The ISPRS Benchmark on Urban Object Classification and 3D Building Reconstruction

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Outline

- Introduction
- Test Data
- Object Detection
  - Task and Evaluation Methodology
  - Evaluation of Building Detection
  - Evaluation of Tree Detection
  - Discussion
- 3D Building Reconstruction
  - Task and Evaluation Methodology
  - Results
  - Discussion
- Outlook

Benchmarks on Urban Object Extraction

- Benchmarks are widely used in Computer Vision to make different solutions comparable
- Photogrammetry & Remote Sensing:
  - Test data by OEEPE/EuroSDR: outdated as far as aerial sensor data are concerned

  → New data set of ISPRS WG III/4 "Complex scene analysis and 3D reconstruction": http://www.itc.nl/ISPRS_WGIII4/tests_datasets.html

- Test with two tasks

  1) Urban object detection

  2) 3D building reconstruction

- Results submitted by the participants are evaluated by WG III/4 based on reference data
- This presentation: report on the results

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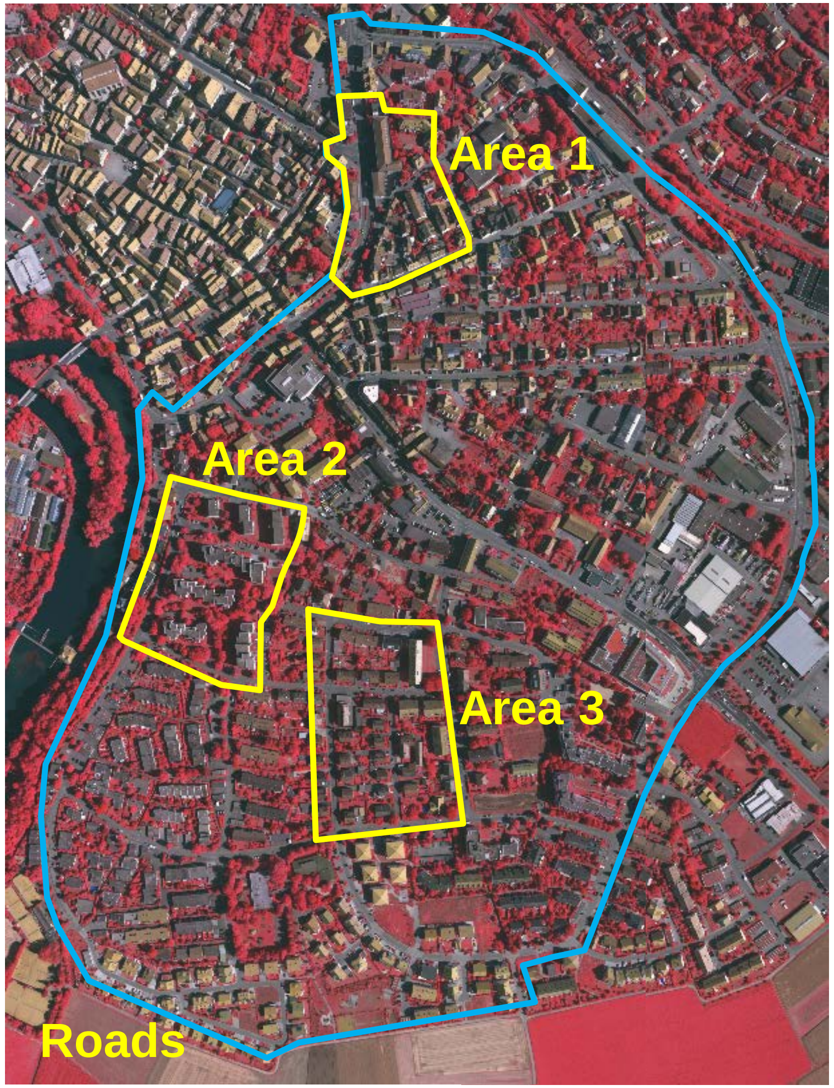
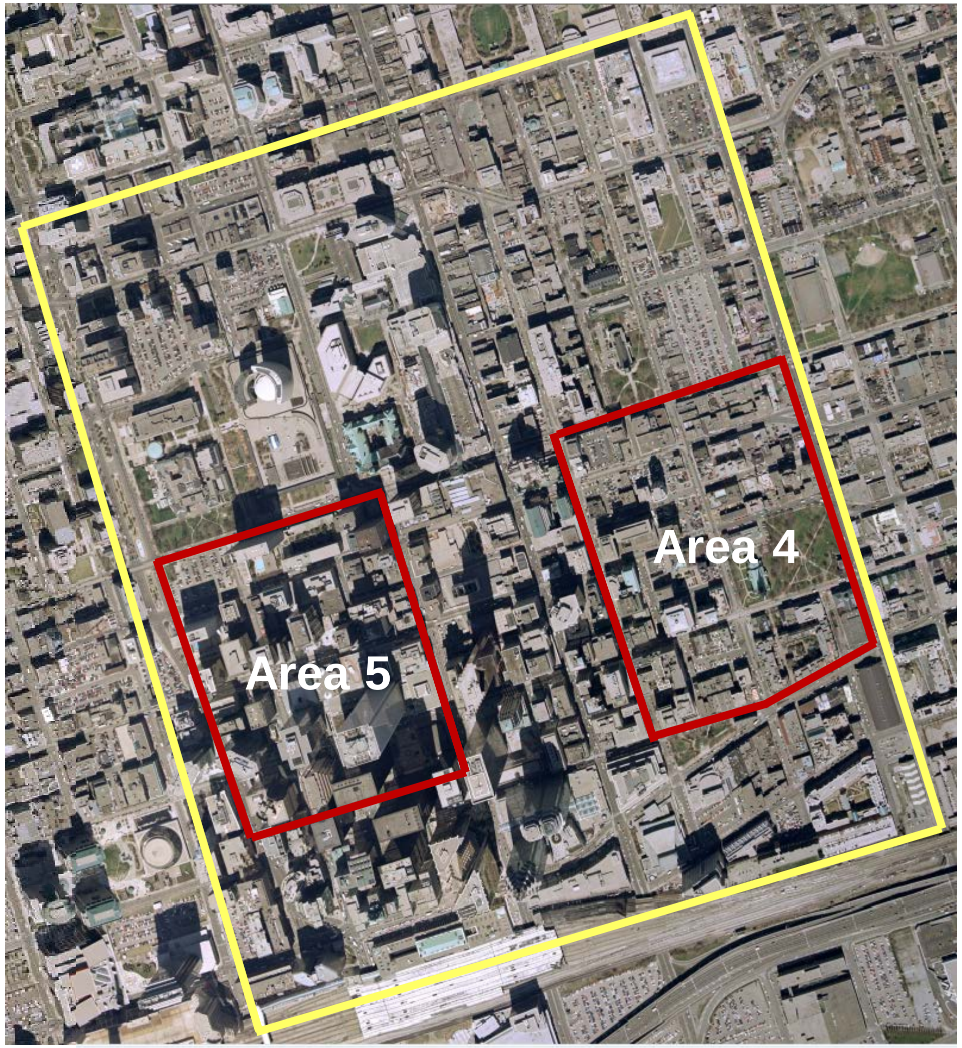
Data Set 1: Vaihingen / Enz (Germany)

- **Multiple colour infrared (CIR) aerial images:**
  - Z/I DMC (c = 120 mm)
  - GSD: 8 cm
  - Fourfold overlap
  - Accuracy of orientation: ± 1 pixel
- **ALS data:**
  - Leica ALS 50
  - 4-7 pts/m^2, multiple pulses + intensities
  - DSM grid (25 cm)
- **Three test areas** (~150 m x 200 m)
- **Reference:** photogrammetric plotting



Data Set 2: Downtown Toronto (Canada)

- **Multiple colour (RGB) aerial images:**
  - Microsoft Vexcel UltraCam-D (c = 101.4 mm)
  - GSD: 15 cm
  - Stereo Overlap
  - Accuracy of orientation: ± 1 pixel
- **ALS data:**
  - Optech ALTM-ORION M
  - 6 pts/m^2, multiple pulses + intensities
  - DSM grid (25 cm)
- **Two test areas** (530 m x 600 m)
- **Reference:** photogrammetric plotting



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Task of the Participants

- Detection of urban objects:
  - Buildings
  - Trees
  - (...)
- Deliverables per object class:
  - Object outlines as polygons in object space
  - (Geocoded images representing the detected objects)

Evaluation Methodology

- Evaluation of thematic accuracy:

Completeness = TP / (TP + FN)
Correctness = TP / (TP + FP)
Quality = TP / (TP + FN + FP)

} per-area, per-object

  - TP: Number of True Positives
  - FP: Number of False Positives
  - FN: Number of False Negatives

- Evaluation of geometrical accuracy:
  - RMS error of distances from (correct) extracted outlines to reference outlines
- Requirements for practical relevance (Mayer et al, 2006):
  - Completeness ≥ 70%
  - Correctness ≥ 85%

Results Submitted by Participants

Submitted by	Abbr.	Affiliation	Areas				
			1	2	3	4	5
A. Moussa	**CAL**	University of Calgary, Canada	B+T	B+T	B+T		
D. Bulatov	**FIE**	Fraunhofer Inst. Ettlingen, Germany			B		
J. Niemeyer	**HAN**	University of Hannover, Germany	B+T	B+T	B+T		
D. Grigillo	**LJU**	University of Ljubljana, Slovenia	B+T	B+T	B+T		
C. Liu	**TON**	Tongji University, Japan	B	B	B		
W. Yao	**TUM**	TU Munich, Germany	B+T	B+T	B+T	B	B
P. Dorninger	**VSK**	TU Vienna, Austria	B	B	B		
Q. Zhan	**WHU**	Wuhan University, China	B+T	B+T	B+T		

- Only one participant delivered results for Toronto (areas 4 + 5)
- One participant only delivered results for area 3
- Some participants only delivered results for building detection

Data Used by the Participants

Submitted by	Abbr.	Affiliation	Areas				
			1	2	3	4	5
A. Moussa	**CAL**	University of Calgary, Canada	B+T	B+T	B+T		
D. Bulatov	**FIE**	Fraunhofer Inst. Ettlingen, Germany			B		
J. Niemeyer	**HAN**	University of Hannover, Germany	B+T	B+T	B+T		
D. Grigillo	**LJU**	University of Ljubljana, Slovenia	B+T	B+T	B+T		
C. Liu	**TON**	Tongji University, Japan	B	B	B		
W. Yao	**TUM**	TU Munich, Germany	B+T	B+T	B+T	B	B
P. Dorninger	**VSK**	TU Vienna, Austria	B	B	B		
Q. Zhan	**WHU**	Wuhan University, China	B+T	B+T	B+T		

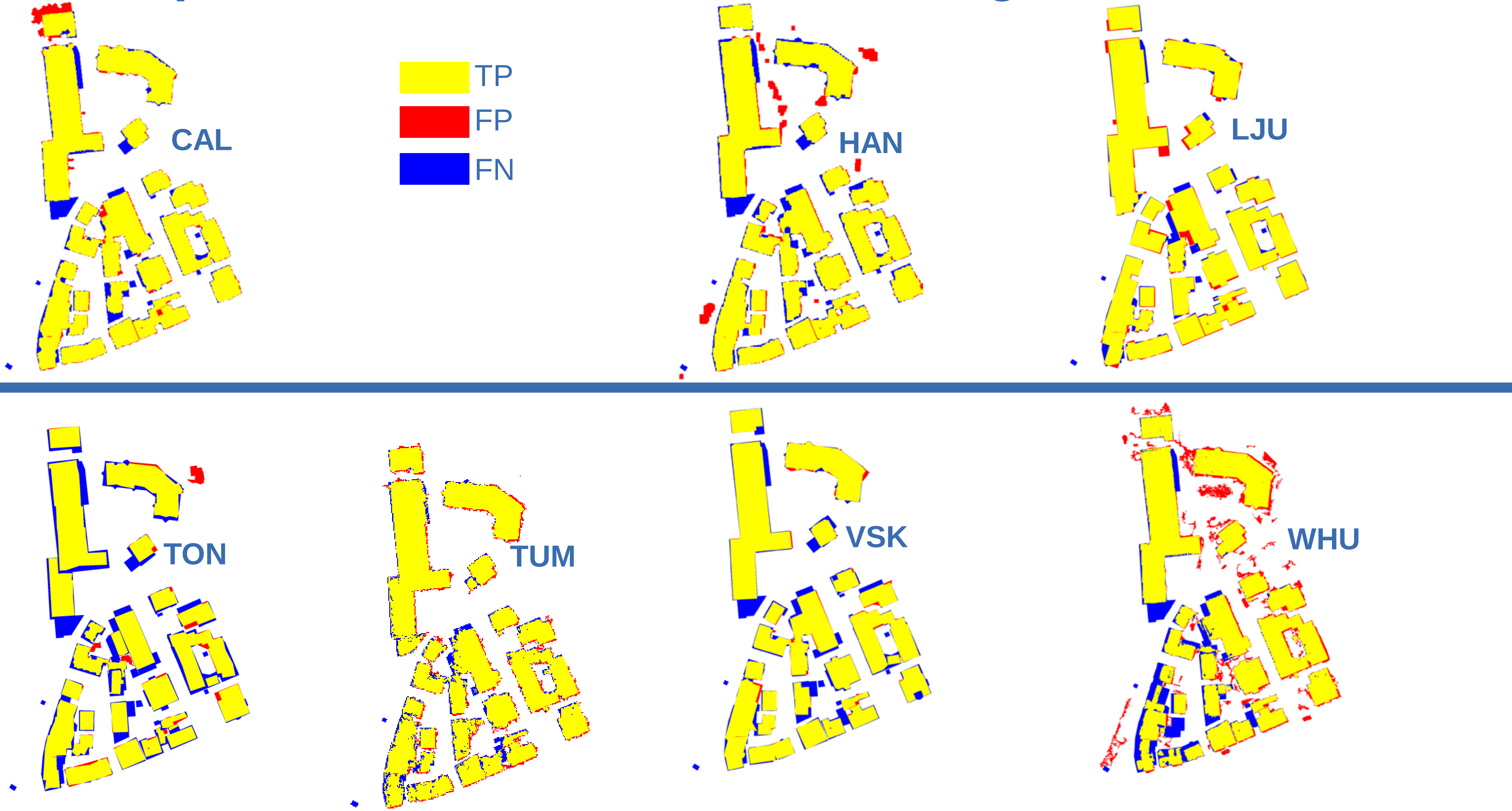
- Original images only (1)
- DSM (ALS) + orthophoto (4)
- DSM (ALS) (1)
- ALS points (2)

Processing Strategies

Submitted by	Abbr.	Affiliation	Areas				
			1	2	3	4	5
A. Moussa	**CAL**	University of Calgary, Canada	B+T	B+T	B+T		
D. Bulatov	**FIE**	Fraunhofer Inst. Ettlingen, Germany			B		
J. Niemeyer	**HAN**	University of Hannover, Germany	B+T	B+T	B+T		
D. Grigillo	**LJU**	University of Ljubljana, Slovenia	B+T	B+T	B+T		
C. Liu	**TON**	Tongji University, Japan	B	B	B		
W. Yao	**TUM**	TU Munich, Germany	B+T	B+T	B+T	B	B
P. Dorninger	**VSK**	TU Vienna, Austria	B	B	B		
Q. Zhan	**WHU**	Wuhan University, China	B+T	B+T	B+T		

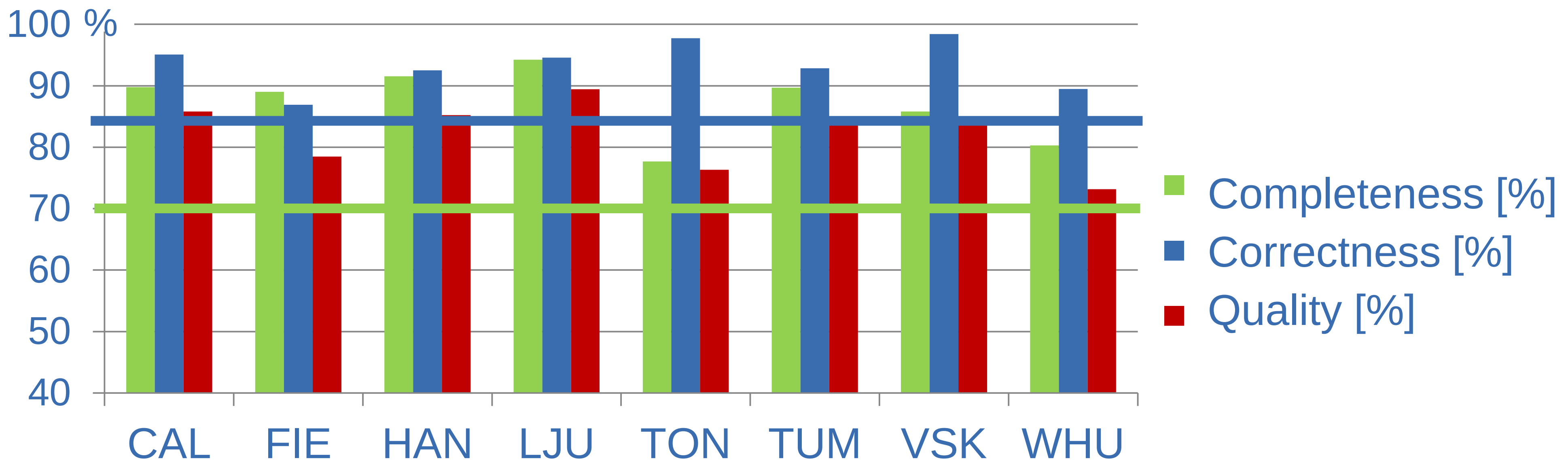
- Supervised, without segmentation (3)
- Unsupervised, with segmentation (5)

Example for the Evaluation of Building Detection – Area 1



Evaluation of Building Detection - Vaihingen

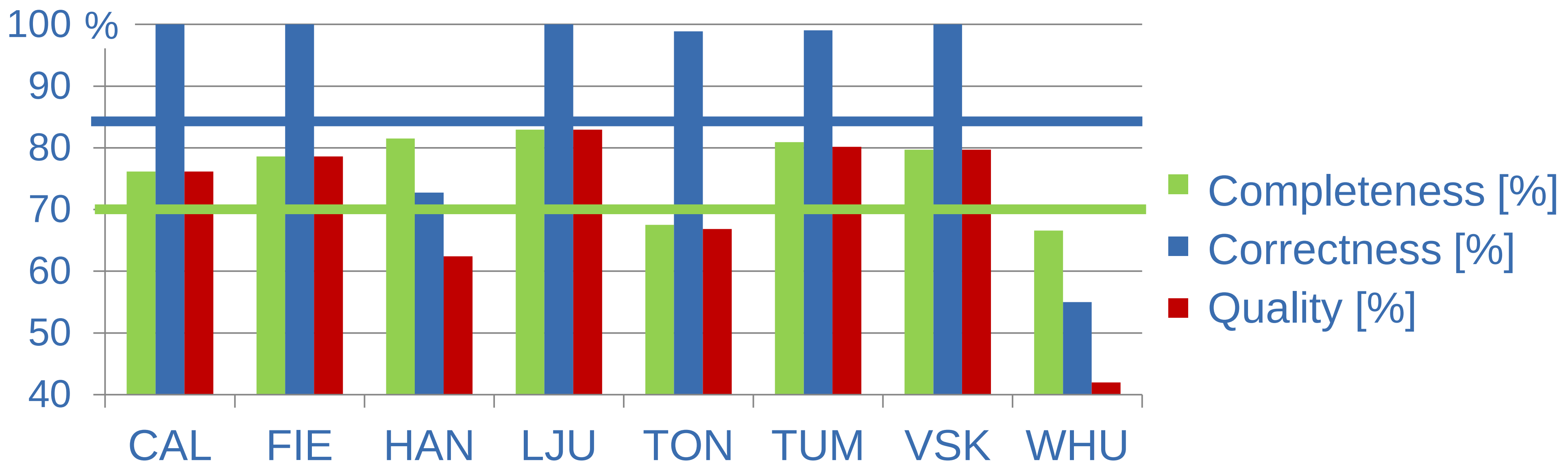
- Area-based evaluation (average Areas 1-3)



- All methods fulfil the requirements for practical relevance according to (Mayer et al., 2006)

Evaluation of Building Detection - Vaihingen

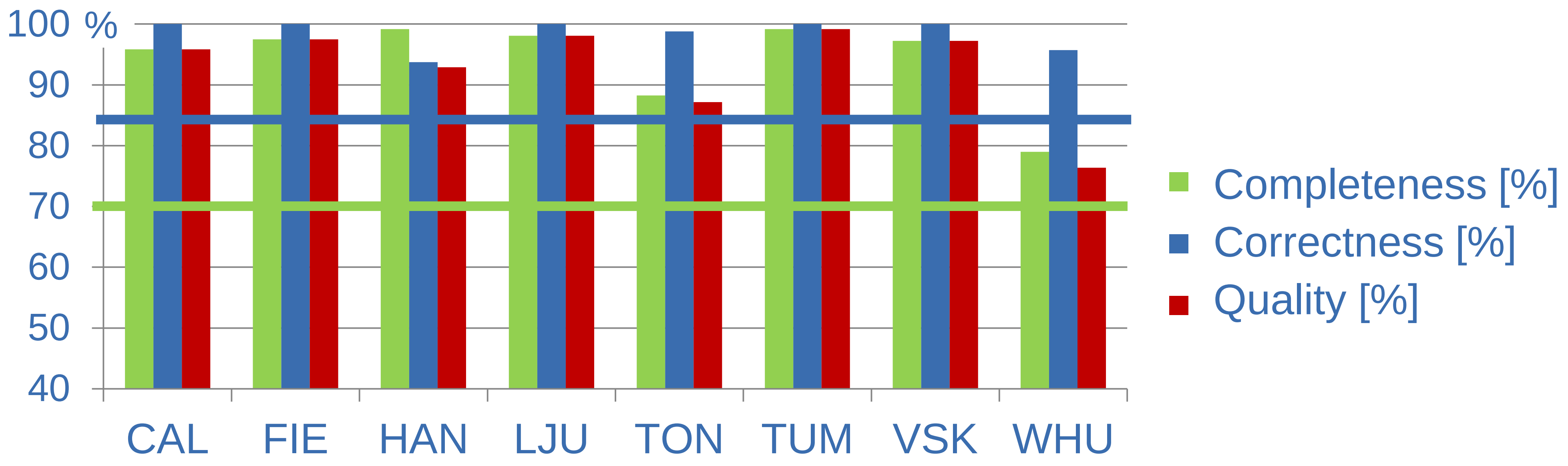
- Object-based evaluation (all objects, average Areas 1-3)



- HAN, TON and WHU do not fulfil the requirements for practical relevance according to (Mayer et al., 2006)
- Problems are largely related to small building structures

Evaluation of Building Detection - Vaihingen

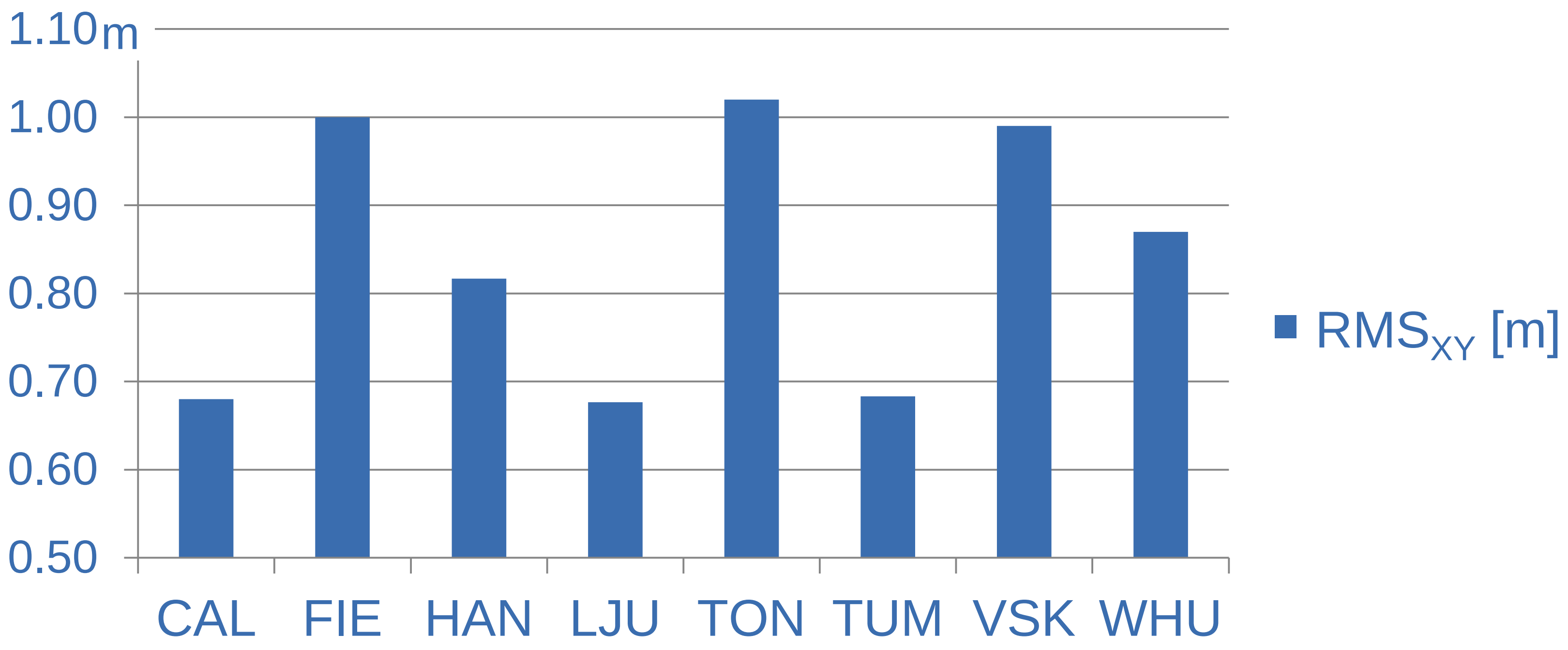
- Object-based evaluation for buildings ≥ 50 m^2 (average Areas 1-3)



- Large structures can be detected reliably by most methods
- All methods fulfil the requirements for practical relevance according to (Mayer et al., 2006)

Evaluation of Building Detection - Vaihingen

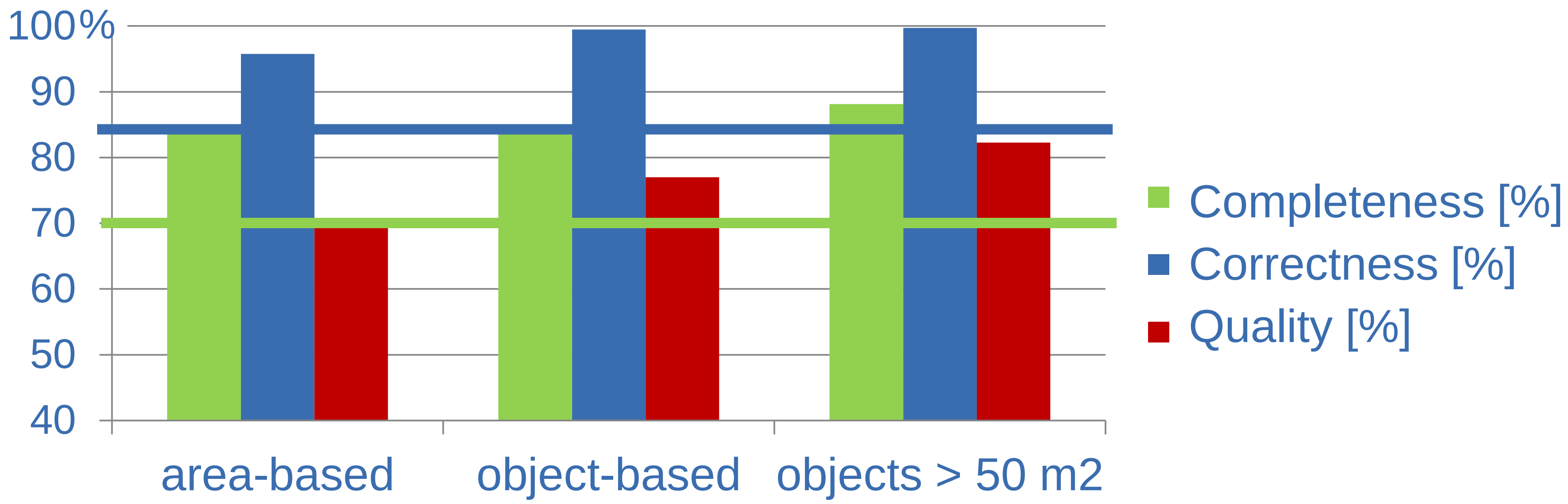
- RMS_{XY}: error of planimetric distances (average Areas 1-3)



- Order of magnitude: 2 - 4 times the resolution of ALS data
- Full potential of images is not exploited

Evaluation of Building Detection - Toronto

- Evaluation for TUM (average of Areas 4 and 5)

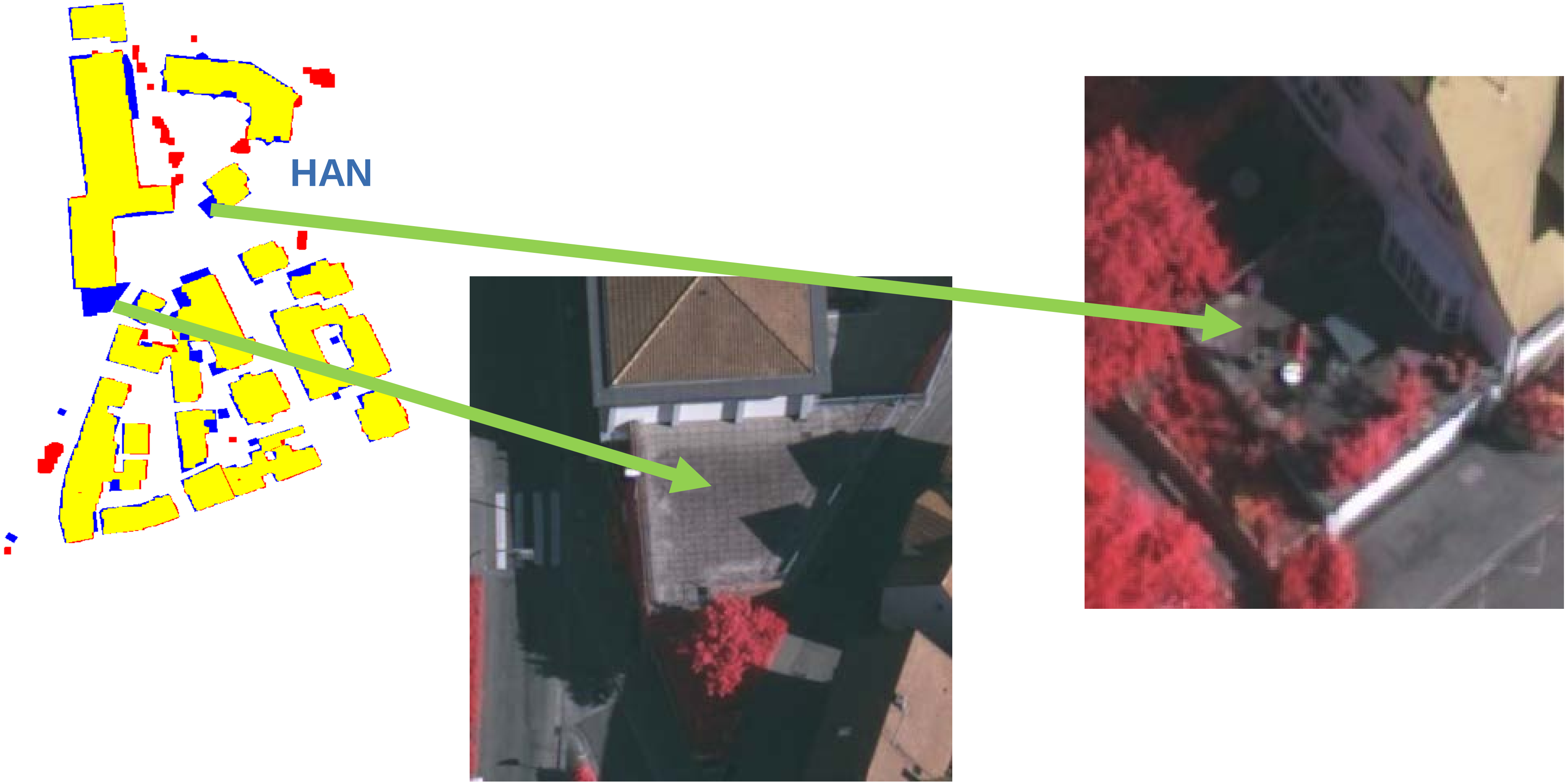


$RMS_{XY} = 1.5$ m

- More difficult scenario than Vaihingen
  - No Infrared band
  - Occlusions, extremely high-rise buildings
- Nevertheless, requirements according to (Mayer et al., 2006) fulfilled

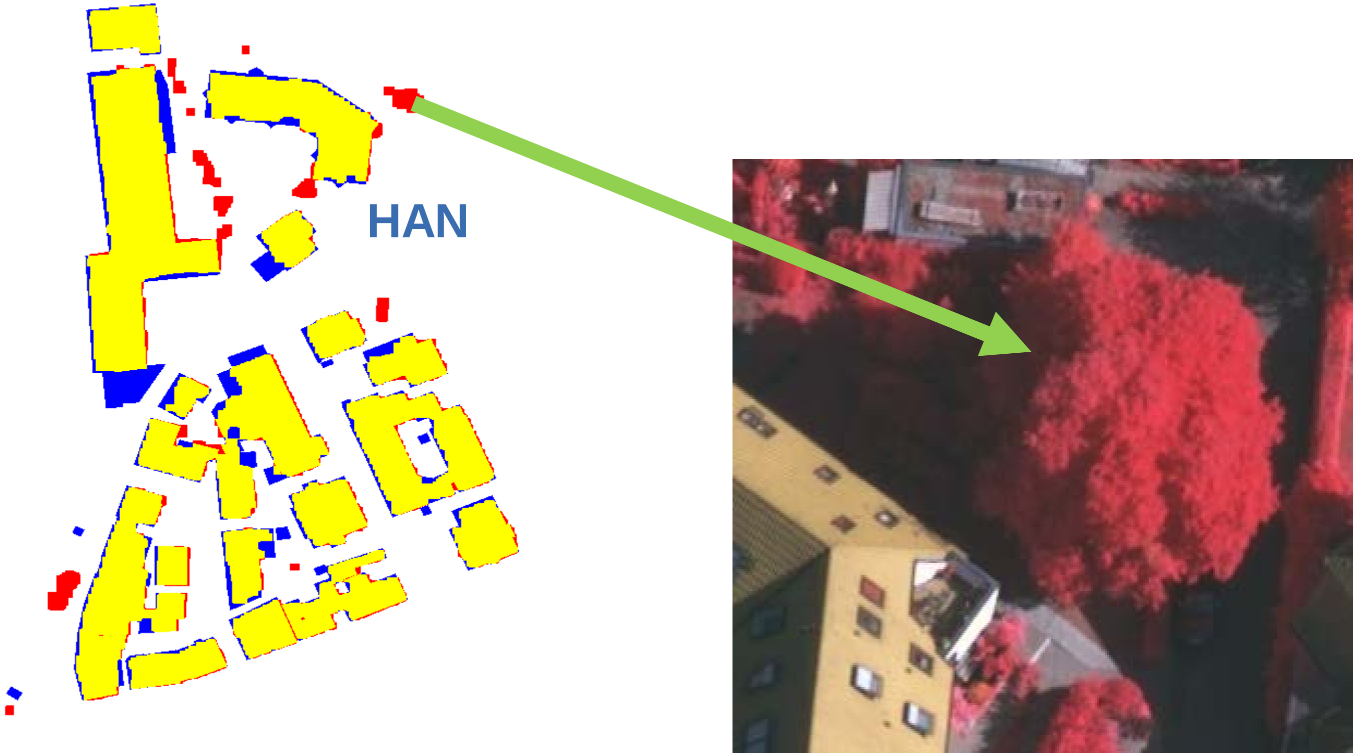
Common Problems in Building Detection

- Horizontal roof planes in combination with complex terrain, objects on roofs



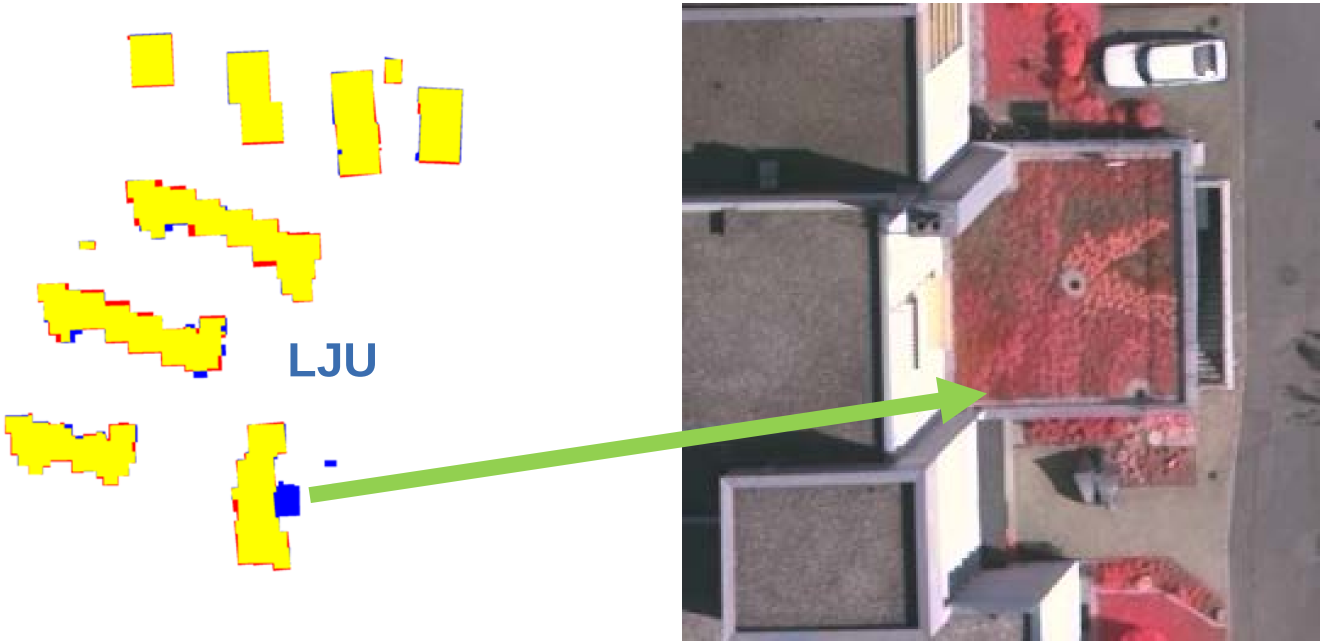
Common Problems in Building Detection

- Horizontal roof planes in combination with complex terrain, objects on roofs
- Dense tree canopies → Problems for methods directly classifying ALS points



Common Problems in Building Detection

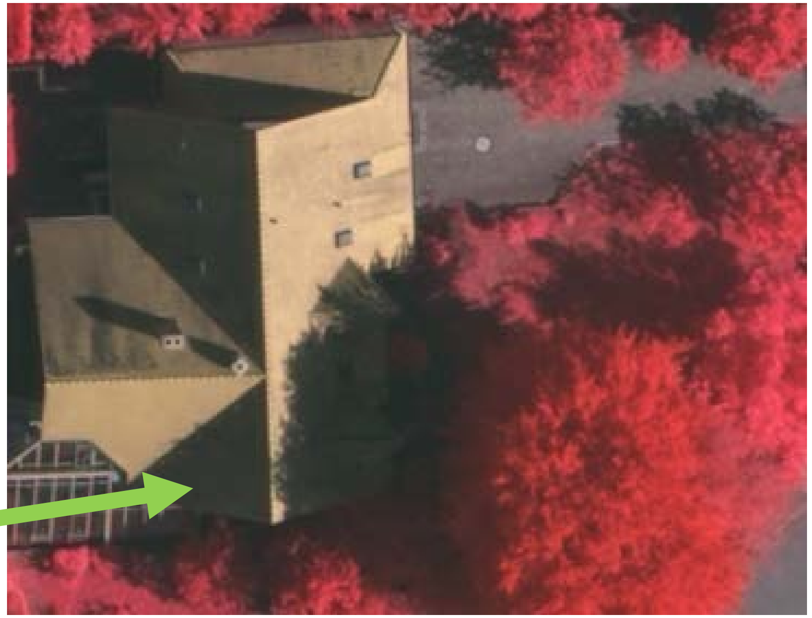
- Horizontal roof planes in combination with complex terrain, objects on roofs
- Dense tree canopies → Problems for methods directly classifying ALS points
- Roofs covered by grass



Common Problems in Building Detection

- Horizontal roof planes in combination with complex terrain, objects on roofs
- Dense tree canopies → Problems for methods directly classifying ALS points
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods

CAL

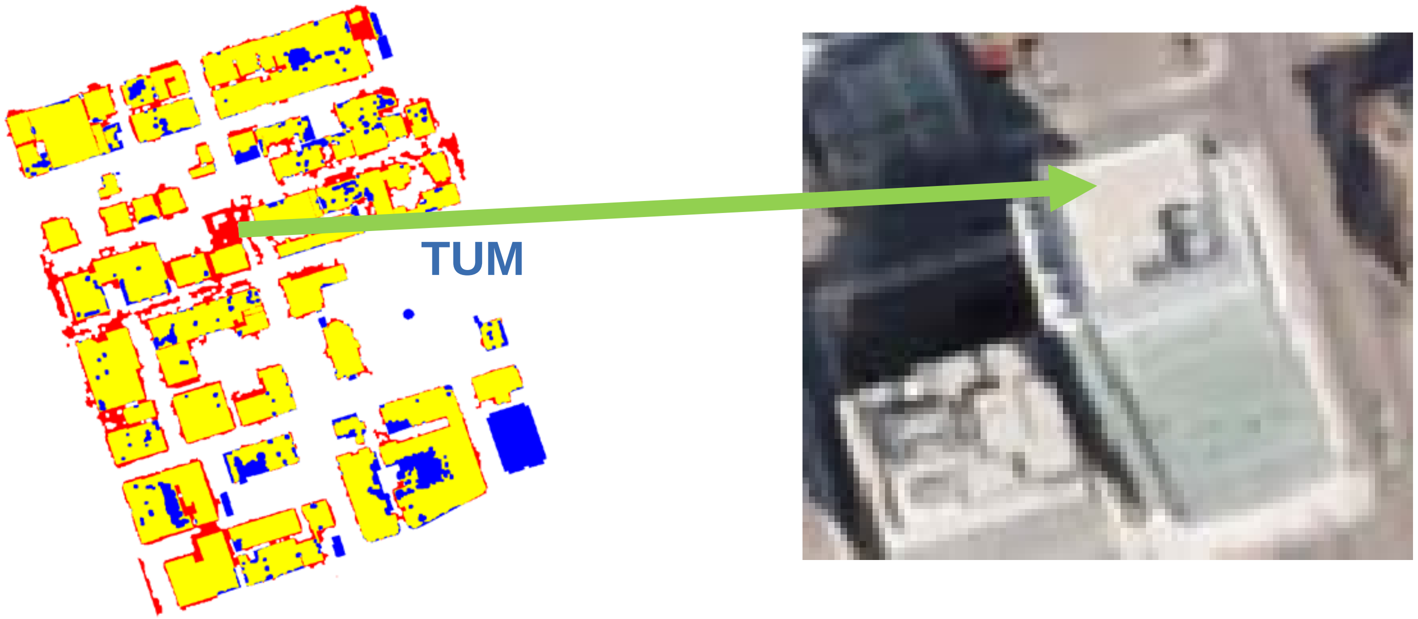


Common Problems in Building Detection

- Horizontal roof planes in combination with complex terrain, objects on roofs
- Dense tree canopies → Problems for methods directly classifying ALS points
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods
- Small building structures

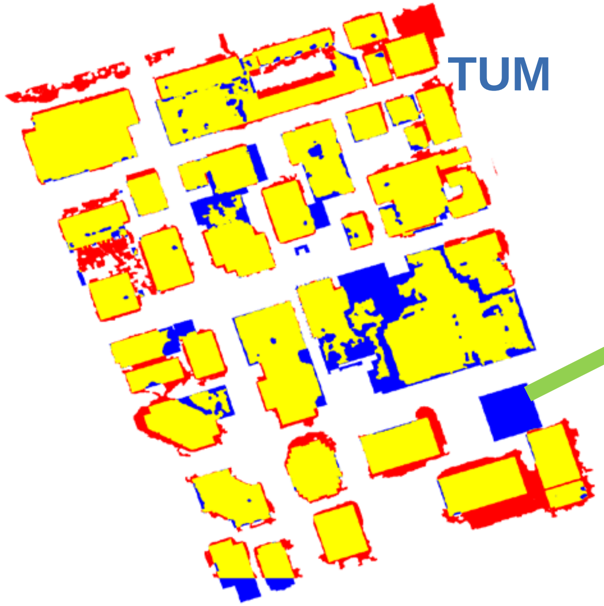
Common Problems in Building Detection

- Horizontal roof planes in combination with complex terrain, objects on roofs
- Dense tree canopies → Problems for methods directly classifying ALS points
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods
- Small building structures
- Occlusion / perspective distortion

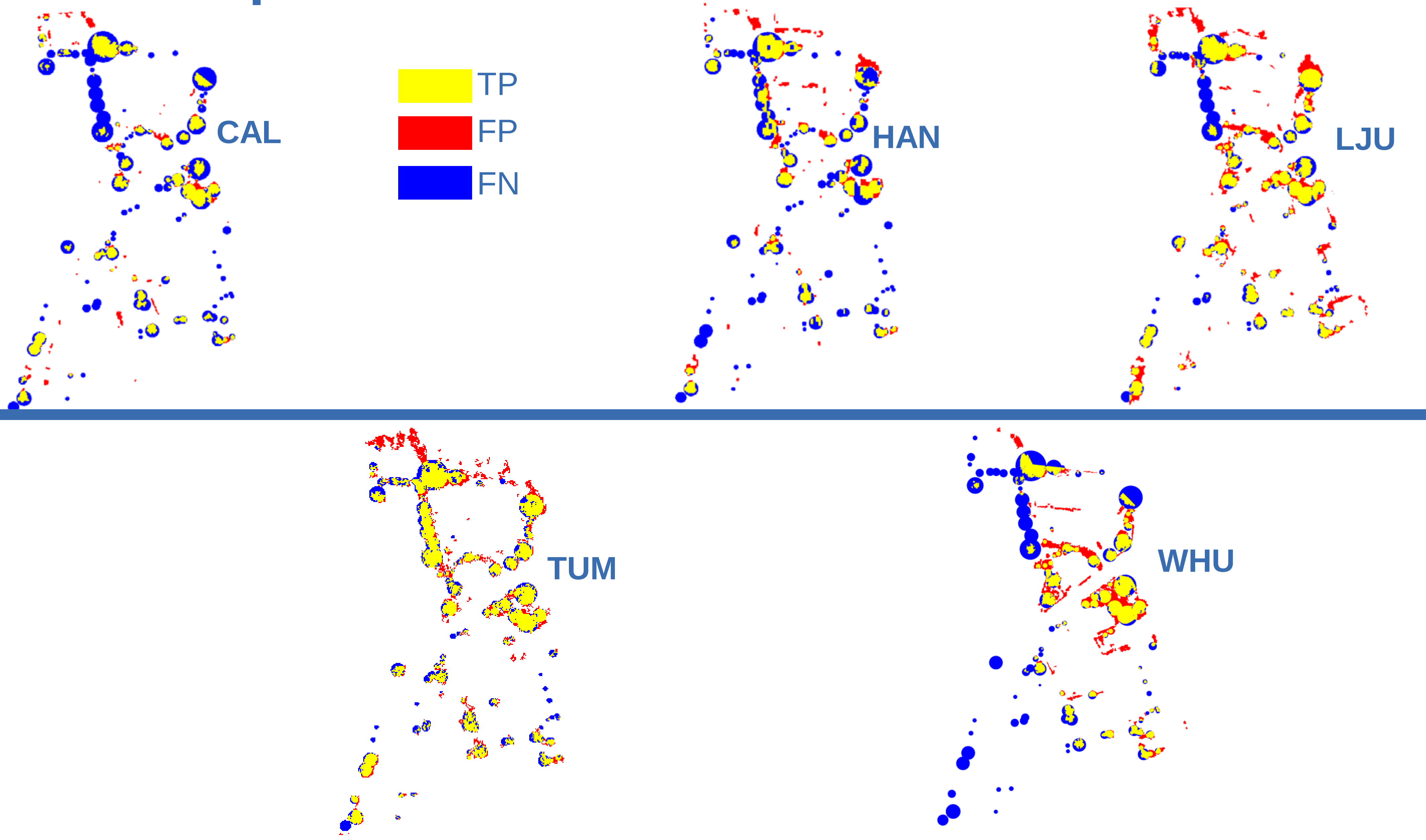


Common Problems in Building Detection

- Horizontal roof planes in combination with complex terrain, objects on roofs
- Dense tree canopies → Problems for methods directly classifying ALS points
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods
- Small building structures
- Occlusion / perspective distortion
- Shadow
- Very low buildings in CBD

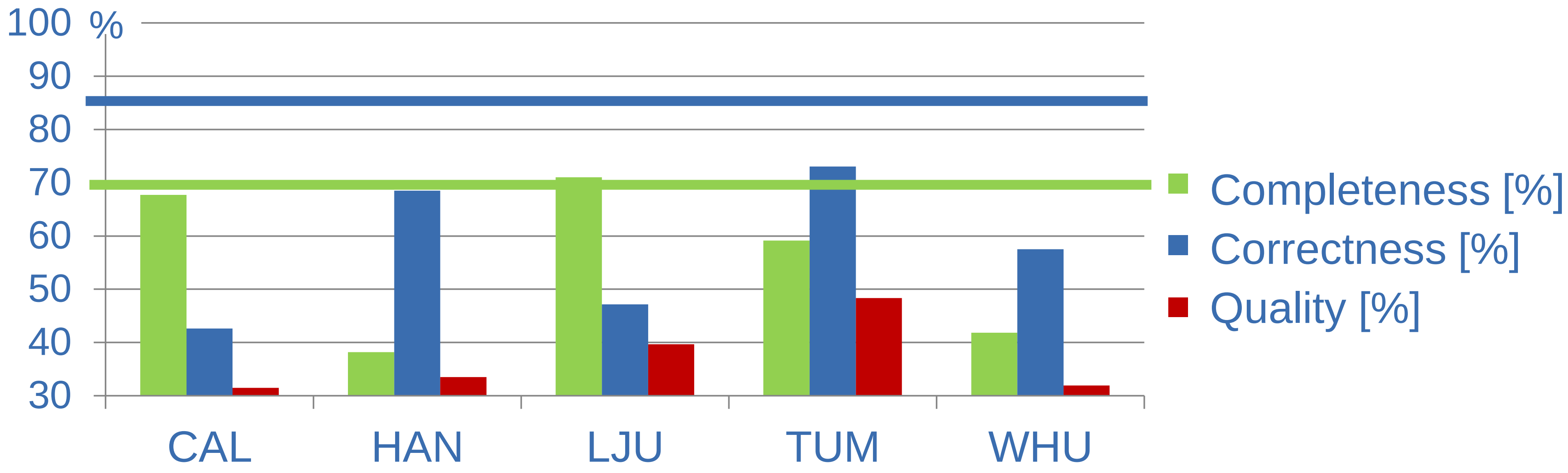


Example for the Evaluation of Tree Detection– Area 1



Evaluation of Tree Detection - Vaihingen

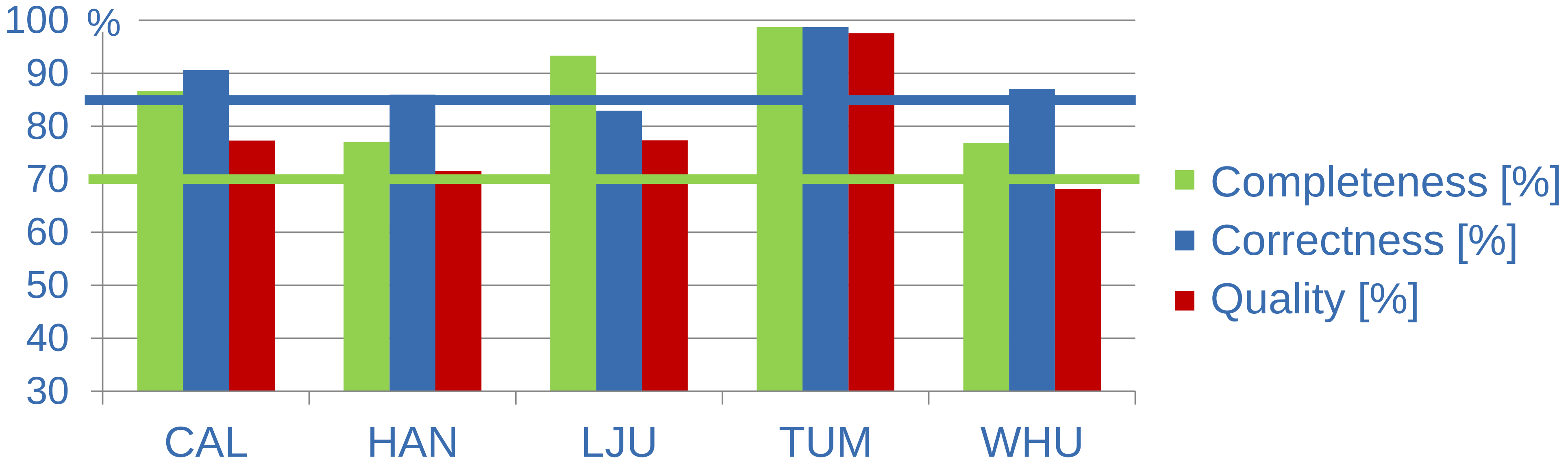
- Object-based evaluation (average Areas 1-3)



- Low performance for all methods compared to building detection
- No method achieves the requirements for practical relevance according to (Mayer et al., 2006)

Evaluation of Tree Detection - Vaihingen

- Object-based evaluation for trees ≥ 50 m^2 (average Areas 1-3)



- 50 m^2 correspond to a crown diameter of about 8 m
- All methods except LJU fulfil the requirements for practical relevance according to (Mayer et al, 2006)
- Problems of tree detection: similar to problems in building detection

Object Detection: Discussion

- **Buildings:**
  - Main buildings per plot can be detected reliably by most methods
  - Most methods can be practically relevant
  - Small buildings remain a problem
  - Occlusions in CBD scene → Multiple overlap required?
  - Slight advantage for methods based on segmentation
  - Full geometrical accuracy potential of images not yet exploited
- **Trees:**
  - More problematic than buildings
  - Practical relevance questionable for small trees
- **Most favourable conditions:** Area 2 (high-rise residential)

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Task of the Participants

- 3D Reconstruction of Buildings (LoD2 of CityGML standard):
  - Detailed roof structures
  - No roof overhangs, balconies

- Deliverables:
  - Roof plane outlines as 3D polygons in object space

Evaluation Methodology

- Quality of roof plane segmentation:
  - Completeness / Correctness / Quality of roof planes
    - Check whether a plane has a substantial overlap with planes in the other data set

- Geometrical Accuracy:
  - RMS_{XY}: RMS errors of the planimetric distances of roof plane boundary points from reference
  - RMS_{Z}: RMS errors of height differences between synthetic DSMs
  - RMS_{Z} is also affected by segmentation errors

Results Submitted by Participants

Submitted by	Abbr.	Affiliation	Areas				
			1	2	3	4	5
W. Zhang	BNU	Beijing Normal University, China			X		
J.-Y. Rau	CKU	Cheng Kung University, Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen, Germany			X		
S. Oude Elberink	ITCE1	ITC, Enschede, The Netherlands	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede, The Netherlands	X	X	X		
B. Xiong	ITCX	ITC, Enschede, The Netherlands	X	X	X		
P. Dorninger	VSK	TU Vienna, Austria	X	X	X		
G. Sohn	YOR	York University, Canada	X	X	X	X	X

- Two participants delivered results for Toronto (areas 4 + 5)
- Two participants only delivered results for area 3

Data used by the participants

Submitted by	Abbr.	Affiliation	Areas				
			1	2	3	4	5
W. Zhang	BNU	Beijing Normal University, China			X		
J.-Y. Rau	CKU	Cheng Kung University, Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen, Germany			X		
S. Oude Elberink	ITCE1	ITC, Enschede, The Netherlands	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede, The Netherlands	X	X	X		
B. Xiong	ITCX	ITC, Enschede, The Netherlands	X	X	X		
P. Dorninger	VSK	TU Vienna, Austria	X	X	X		
G. Sohn	YOR	York University, Canada	X	X	X	X	X

- Images only (2)
- Images + ALS points (1)
- ALS points (5)

Degree of Automation

Submitted by	**Abbr.**	**Affiliation**	**Areas**				
			1	2	3	4	5
W. Zhang	BNU	Beijing Normal University, China			X		
J.-Y. Rau	CKU	Cheng Kung University, Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen, Germany			X		
S. Oude Elberink	ITCE1	ITC, Enschede, The Netherlands	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede, The Netherlands	X	X	X		
B. Xiong	ITCX	ITC, Enschede, The Netherlands	X	X	X		
P. Dorninger	VSK	TU Vienna, Austria	X	X	X		
G. Sohn	YOR	York University, Canada	X	X	X	X	X

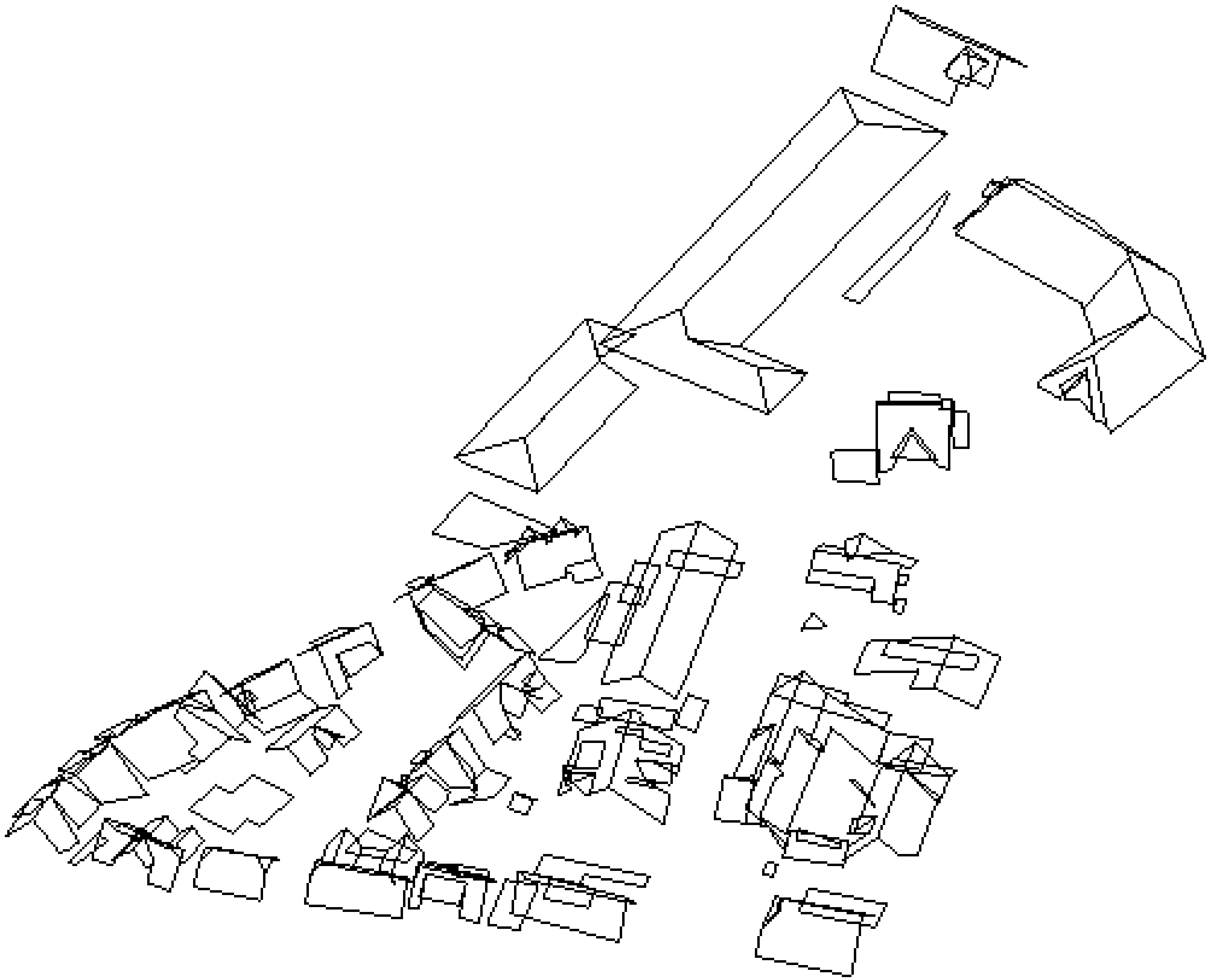
- Semi-automatic (2)
- Fully automatic (6)

Building Models

Submitted by	Abbr.	Affiliation	Areas				
			1	2	3	4	5
W. Zhang	BNU	Beijing Normal University, China			X		
J.-Y. Rau	CKU	Cheng Kung University, Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen, Germany			X		
S. Oude Elberink	ITCE1	ITC, Enschede, The Netherlands	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede, The Netherlands	X	X	X		
B. Xiong	ITCX	ITC, Enschede, The Netherlands	X	X	X		
P. Dorninger	VSK	TU Vienna, Austria	X	X	X		
G. Sohn	YOR	York University, Canada	X	X	X	X	X

- Generic (polyhedral) (4)
- Primitives (1)
- Adaptive (3)

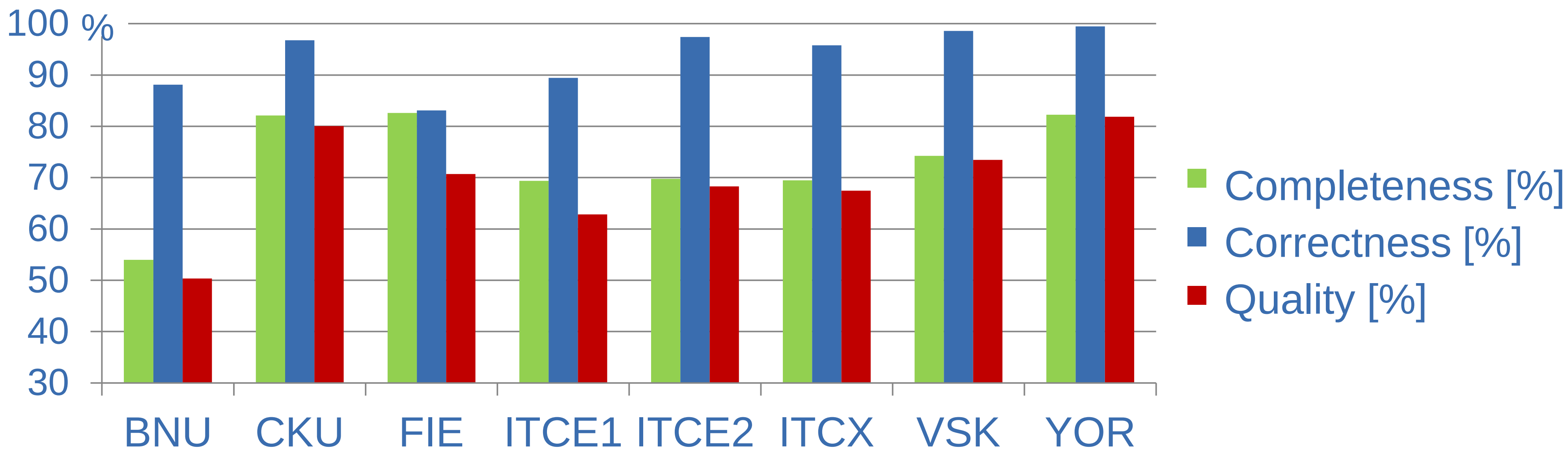
Results: Examples (Vaihingen, Area 1)



3D Visualisation (YOR)

Evaluation of Building Reconstruction - Vaihingen

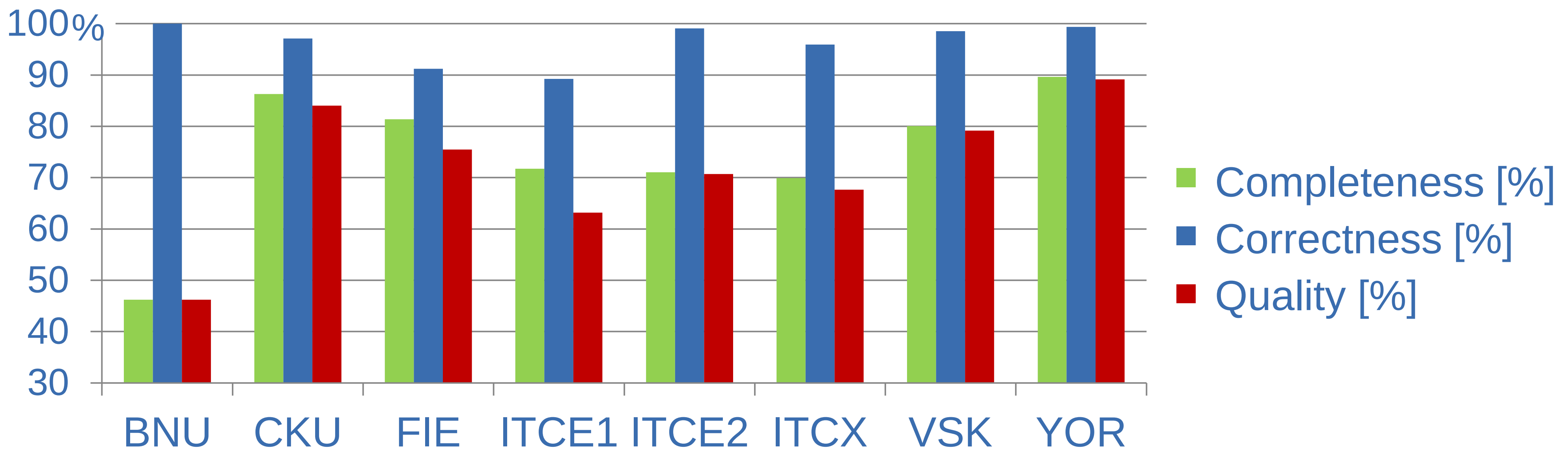
- Evaluation for all roof planes (average Areas 1-3)



- Correctness > 80% for all methods
- Number of undetected roof planes > 25% except for CKU (semi-automatic), FIE, YOR

Evaluation of Building Reconstruction - Vaihingen

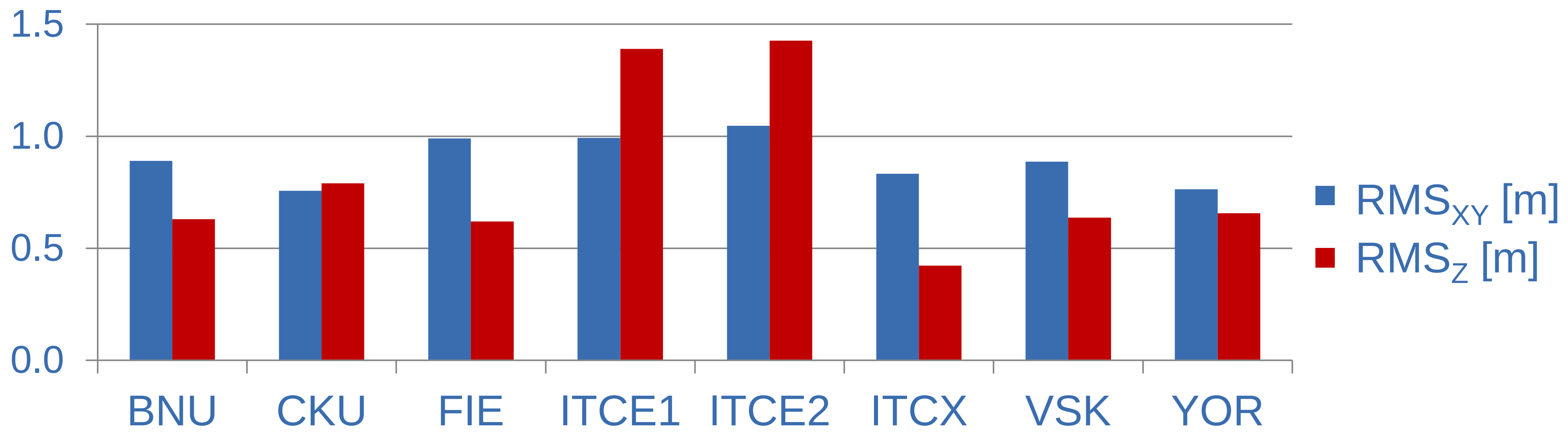
- Evaluation for roof planes >10 m^2 (average Areas 1-3)



- Correctness > 89% for all methods
- Number of undetected planes is still relatively large for most methods

Evaluation of Building Reconstruction - Vaihingen

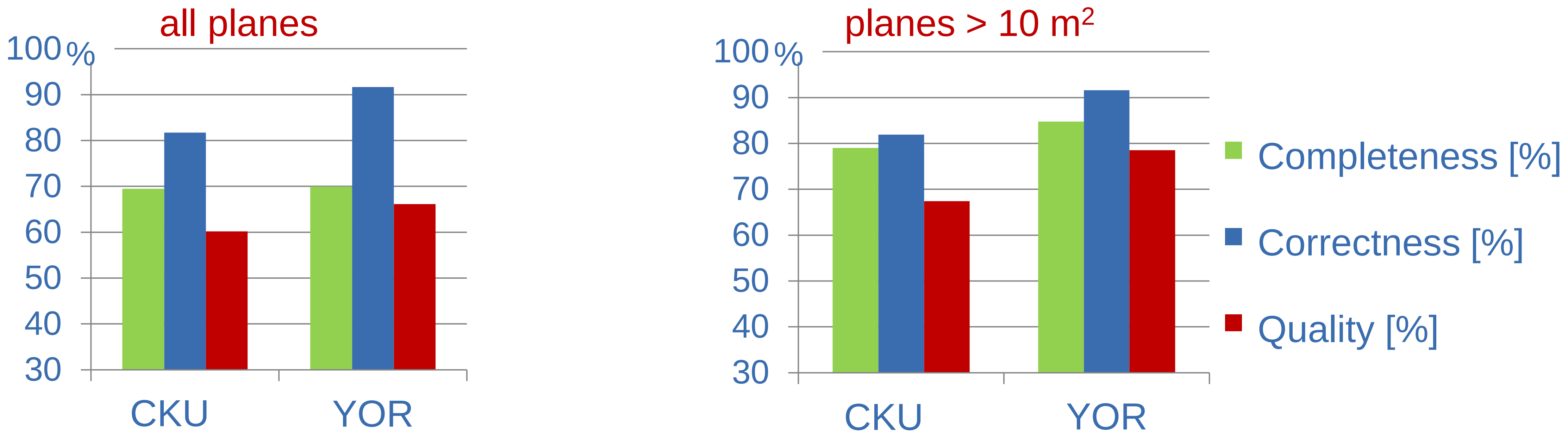
- Geometrical errors(average Areas 1-3)



- Order of magnitude (planimetry): 3 – 4 times the ALS point spacing
- Height errors are relatively large (influenced by segmentation errors)
- Full accuracy potential not exploited

Evaluation of Building Reconstruction - Toronto

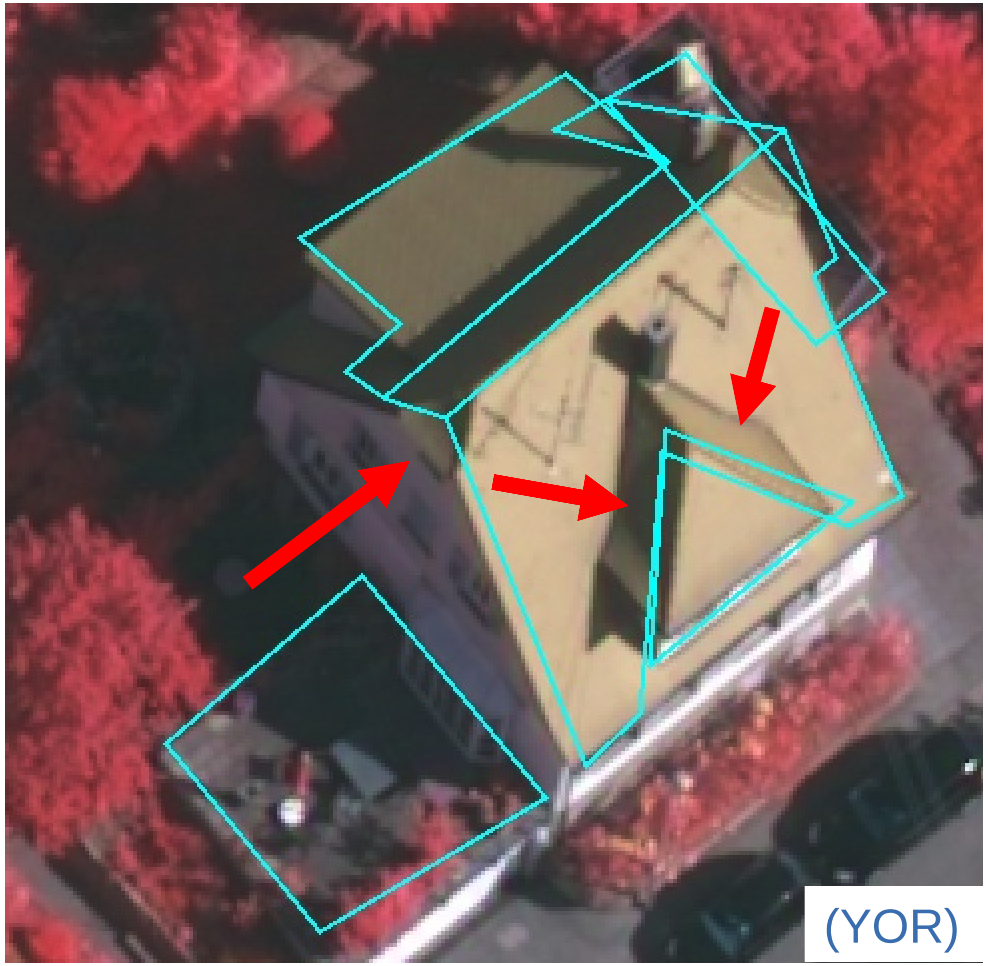
- Evaluation for roof planes (average Areas 4 & 5)



- Correctness > 80% for all methods
- Slightly lower completeness / correctness values than in Vaihingen
- RMS errors larger than Vaihingen
  - YOR: 1.05 m (X,Y) / 15 m (Z)

Common Problems in Building Reconstruction

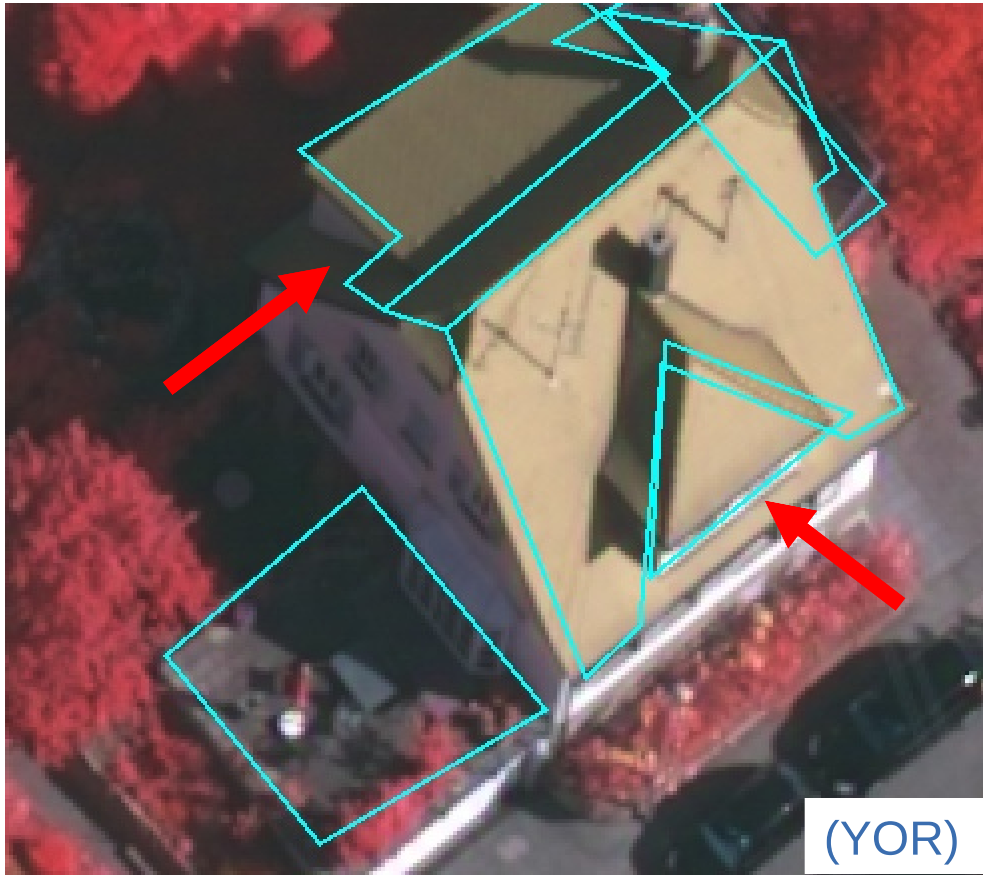
- Small roof planes



(YOR)

Common Problems in Building Reconstruction

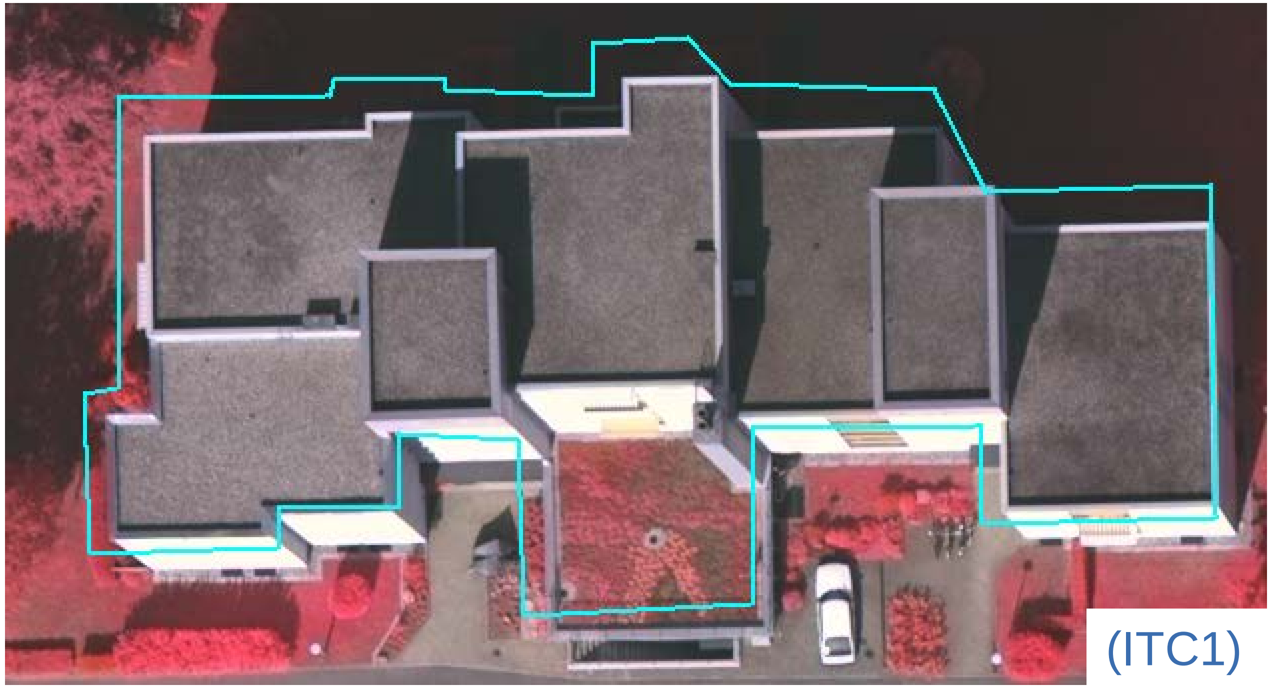
- Small roof planes
- Small appendices to larger roof planes



(YOR)

Common Problems in Building Reconstruction

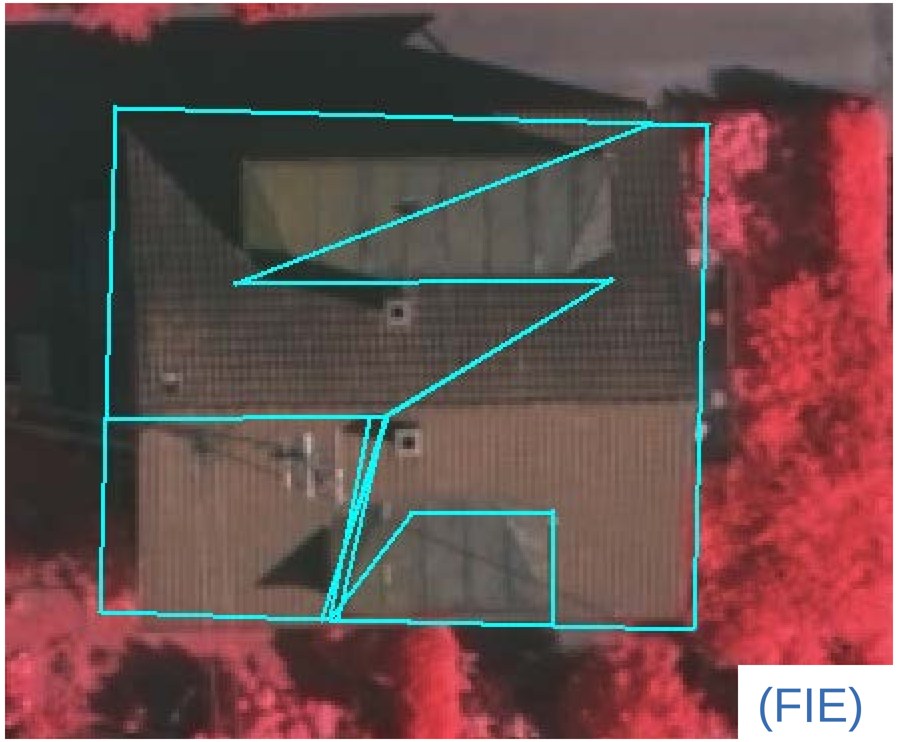
- Small roof planes
- Small appendices to larger roof planes
- Undersegmentation



(ITC1)

Common Problems in Building Reconstruction

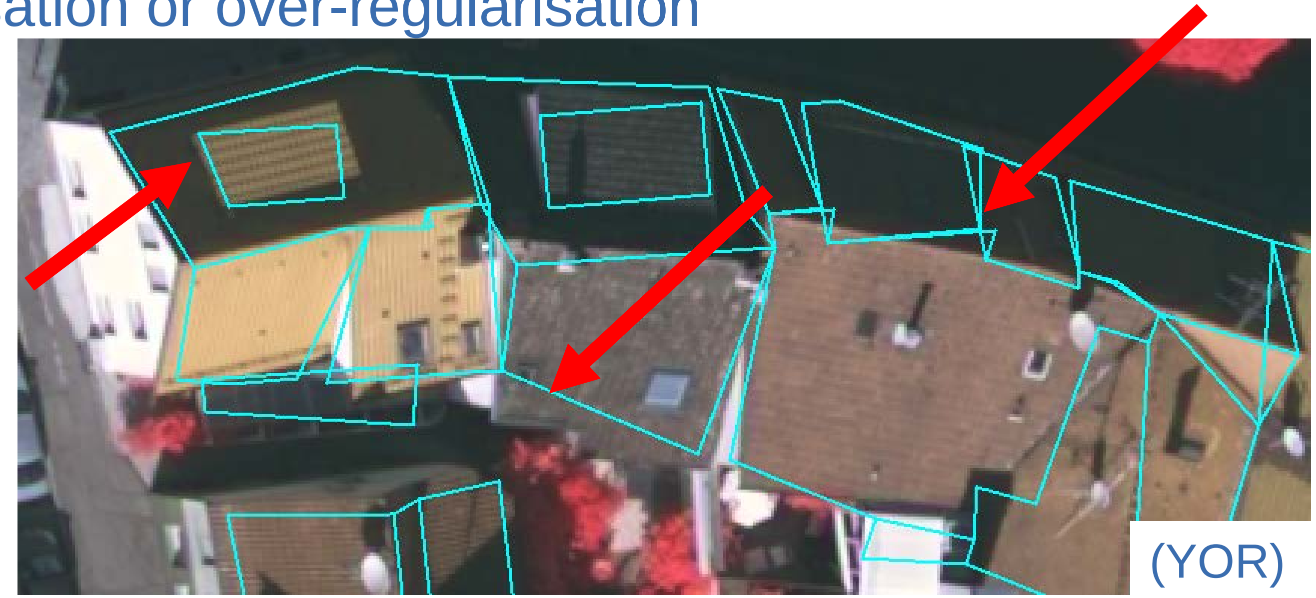
- Small roof planes
- Small appendices to larger roof planes
- Undersegmentation
- Wrong segmentation



(FIE)

Common Problems in Building Reconstruction

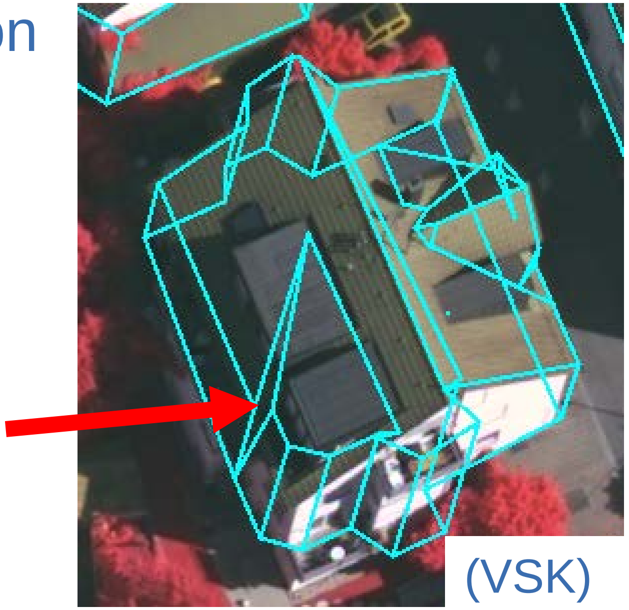
- Small roof planes
- Small appendices to larger roof planes
- Undersegmentation
- Wrong segmentation
- Missing regularisation or over-regularisation



(YOR)

Common Problems in Building Reconstruction

- Small roof planes
- Small appendices to larger roof planes
- Undersegmentation
- Wrong segmentation
- Missing regularisation or over-regularisation
- Incorrect combination of planes



(VSK)

Building Reconstruction: Discussion

- Building reconstruction works well for
  - Simply-shaped buildings
  - Buildings whose dormers are small compared to dominant roof planes
- Complex objects do not just lead to more generalized models
- Accuracy potential of the sensors not yet fully exploited
- Most favourable conditions: Area 2 (high-rise residential)
- Results are generally sufficient for a ‘nice’ visualisation
- Fully automatic generation of topologically and geometrically correct models in complex environments is still a challenge

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Outlook

- The data may still be obtained via the WWW:
  http://www.itc.nl/ISPRS_WGIII4/tests_datasets.html
- Results are still accepted and evaluated
- Results are available in the WWW
- Changed conditions of use: **Vaihingen data may be used for any scientific purpose**
- Basis for a **standard data set for urban object extraction**
- Special issue of a journal will be announced soon
- Interested in individual methods?

  → Sessions ISPRS Benchmark – 1 at 14:00 – 15:30, Room MCEC 219
  ISPRS Benchmark – 2 at 16:00 – 17:30, Room MCEC 219