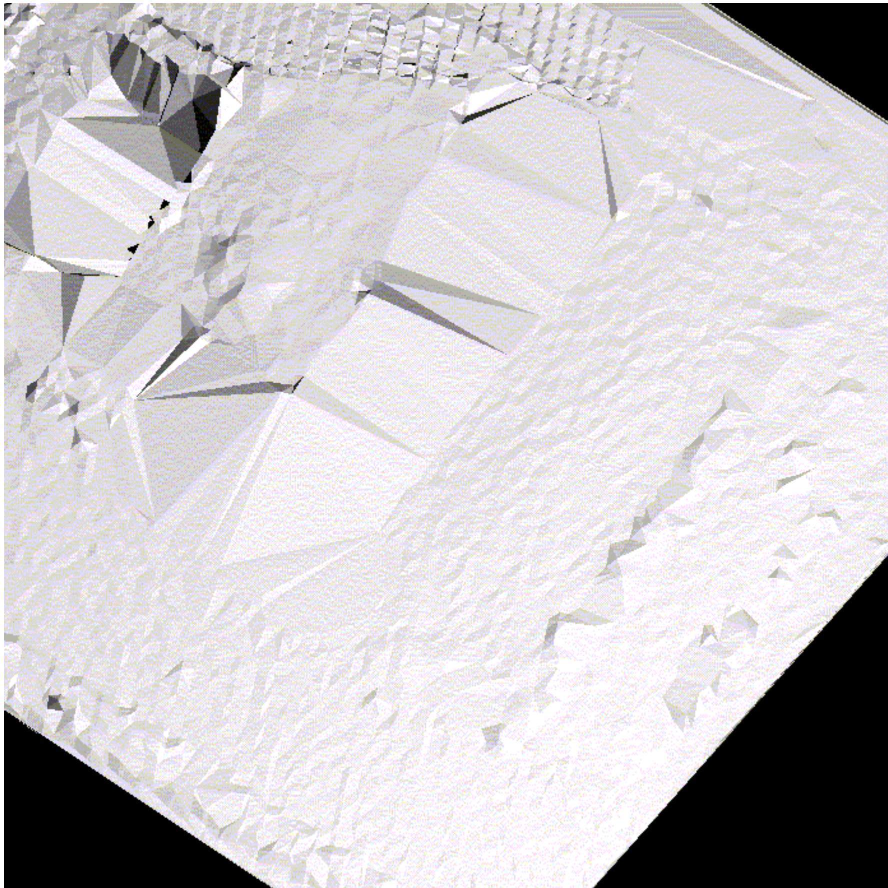
ESTIMATED HEIGHT ACCURACY



QUALITY OF FILTERING

Visual inspection





KEEPING YOUR NATIONAL POINT CLOUD UP TO DATE

- Currently: revision cycle of 5 year
- Expensive
- Not frequent enough
- Alternatives for traditional laser scanning?

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GEIGER MODE LIDAR

Harris Corporation

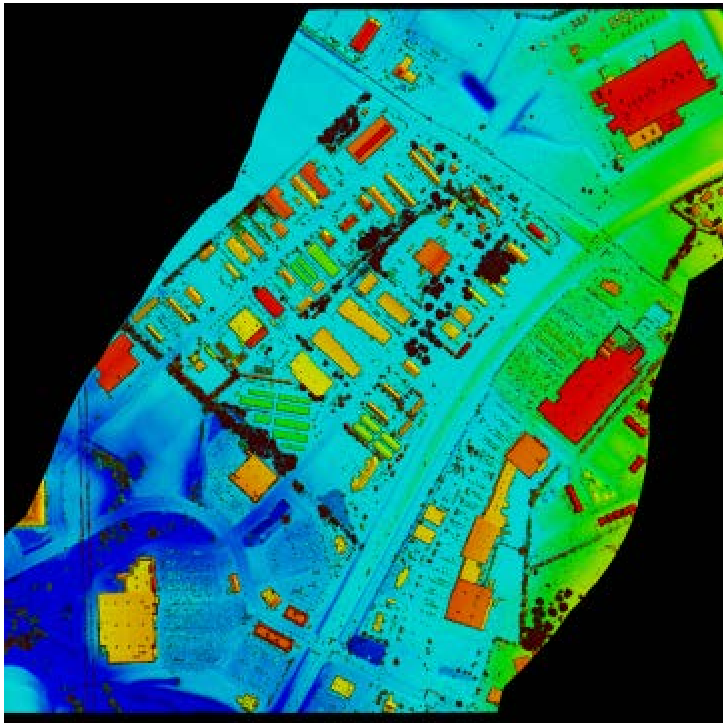
- Photo diode array with 4096 detectors
- 200 million points per second
- 8 points/m^2 at 9 km flight altitude
- > 1000 km^2 per hour
- Height accuracy evaluated by USGS
  - 15-17 cm non-vegetated (USGS requires 19.6 cm)
  - 26-92 cm vegetated (USGS requires 29.6 cm)

(Harris Corporation)

SINGLE PHOTON LIDAR

Sigma Space Corporation

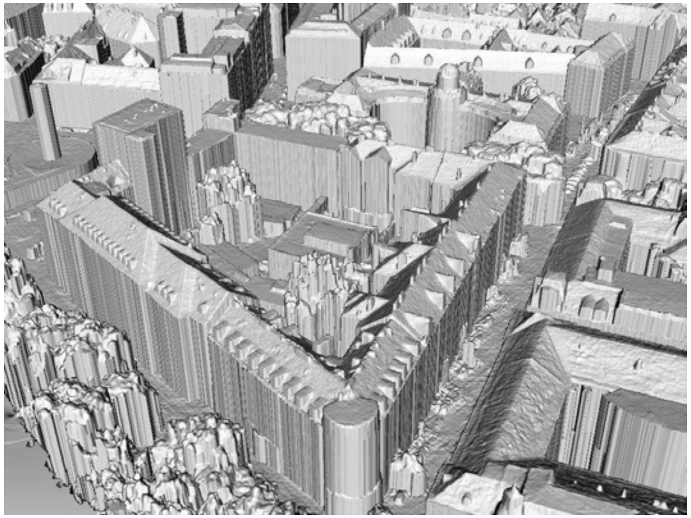
- Operation altitude 2 - 4.5 km
- 20 points/m^2 at 4 km flight altitude
- Specs:
  - Vertical accuracy 10 cm (1 sigma)
  - Horizontal accuracy 15 cm (1 sigma)
- Height accuracy evaluated by USGS
  - 14-17 cm non-vegetated (USGS requires 19.6 cm)
  - 17-41 cm vegetated (USGS requires 29.6 cm)
- Green lidar – water penetration



(Sigma Space)

DENSE MATCHING OF AERIAL IMAGERY

- Large advances in image matching

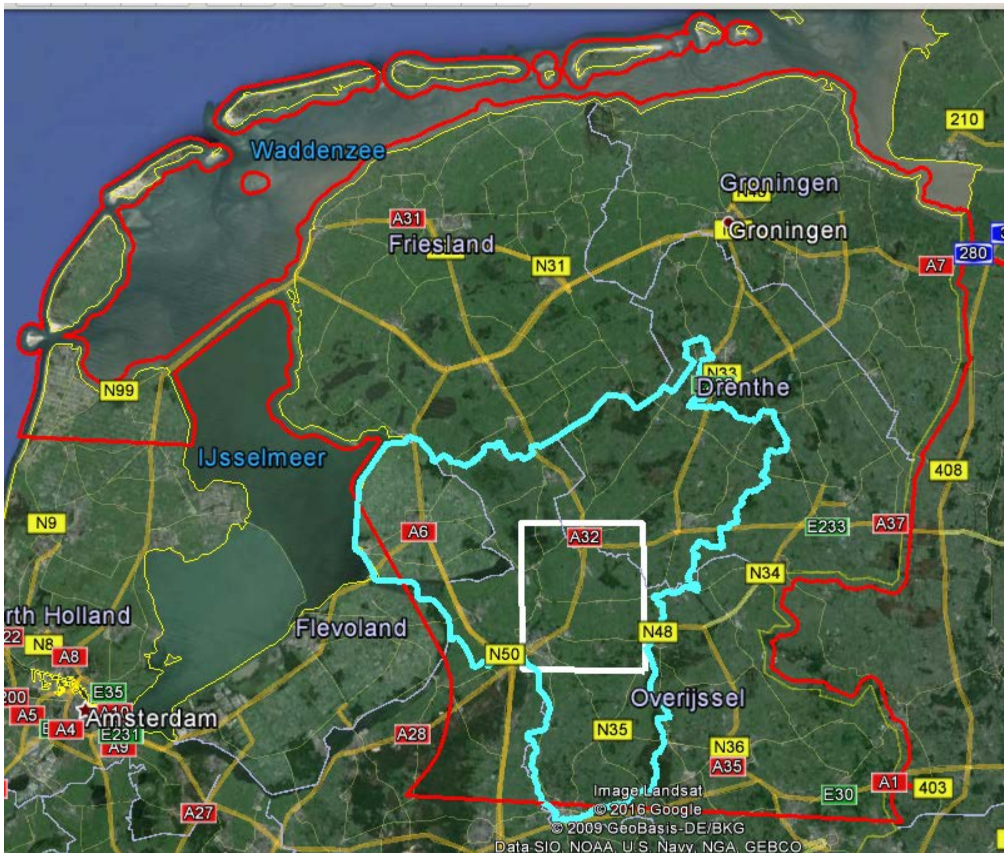


(Hirschmüller, 2007)

- Available in various commercial and open source implementations
- Better results with large image overlaps

DENSE MATCHING OF AERIAL IMAGERY

- Use annual aerial photographs for point cloud generation?
- Default 60% / 30% overlap insufficient
- Experiment with 80% / 30%
- Pixel size 10 cm
- Hard to get 5 cm height accuracy
- No penetration in vegetated areas



UPDATING STRATEGY

- Only update point cloud in areas with change
- Detect change with point clouds from Geiger or Single photon lidar or dense matching
- Assess new point cloud quality (depends on surface type)
- Update in case of change, but mark low quality updates
- Decide on linear lidar flights depending on amount of low quality updates

CONCLUSIONS ON POINT CLOUDS

- Airborne laser scanning can well meet high demands on point cloud accuracy (5 cm noise + 5 cm systematic error)
- Relative accuracy checking is very effective, but doesn't replace reference measurements
- New technologies increase efficiency in point cloud generation, but at a lower accuracy level

3D PILOT NL

Initiated in 2010 by

- Kadaster
- Dutch Geodetic Commission
- Geonovum
- Ministry of Infrastructure and the Environment

Goal: Stimulate applications of 3D geo-information by

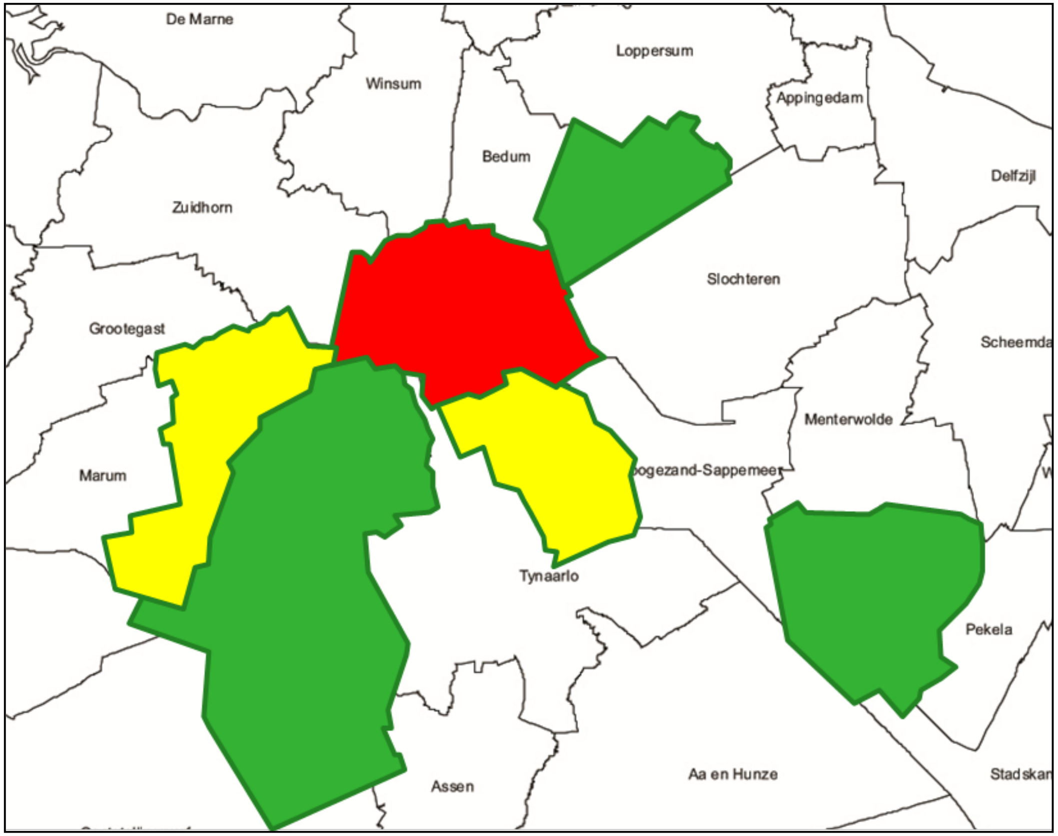
- Establishing a standard for 3D geo-information
- Cooperate on use cases with 3D data in a test area
- Exchange knowledge, technology and needs

3D PATCH WORK

- Various initiatives at city level
- Different LODs
- Different definitions of building outlines

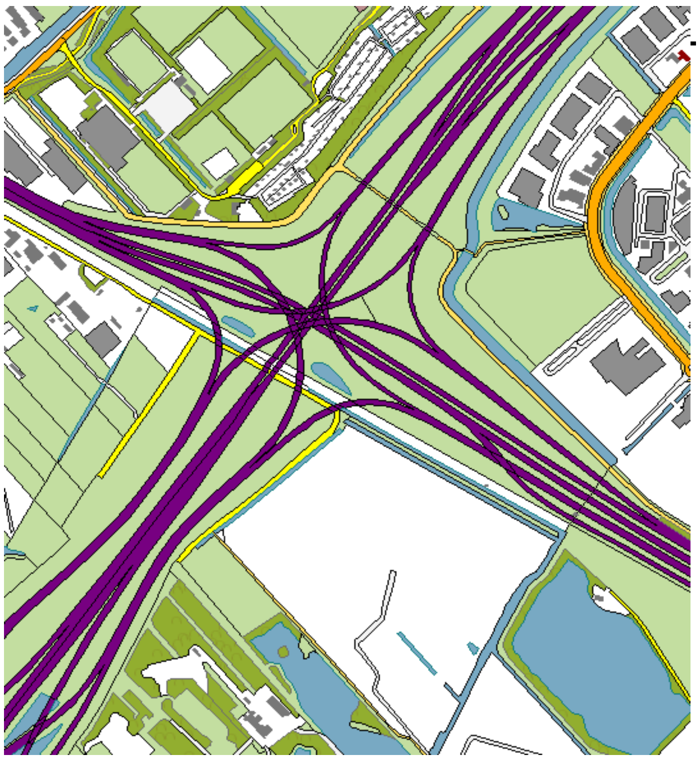
Regional applications hampered by

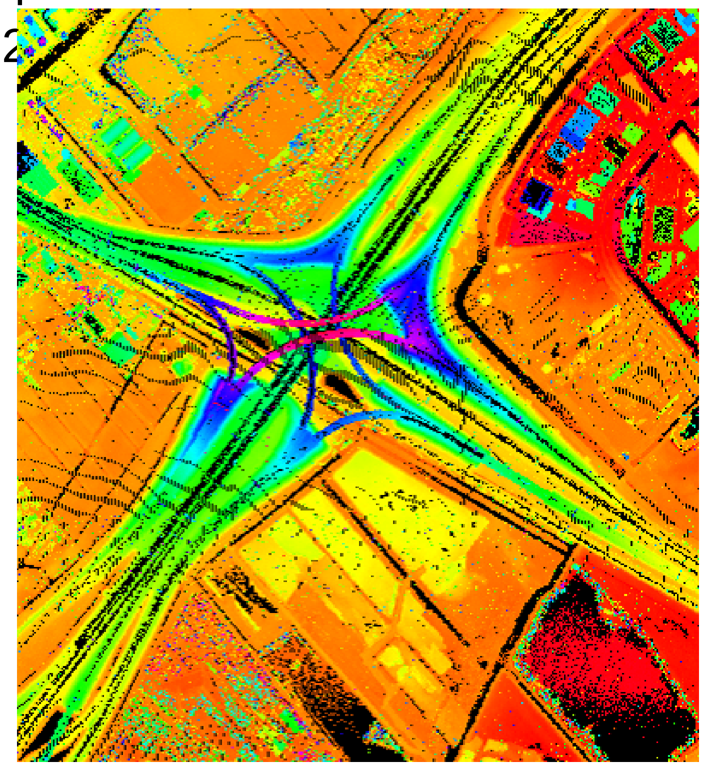
- Incomplete coverage
- Different models



3D NATIONAL LANDSCAPE MODEL

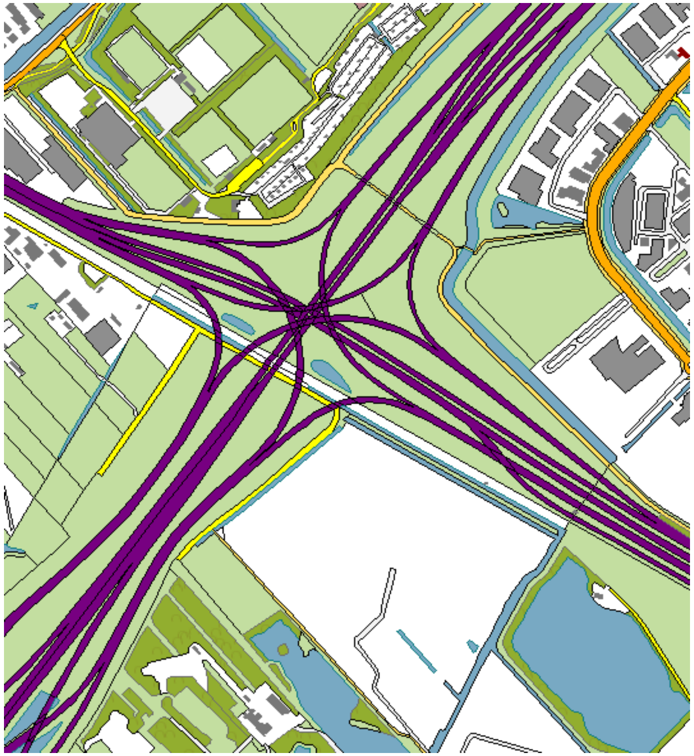
Can we fuse the national topographic database TOP10NL with





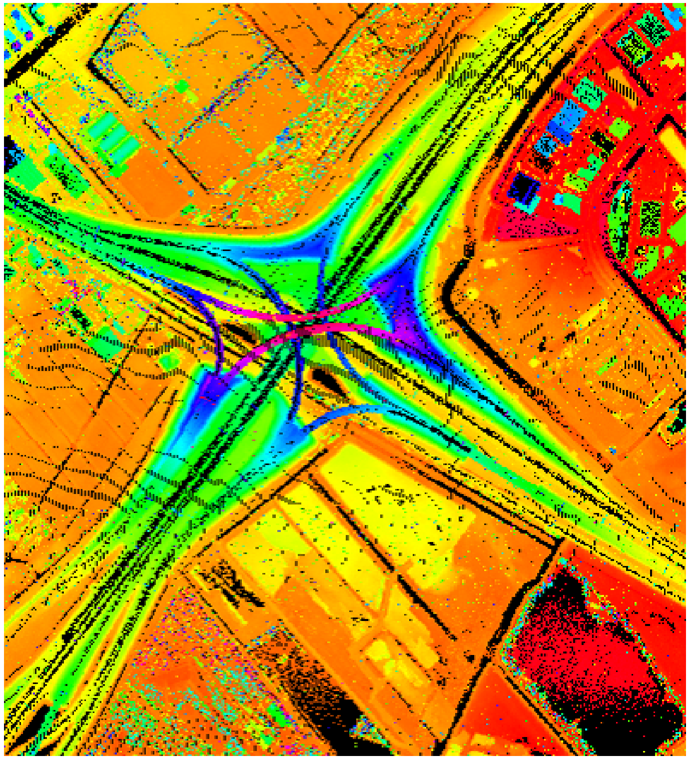
TOP10NL TOPOGRAPHIC DATABASE

- Object based
- 15,000,000 objects
- 1:10,000 scale
- 1-2 m accuracy
- Slightly generalised
- Land use, water, and road provide complete partitioning
- Open data



AHN-2 ELEVATION DATA

- Captured by airborne laser scanning 2007-2012
- Minimum of 8-10 points / m^2
- 640,000,000,000 points
- 5-10 cm accuracy
- Classified terrain / non-terrain
- Open data

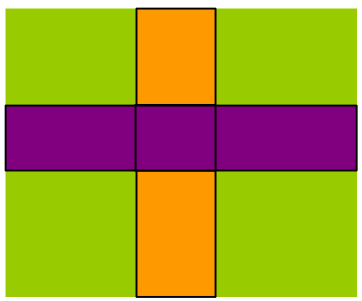


MODEL SPECIFICATIONS

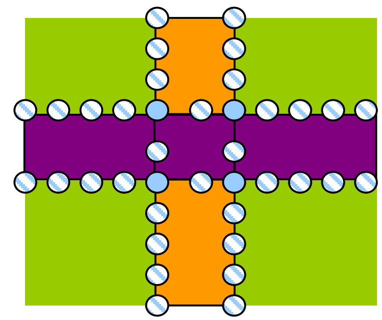
- 3D surface model without gaps
- Modelling of bridges and multi-level road crossings
- Focus on areal objects (no point or line objects)
- Buildings modelled at LOD1 (flat roofs)

MODELLING APPROACH

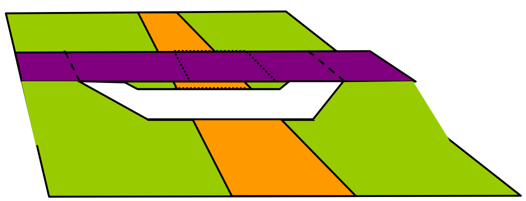
Based on earlier work (Oude Elberink and Vosselman, 2009)



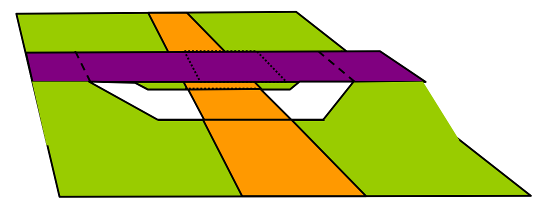
2D map



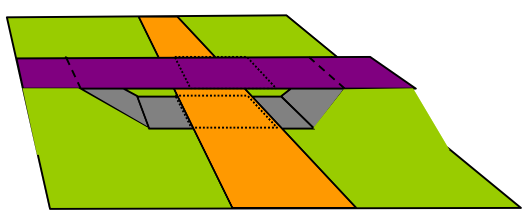
Densification of map points



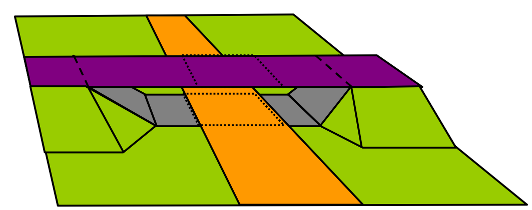
3D boundaries



Add hidden road



Add new terrain pieces



Add height to surface

MODELLING APPROACH

Object class dependent modelling

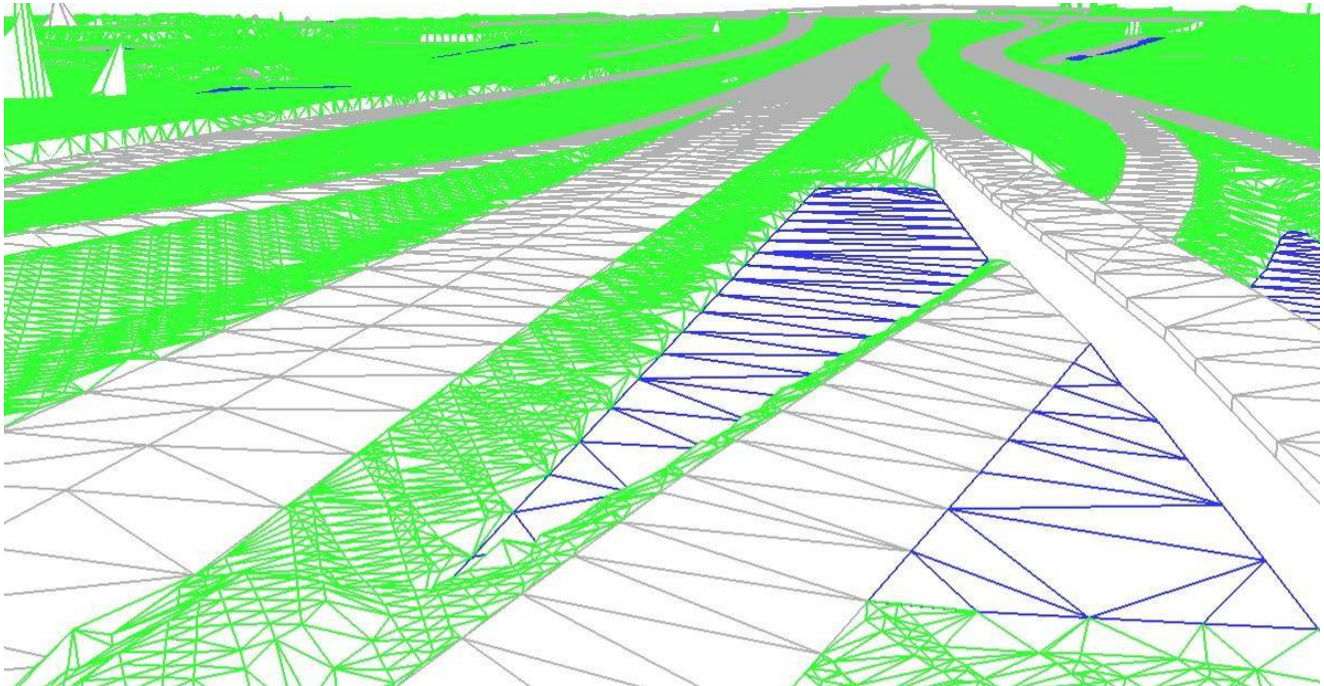
- For object surfaces
  - Water : Horizontal plane
  - Road : Smooth surface, only triangulate road side points
  - Terrain : Reduce point set and triangulate remaining points

- For object boundaries
  - Water – Terrain : Use water height
  - Road – Terrain : Use road height
  - Road – Building : Keep both heights, generate walls

3D MODELLING

Utilisation of knowledge

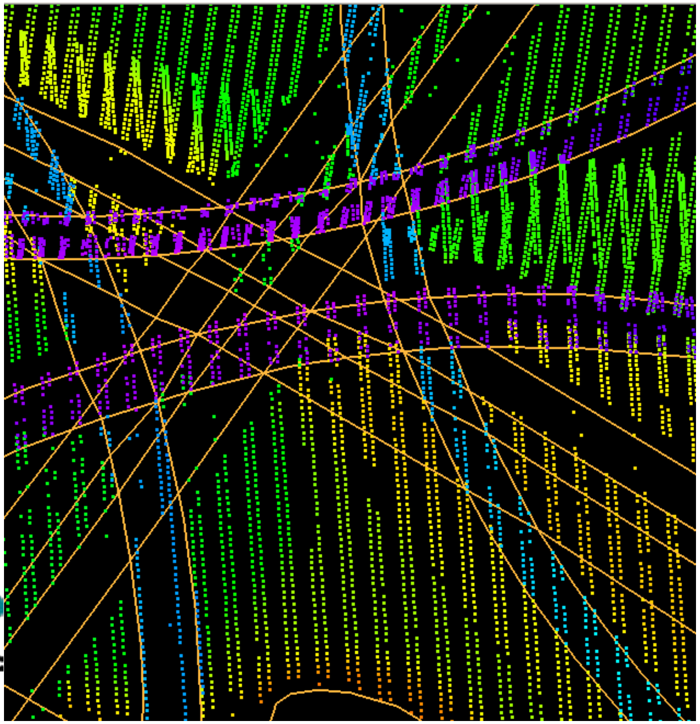
- Water surfaces are horizontal
- Road surfaces are smooth
- Road heights more accurate then shoulder heights

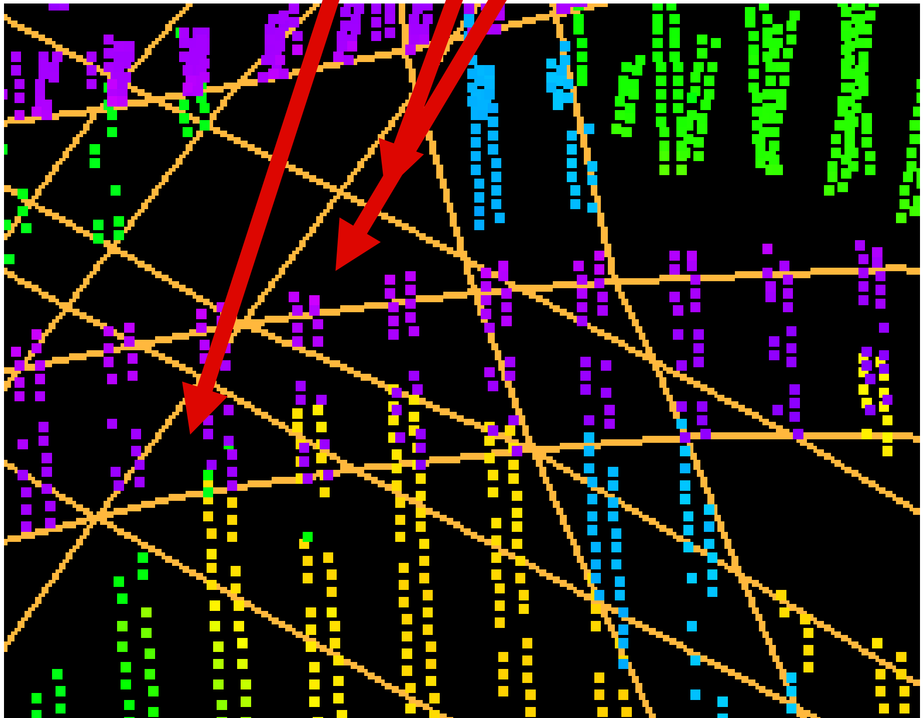


3D ROAD MODELLING

Complex cases

- No laser data in map segment
- Incorrect heights in map segment
- Multiple heights in map segment





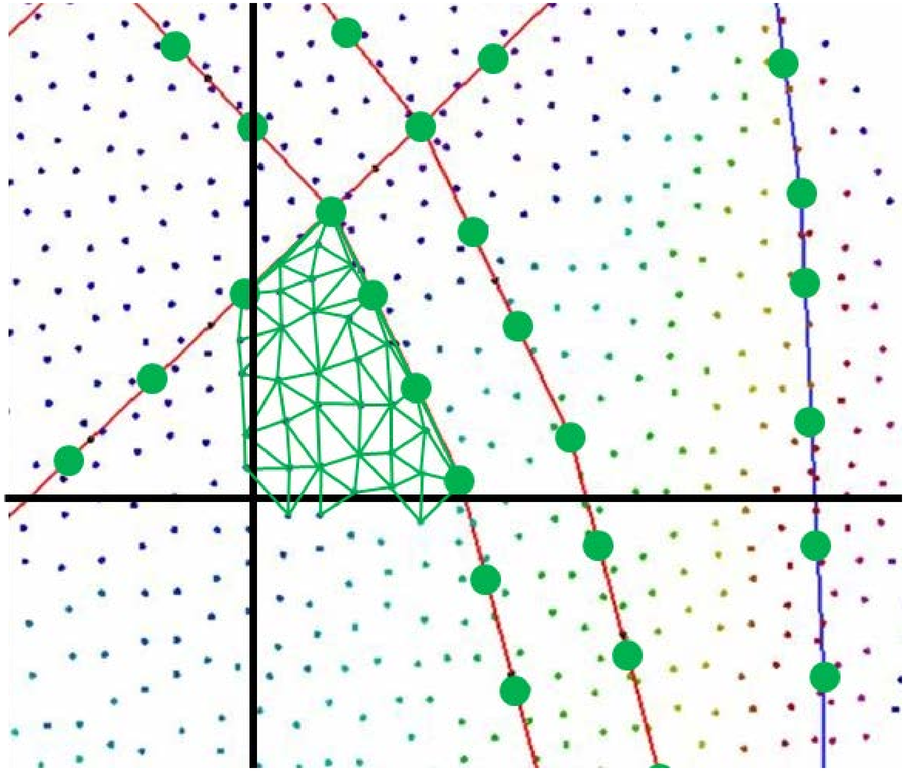
MODELLING APPROACH FOR TILE-BASED PROCESSING

Need for tiling

- Memory requirements
- Parallel processing

Tile-wise modelling

- Tile boundaries not visible in 3D landscape model
- Repeated reconstruction around tile boundaries
- Only store TIN mesh in tile model if mesh centre is inside tile bounds



IMPLEMENTATION AND COMPUTATION

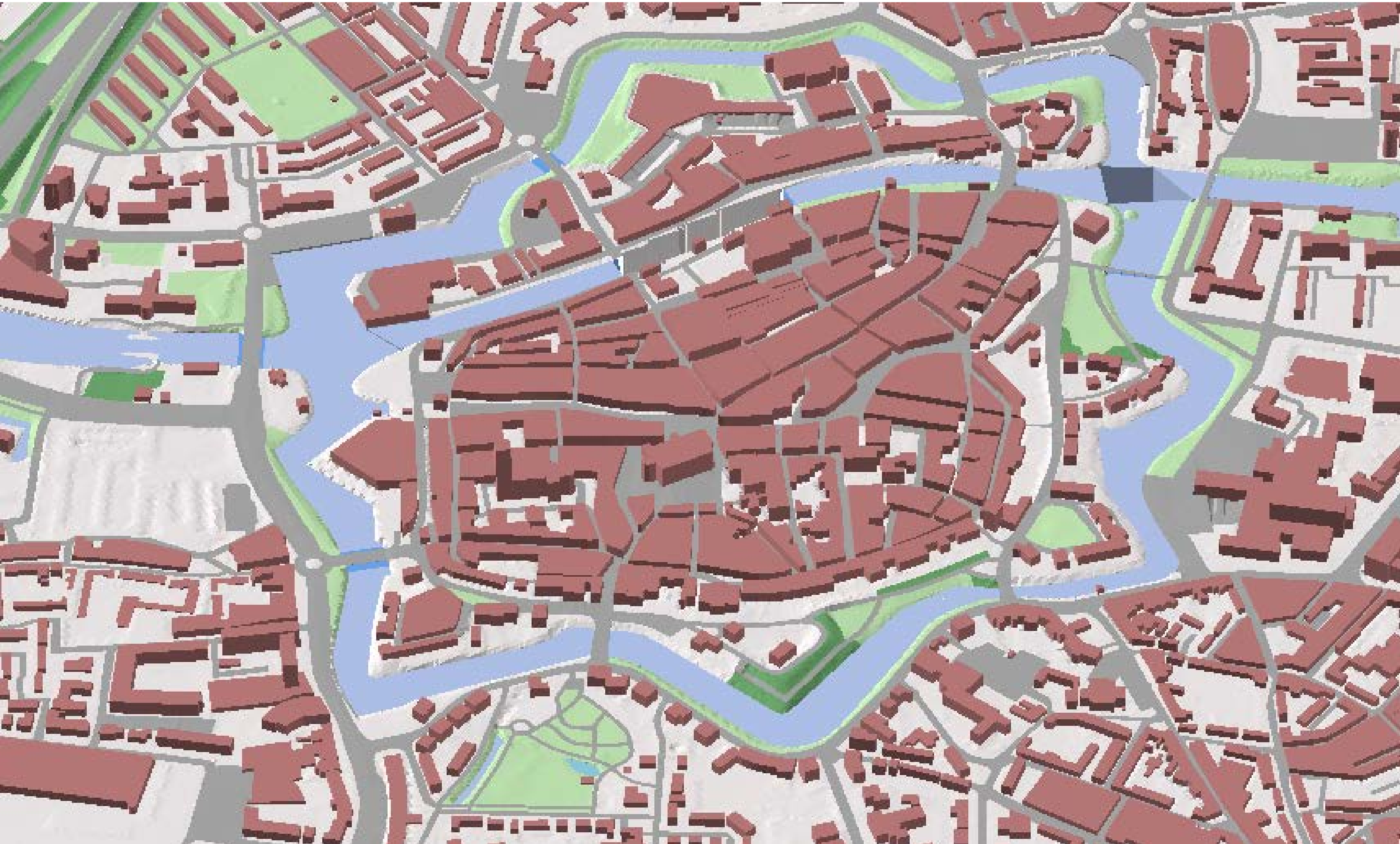
Data and software preparation

- National point cloud split into 30,000 tiles of 1 km^2
- For each tile: select TOP10NL polygons that overlap with tile
- Software installation on a SARA supercomputer

Computation

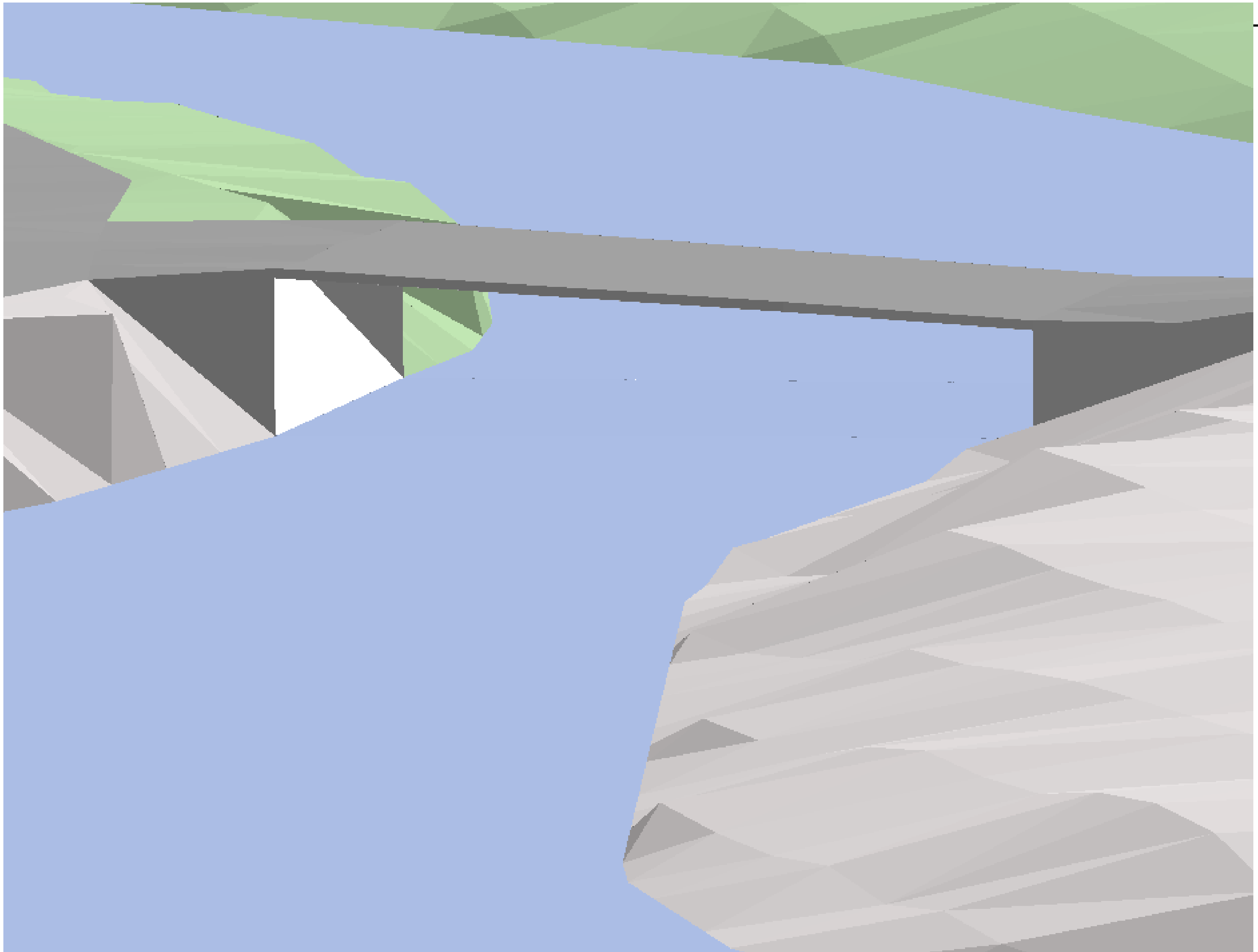
- 2.5 hours processing per tile
- 8.5 years for 30,000 tiles on a single CPU
- Job done in one month on 100 cores

3D TOP10NL



3D TOP10NL

3D TOP10NL



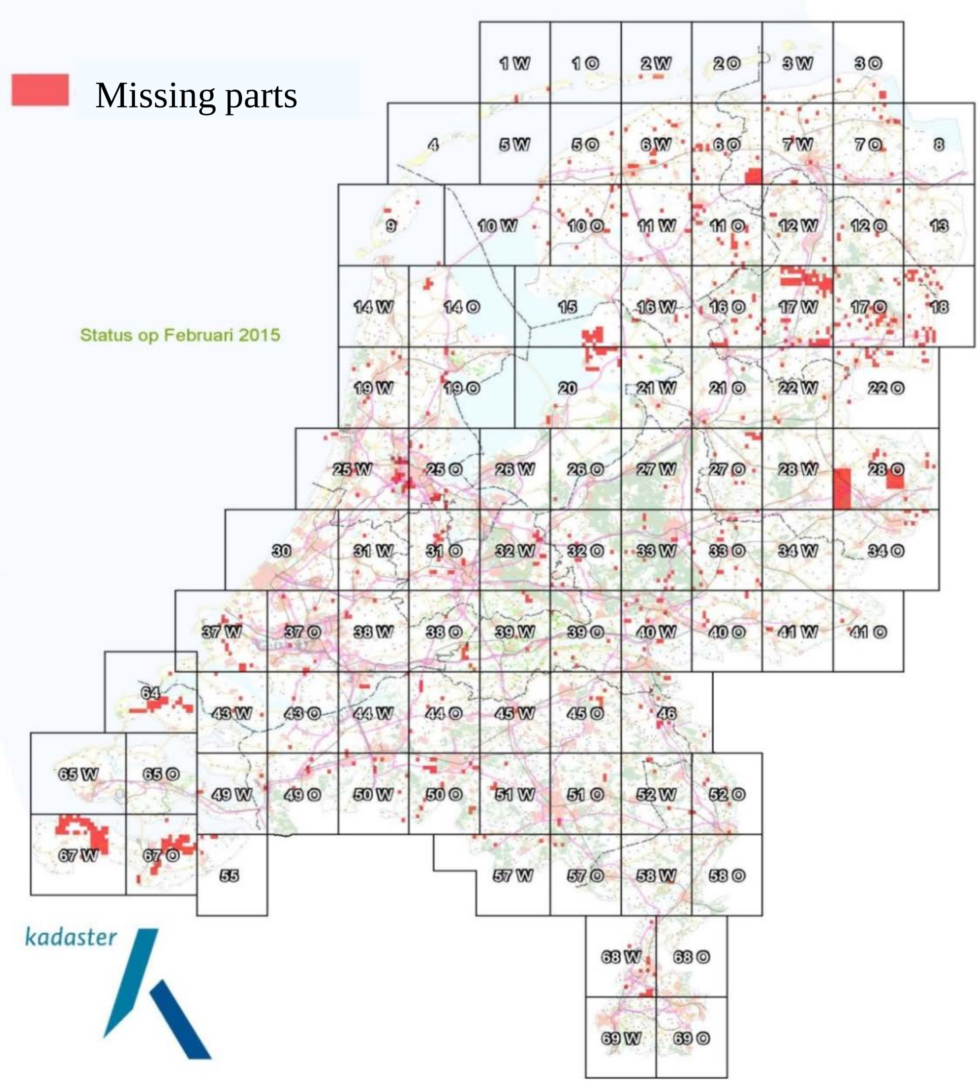
3D TOP10NL

BUGS, LEAKS, CRASHES, AND OTHER PROBLEMS

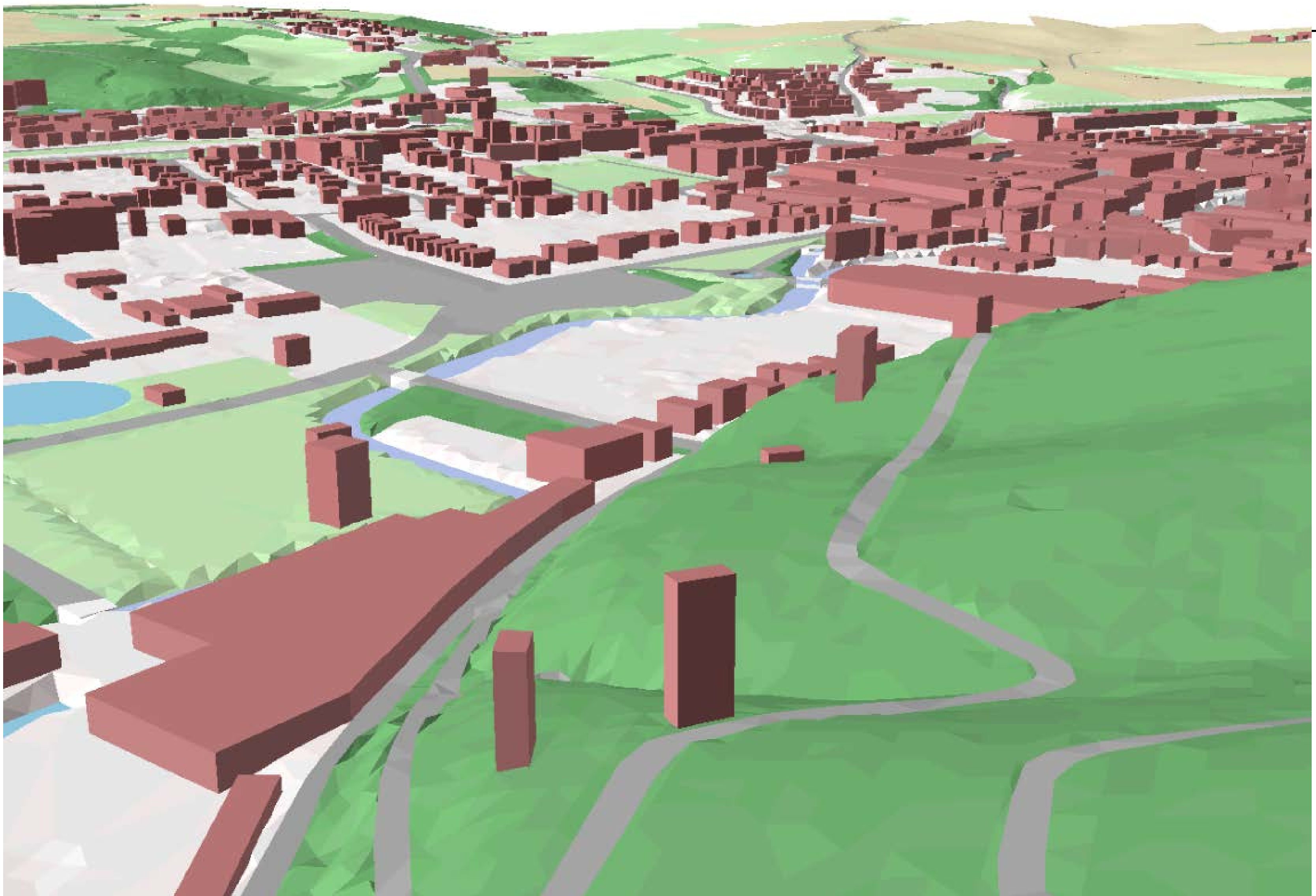
- Initially 90% complete
- Now at 97%
- 64 bit implementation needed

Modelling errors

- Bumps in terrain caused by points on walls
- Peaks in forest surfaces



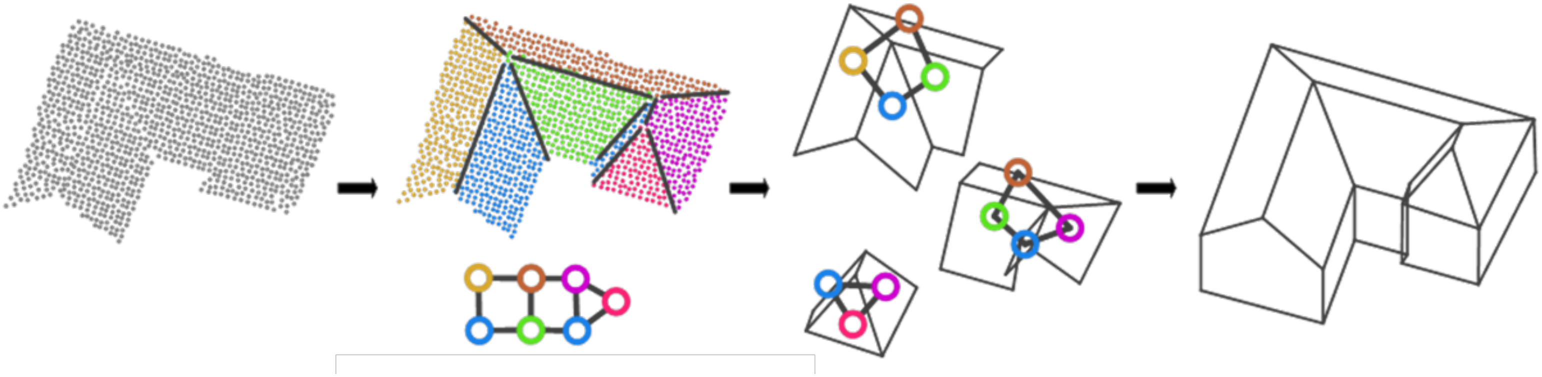
3D TOP10NL NOW AVAILABLE AS OPEN DATA



FEASIBILITY OF NATIONWIDE LOD2 BUILDING MODELLING

- Various approaches (data-driven, model-driven)
- Roof topology graphs and target graph libraries

Point cloud Segmentation Decomposition Building model

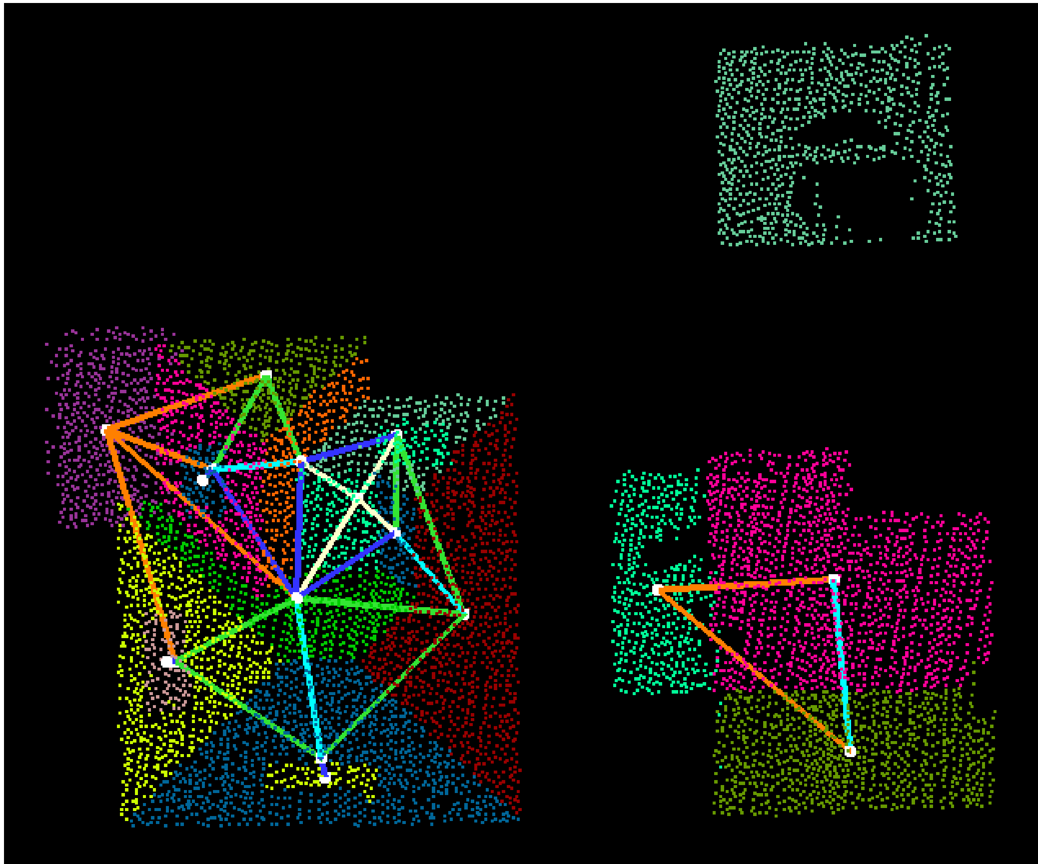


Roof topology graph Target graphs

3D BUILDING MODELLING

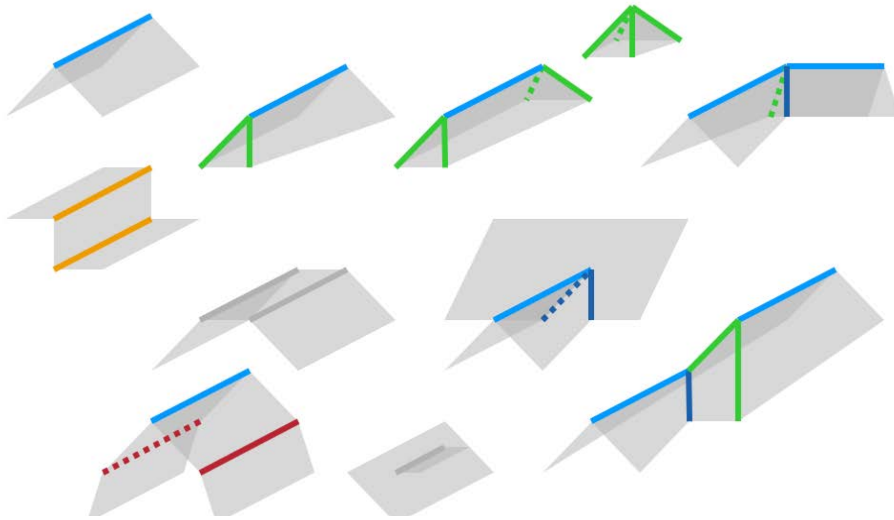
Graph matching for building reconstruction

- Point cloud segmentation
- Selection of roof segments
- Analysis of intersection lines and height jump edges
- Roof topology graph

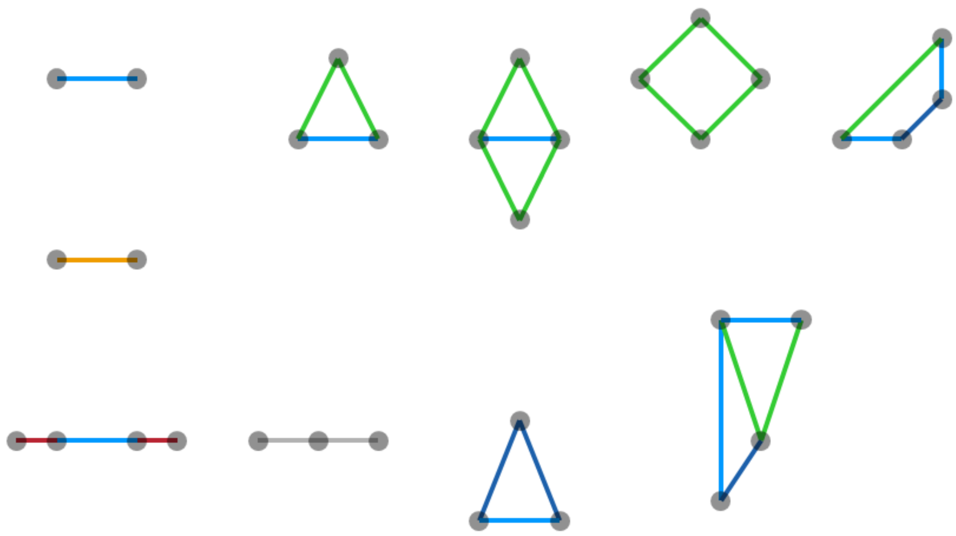


3D BUILDING MODELLING

- Target shapes

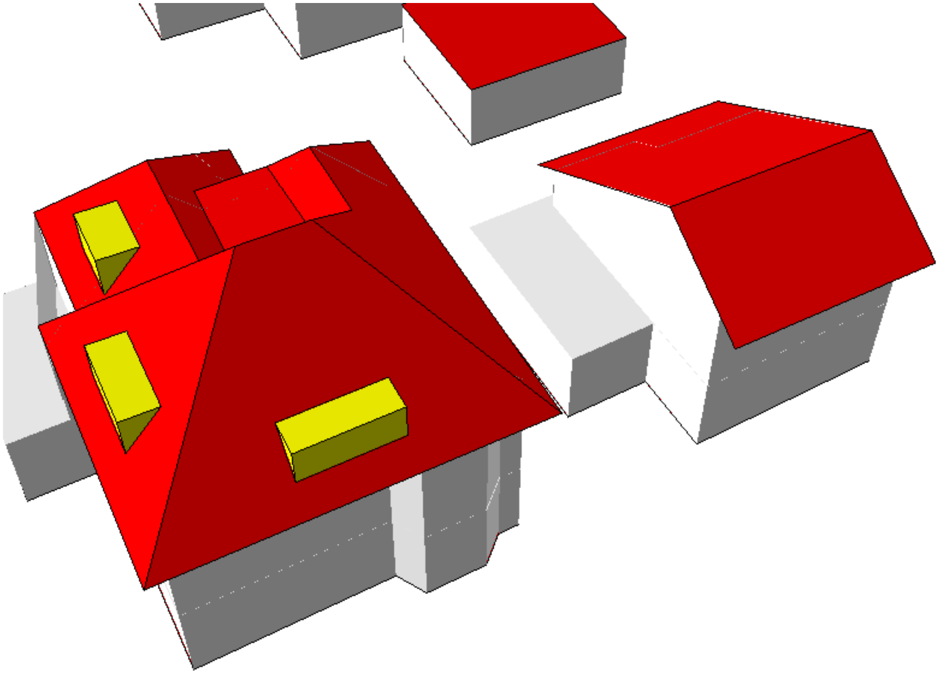


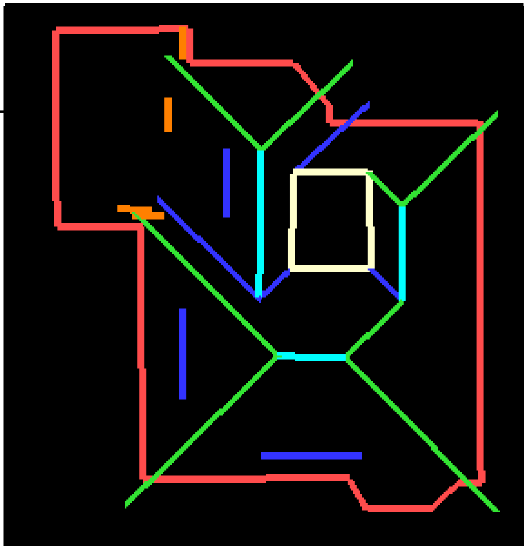
- Target graphs

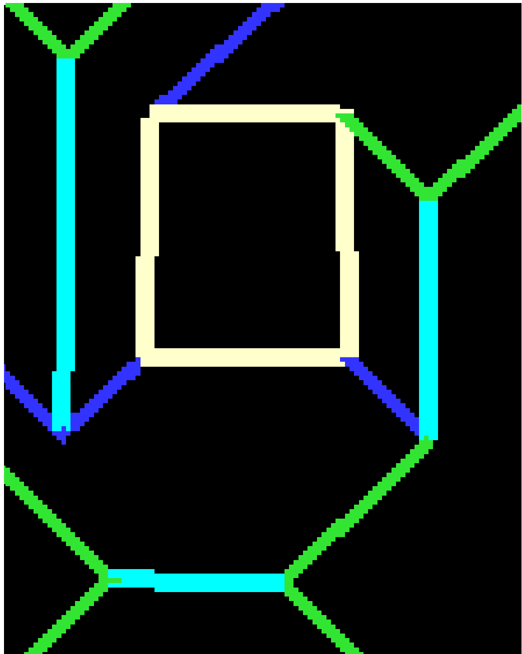


3D BUILDING MODELLING

- After matching
  - join intersection lines
  - determine outer bounds of roof faces
  - extend intersection lines

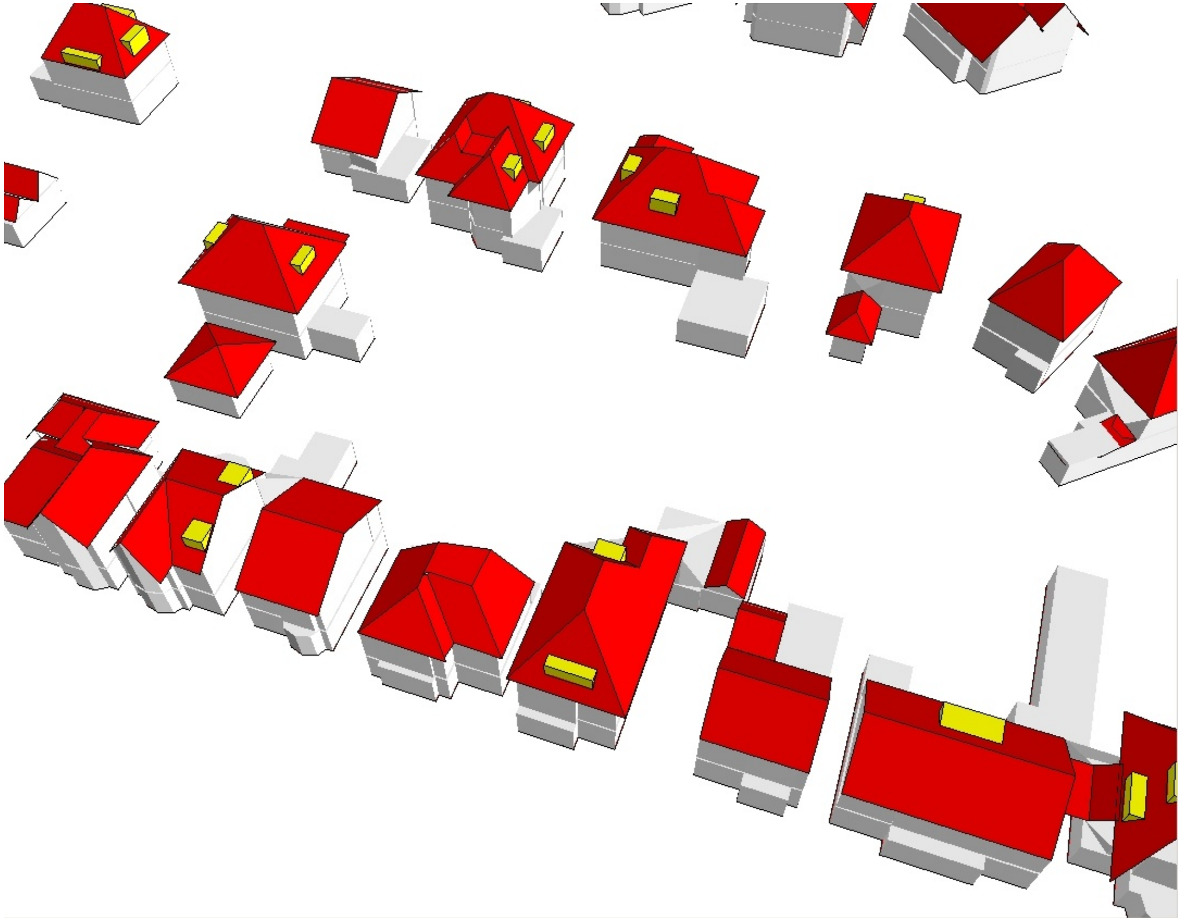






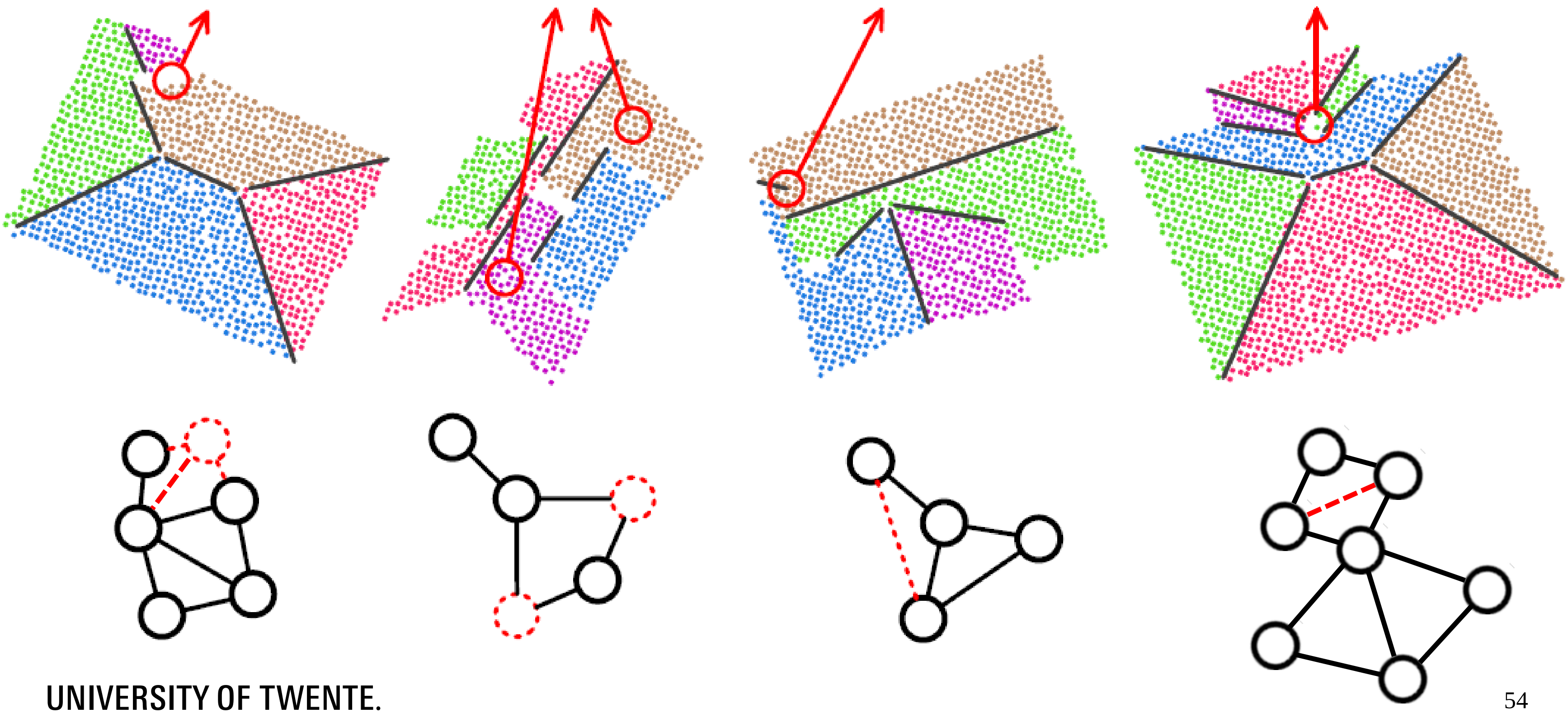
3D BUILDING MODELLING

- Results for suburban areas with 729 buildings
- 81% correct
- Problems
  - Segment not detected (7%)
  - Intersection line not detected (4%)
  - Target shape not in database (2%)



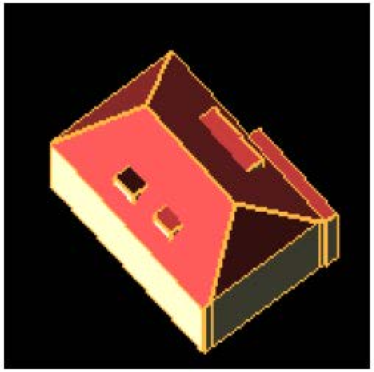
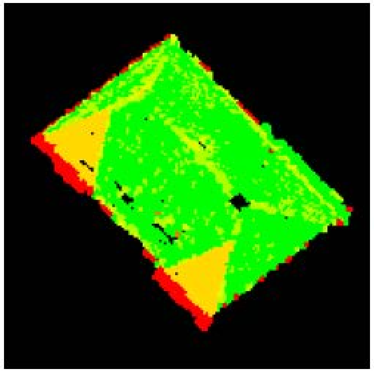
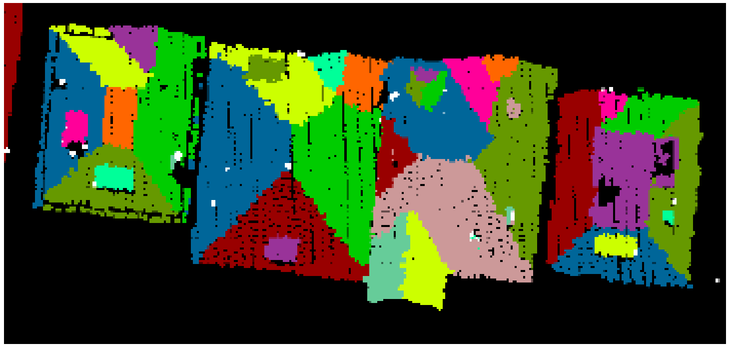
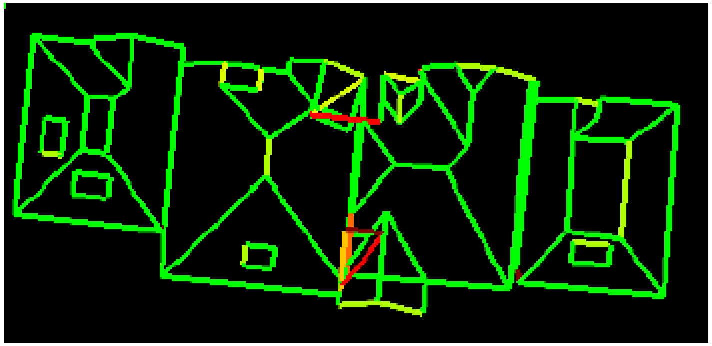
ERRORS IN ROOF TOPOLOGY GRAPHS

Missing segment	Wrong segment	Wrong intersection line	Missing intersection line

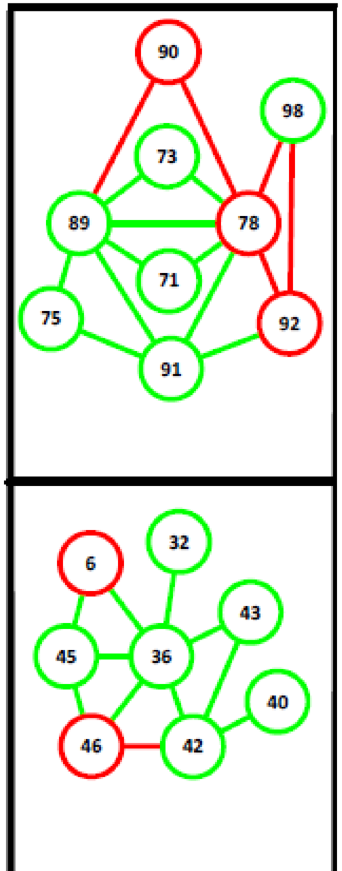


CORRECTING ERRORS IN ROOF TOPOLOGY GRAPHS

- Interactive editing of roof topology graphs
- Recognition of error type – reapplication of earlier graph edits

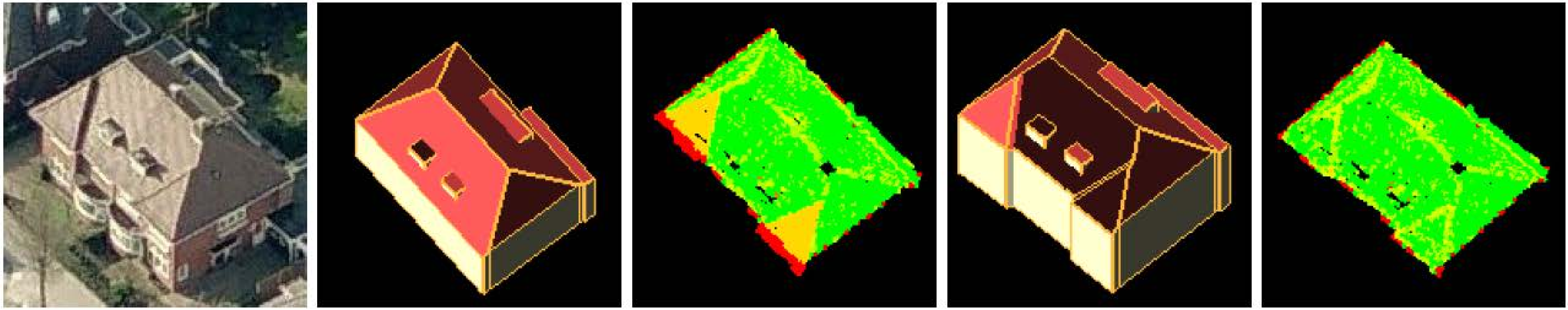






ERROR RECOGNITION WITH AN ERROR LIBRARY

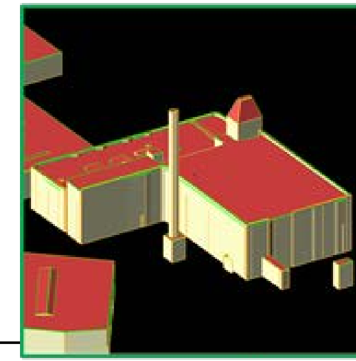


RECONSTRUCTION PROCESS

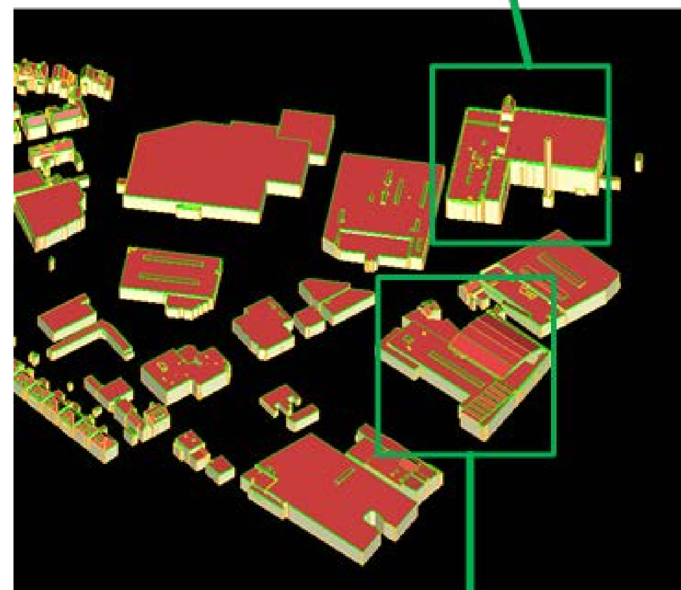
- Automated reconstruction with target graph library
- Iterate
  - Analysis of model quality
  - Automated improvement of errors by matching against entries of error library
- Interactive editing of remaining errors

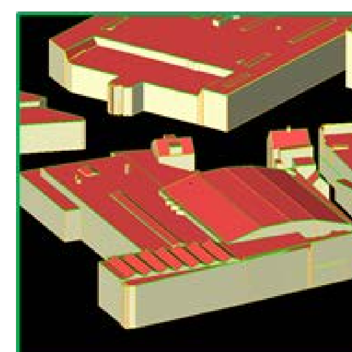


LOD2 MODELLING RESULTS



- 95% buildings correctly modelled





FEASIBILITY OF NATIONWIDE LOD2 BUILDING MODELLING

- 9366 building models reconstructed in Enschede
  - 45 minutes CPU time for automated reconstruction
  - 1 working day for interactive editing of building models

- Scaling up to nationwide LOD2 modelling (4 million building models)
  - 13 days CPU time for automated reconstruction
  - 2 years for interactive editing of building models

CONCLUDING REMARKS

- Nationwide LOD1 modelling nearly complete
  - With some bug fixes, 100% coverage seems feasible
  - Improve modelling of forests and complex road junctions
  - Updating strategy – point clouds from dense matching, but for now assuming up-to-date 2D map.

- Nationwide LOD2 modelling
  - Editing is still time consuming
  - Further editing experience may improve automated corrections
  - Updating strategy - point clouds from dense matching will require larger image overlaps

CLASSIFICATION OF POINT CLOUDS