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

Franz Rottensteiner [a], Gunho Sohn [b], J. Jung [b], Markus Gerke [c], Caroline Baillard [d], Sebastien Benitez [d], Uwe Breitkopf [a]

[a] Institute of Photogrammetry & GeoInformation, University Hannover, Germany

[b] GeoICT Lab, York University, Toronto, Camada

[c] University of Twente, Faculty ITC; EOS Dept., Enschede, The Netherlands

[d] SIRADEL, Rennes, France

Outline

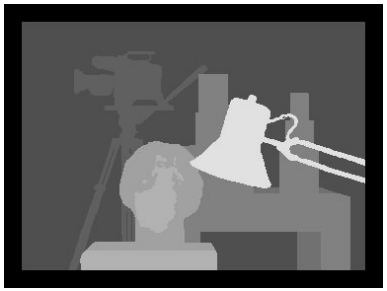
- Introduction
- Test Data
- Object Detection
  - Task and Evaluation Methodology
  - Evaluation of Building Detection
  - Evaluation of Tree Detection
- 3D Building Reconstruction
  - Task and Evaluation Methodology
  - Results
  - Discussion
- Conclusion

Outline

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

Benchmarks

- Benchmarks are widely used in Computer Vision to make the results of different solutions comparable
- Examples:
  - Middlebury Stereo Vision test (Scharstein & Szeliski, 2002)



  - PASCAL VOC (Everingham et al., 2010)

- Urban object extraction in photogrammetry & remote sensing?

Benchmark on (Urban) Object Extraction?

- Benchmarks for object extraction by OEEPE/EuroSDR:
  - Building extraction (Kaartinen et al., 2005): scanned aerial images + airborne laserscanner (ALS) data
  - Road extraction (Mayer et al., 2006): orthophotos from scanned aerial images and from satellite images
  - Updating of building data bases (Champion et al., 2009): digital aerial / satellite images, ALS + (scanned) orthophoto
- Outdated as far as airborne sensors are concerned

→ Need for new benchmark data sets for urban object extraction

Benchmarks on (Urban) Object Extraction!

- Data set of ISPRS WG III/4 “Complex scene analysis and 3D reconstruction”: http://www.itc.nl/ISPRS_WGIII4/tests_datasets.html
- The data have been downloaded by ~140 participants
- Tasks
  1) **Urban object detection:** buildings, trees, roads, cars
  2) **3D building reconstruction:** roof plane boundaries
- Results submitted by the participants are evaluated by WG III/4 based on reference data (cf. http://tinyurl.com/ISPRStest)
- This presentation: report on the results

Outline

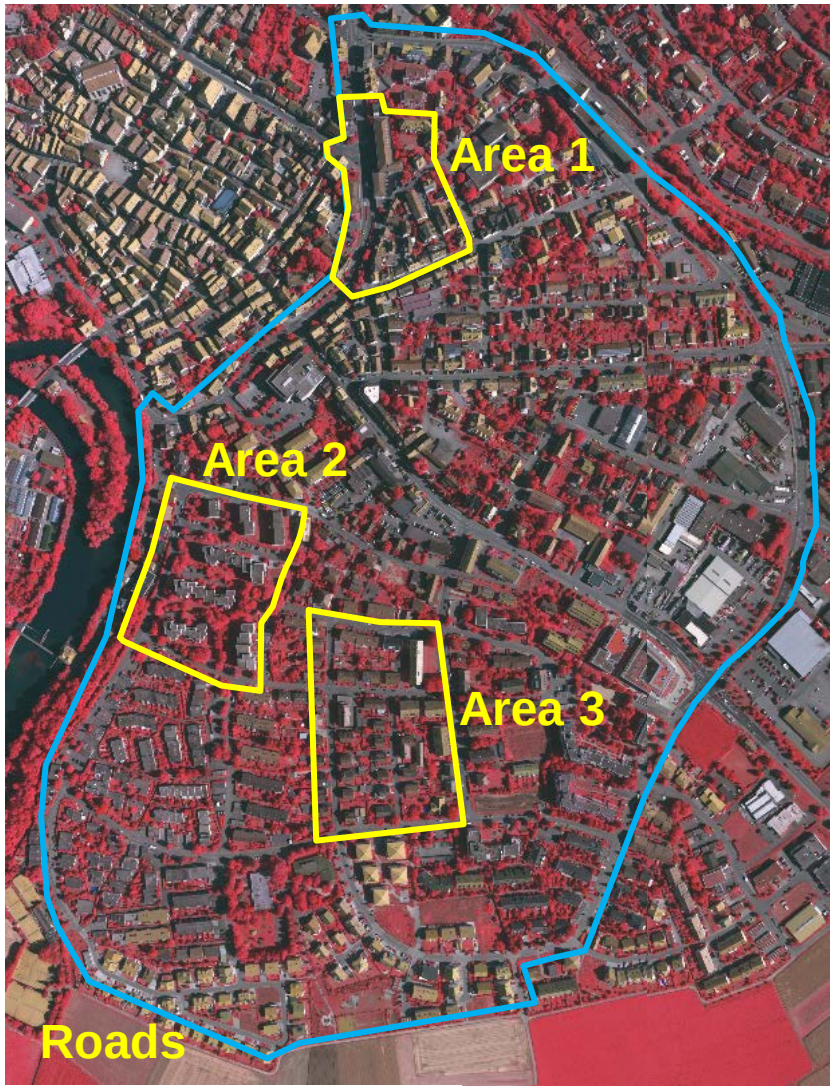
- Introduction
- Test Data
- Object Detection
  - Task and Evaluation Methodology
  - Evaluation of Building Detection
  - Evaluation of Tree Detection
- 3D Building Reconstruction
  - Task and Evaluation Methodology
  - Results
  - Discussion
- Conclusion

Test Data: Overview

- Two urban test data sets consisting of
  - High-resolution digital aerial images + orientation data
  - ALS point cloud
  - Digital surface model (DSM) from last ALS pulses
- Reference data were generated by manual stereo plotting
- **Data sets:**
  1) Vaihingen / Enz (Germany): typical “old world” scenario
  2) Downtown Toronto (Canada): typical “new world” scenario

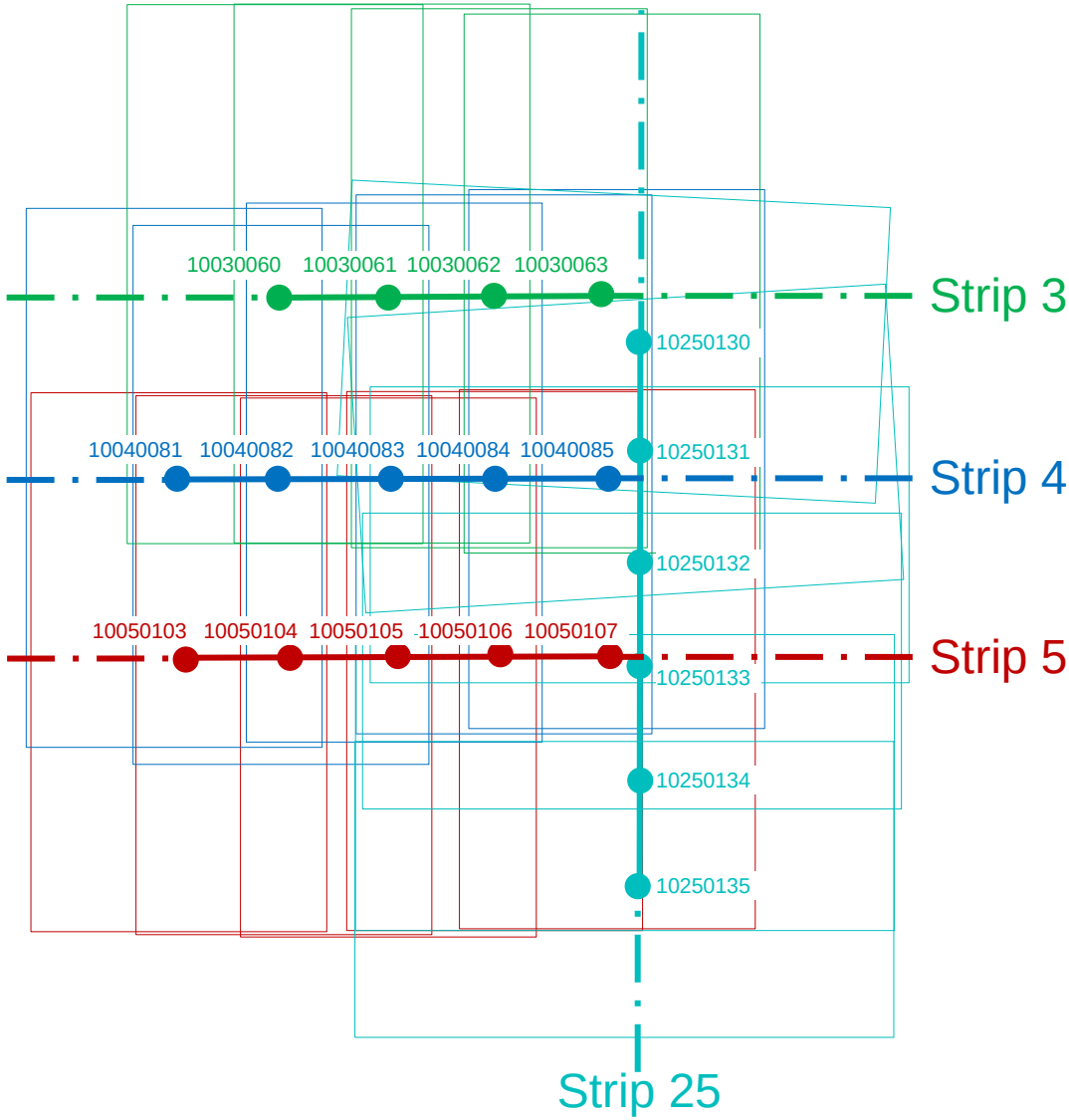
Data Set 1: Vaihingen / Enz (Germany)

- **Aerial images:**
  - Z/I DMC (c = 120 mm)
  - 20 images in 4 strips
  - GSD: 8 cm
  - 11 bit CIR (pan-sharpened)
  - Accuracy of orientation: ± 1 pixel



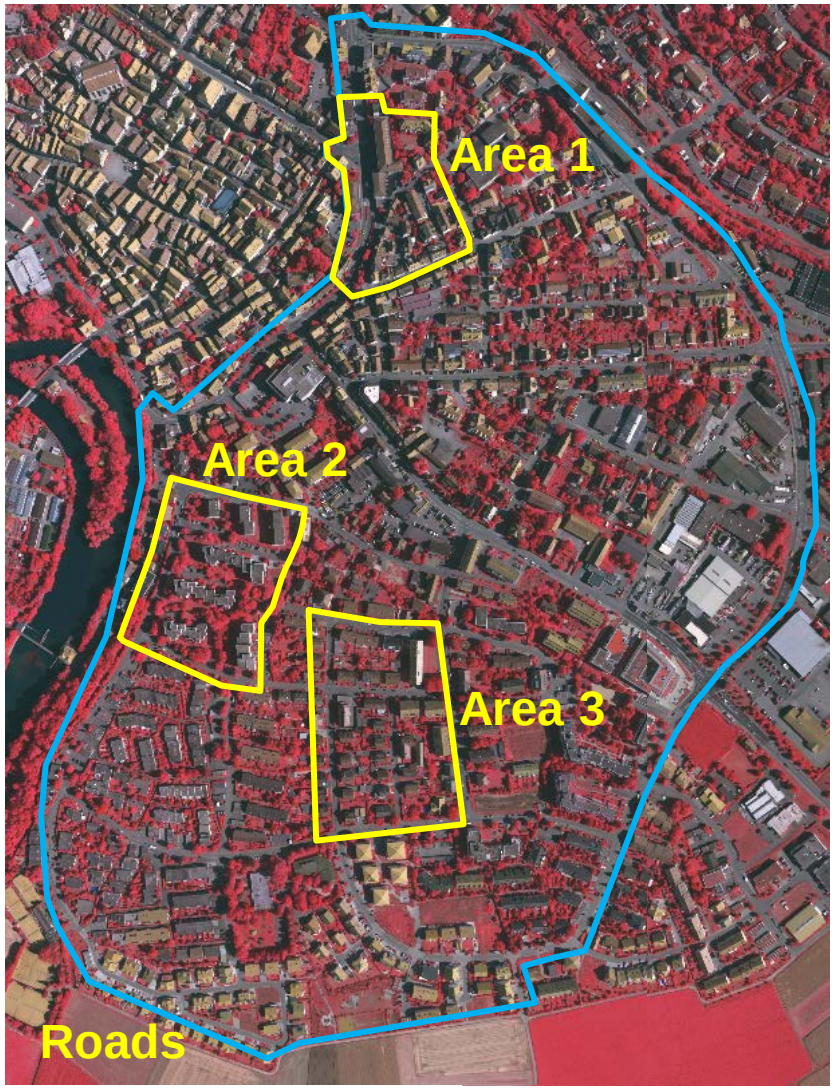
Vaihingen / Enz: Image Configuration

- 4 strips (1 cross strip)
- 70 % forward overlap
- 60% side lap
  → fourfold overlap guaranteed!



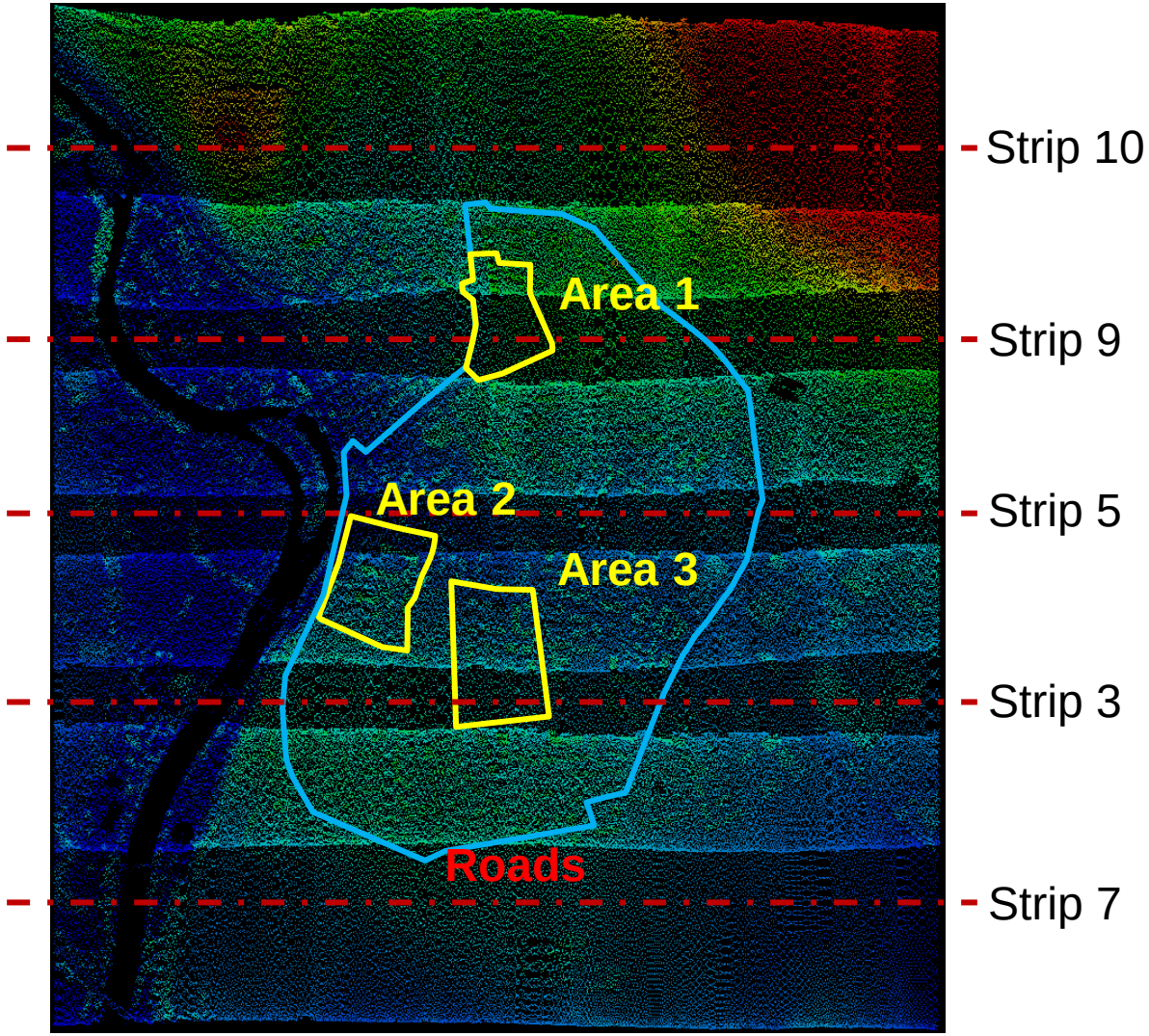
Data Set 1: Vaihingen / Enz (Germany)

- **Aerial images:**
  - Z/I DMC (c = 120 mm)
  - 20 images in 4 strips
  - GSD: 8 cm
  - 11 bit CIR (pan-sharpened)
  - Accuracy of orientation: ± 1 pixel
- **ALS data:**
  - Leica ALS 50
  - 5 strips (30% overlap)
  - 4 - 7 points/m^2, multiple pulses with intensities
  - Accuracy: ± 3 cm



Vaihingen / Enz: ALS Configuration

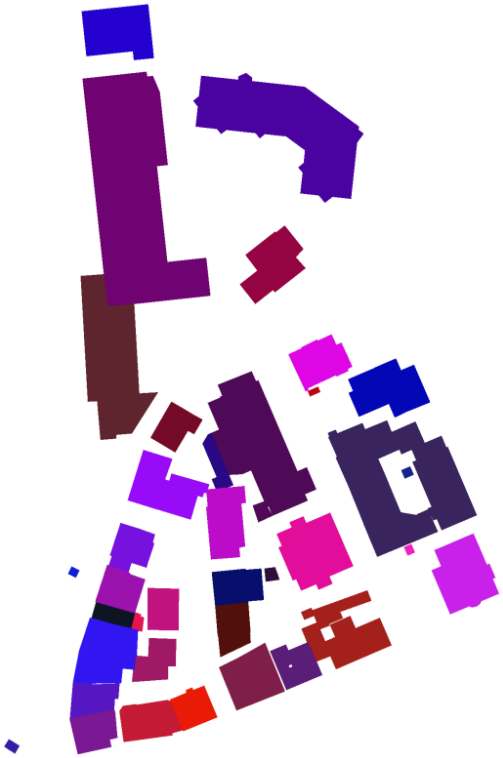
- 5 strips
- DSM interpolated at 25 cm



Vaihingen: Test Area 1

- Dense urban development, historic inner city area

Area 1: 125 m x 200 m

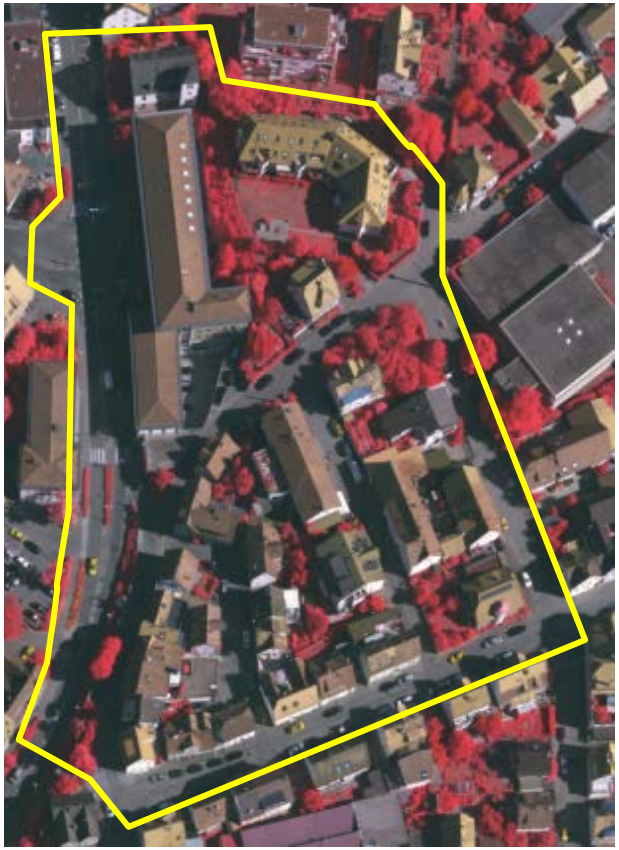


Reference:
37 building outlines
accuracy: ± 10 cm

Reference:
105 trees
accuracy: ± 1 m

Vaihingen: Test Area 1

- Dense urban development, historic inner city area

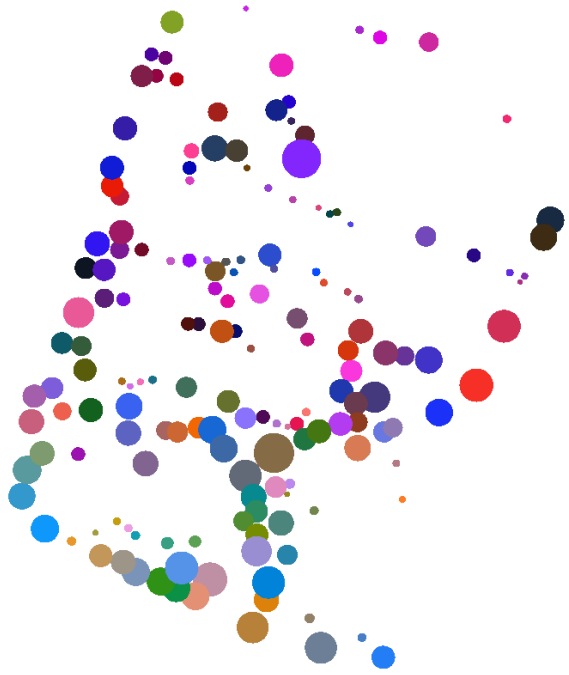


Area 1: 125 m x 200 m

Reference (roofs)
accuracy: ± 10 cm

Vaihingen: Test Area 2

- High-rise residential buildings



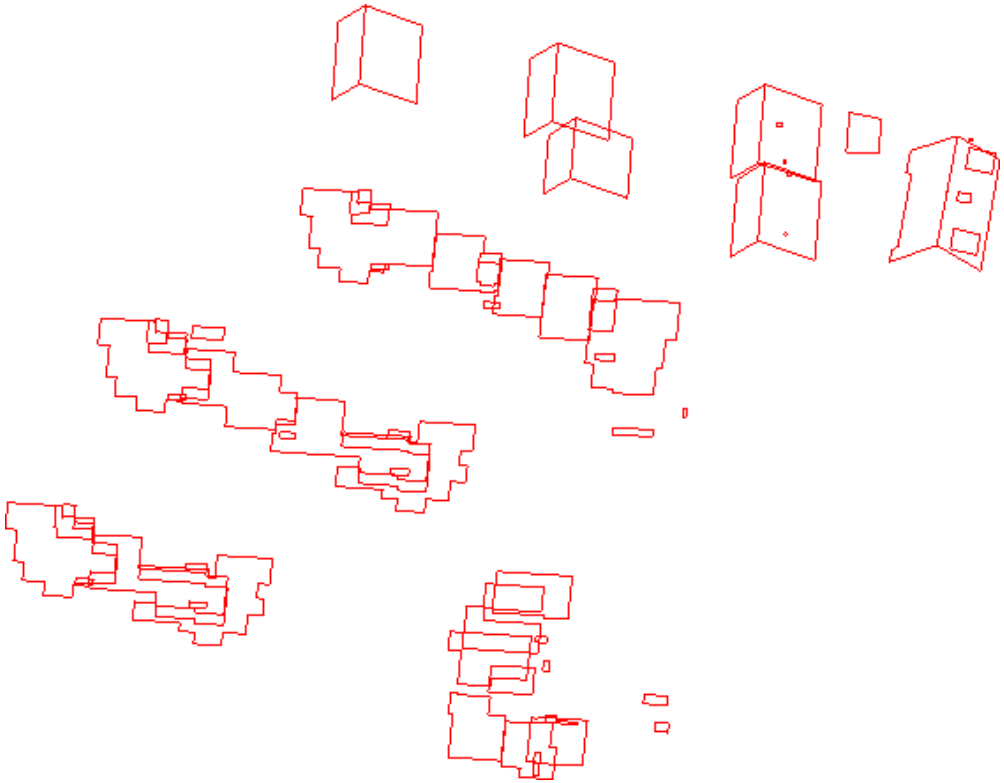
Area 2: 170 m x 190 m

Reference:
14 building outlines
accuracy: ± 10 cm

Reference:
162 trees
accuracy: ± 1 m

Vaihingen: Test Area 2

- High-rise residential buildings



Area 2: 170 m x 190 m

Reference (roofs)
accuracy: ± 10 cm

Vaihingen: Test Area 3

- Residential buildings with detached houses

Area 3: 150 m x 220 m

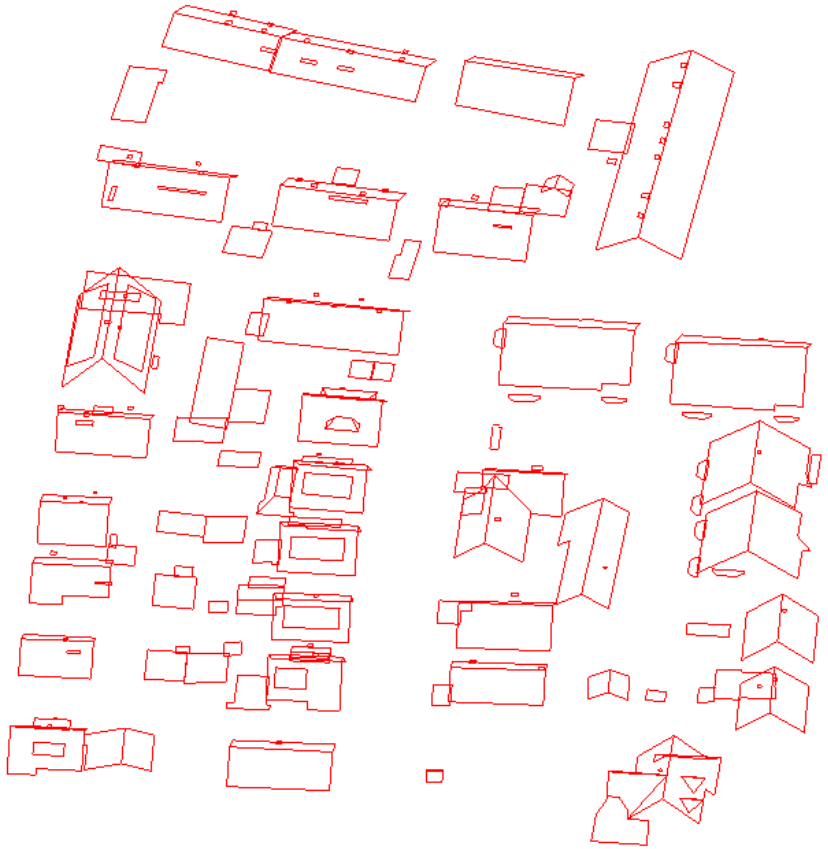
Reference
56 building outlines
accuracy: ± 10 cm

Reference
155 trees
accuracy: ± 1 m

Vaihingen: Test Area 3

- Residential buildings with detached houses

Area 3: 150 m x 220 m



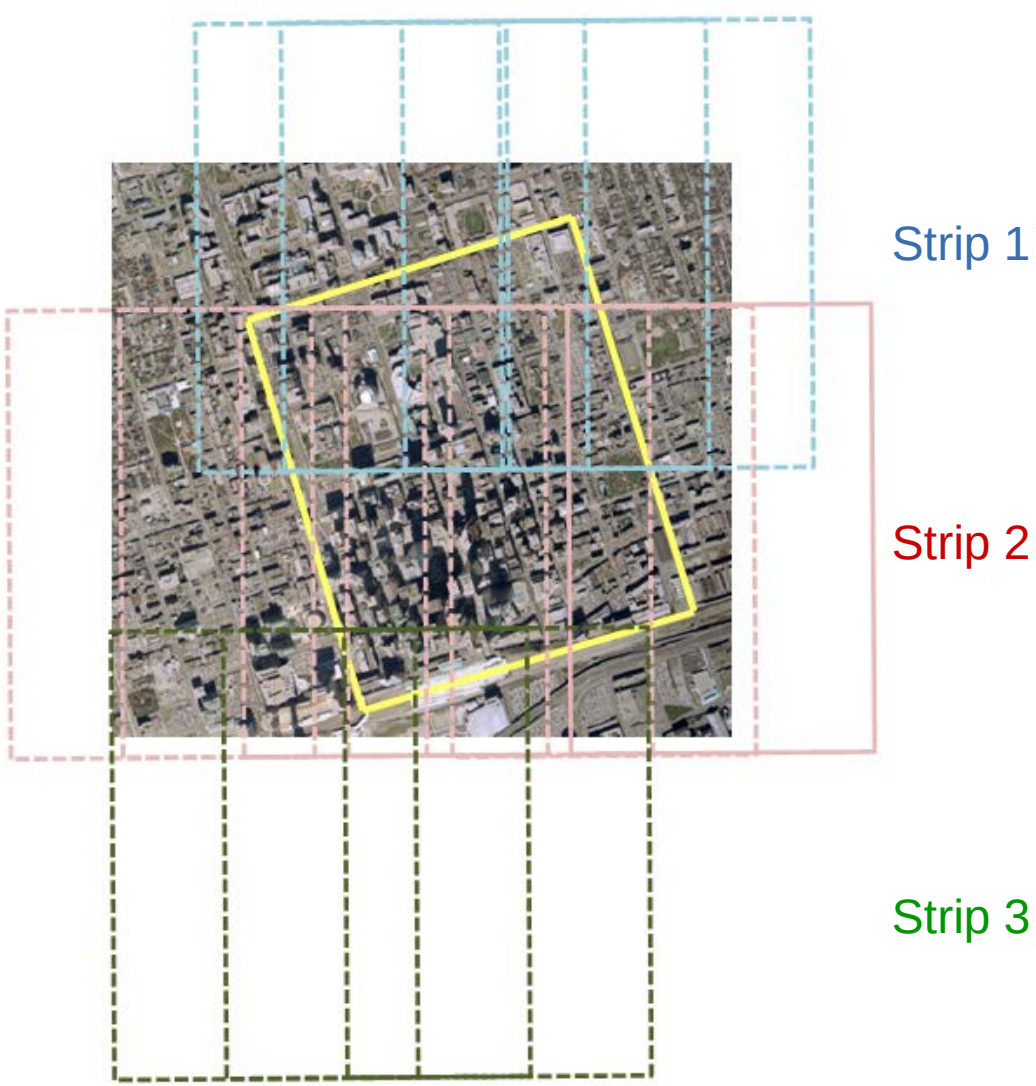
Reference (roofs)
accuracy: ± 10 cm

Data Set 2: Downtown Toronto (Canada)

- **Aerial images:**
  - Microsoft Vexcel UltraCam-D (c = 101.4 mm)
  - 13 images in 3 strips
  - GSD: 15 cm
  - 8 bit RGB (pan-sharpened)
  - Accuracy of orientation: ± 1 pixel

Downtown Toronto: Image Configuration

- 3 strips
- 60 % forward overlap
- 30% side lap
  → occlusions due to high buildings

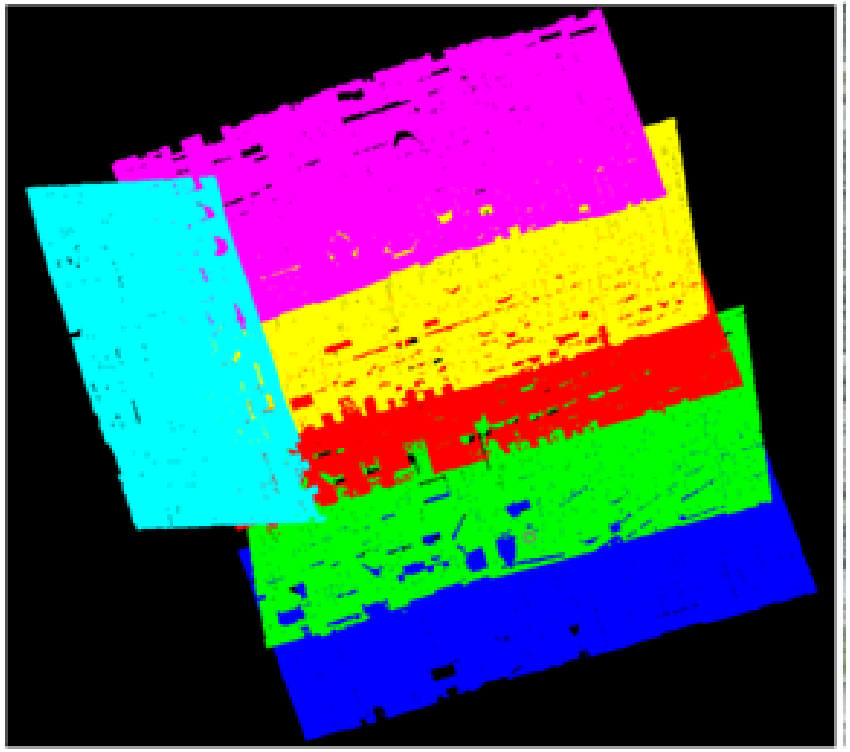


Data Set 2: Downtown Toronto (Canada)

- **Aerial images:**
  - Microsoft Vexcel UltraCam-D (c = 101.4 mm)
  - 13 images in 3 strips
  - GSD: 15 cm
  - 8 bit RGB (pan-sharpened)
  - Accuracy of orientation: ± 1 pixel
- **ALS data:**
  - Optech's ALTM-ORION M
  - 6 strips (30% overlap)
  - 6 points/m^2, multiple pulses with intensities
  - Accuracy: ± 5 cm

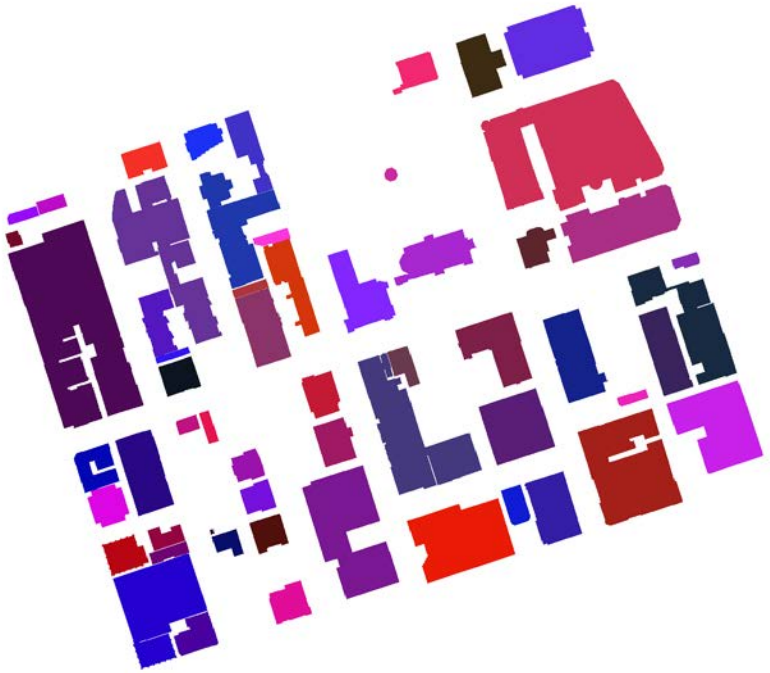
Downtown Toronto: ALS Configuration

- 6 strips
- DSM interpolated at 25 cm



Downtown Toronto: Test Area 4

- Mixture of low and high-storey buildings, Park

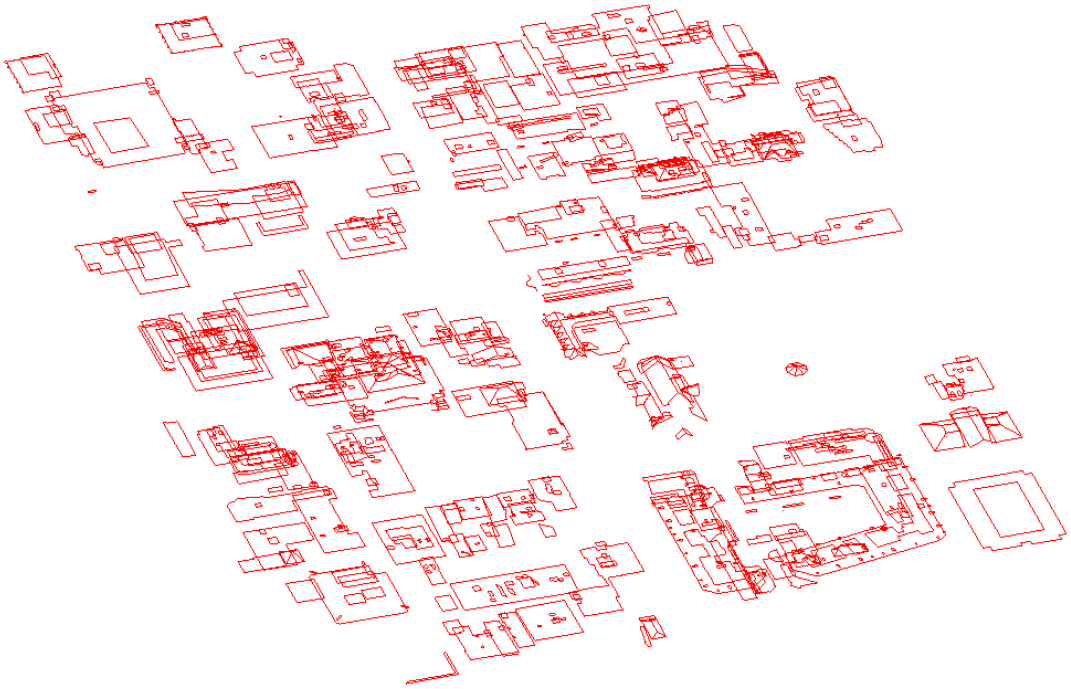


Area 4: 530 m x 600 m

Reference
58 building outlines
accuracy: ± 20 cm

Downtown Toronto: Test Area 4

- Mixture of low and high-storey buildings, Park

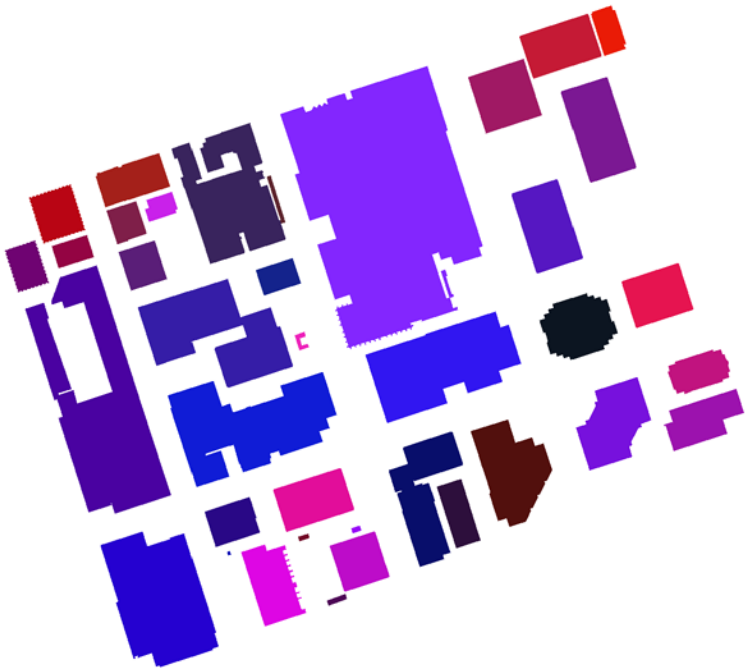


Area 4: 530 m x 600 m

Reference (roofs)
accuracy: ± 20 cm (X / Y)
± 15 cm (Z)

Downtown Toronto: Test Area 5

- Downtown area, high-rise buildings

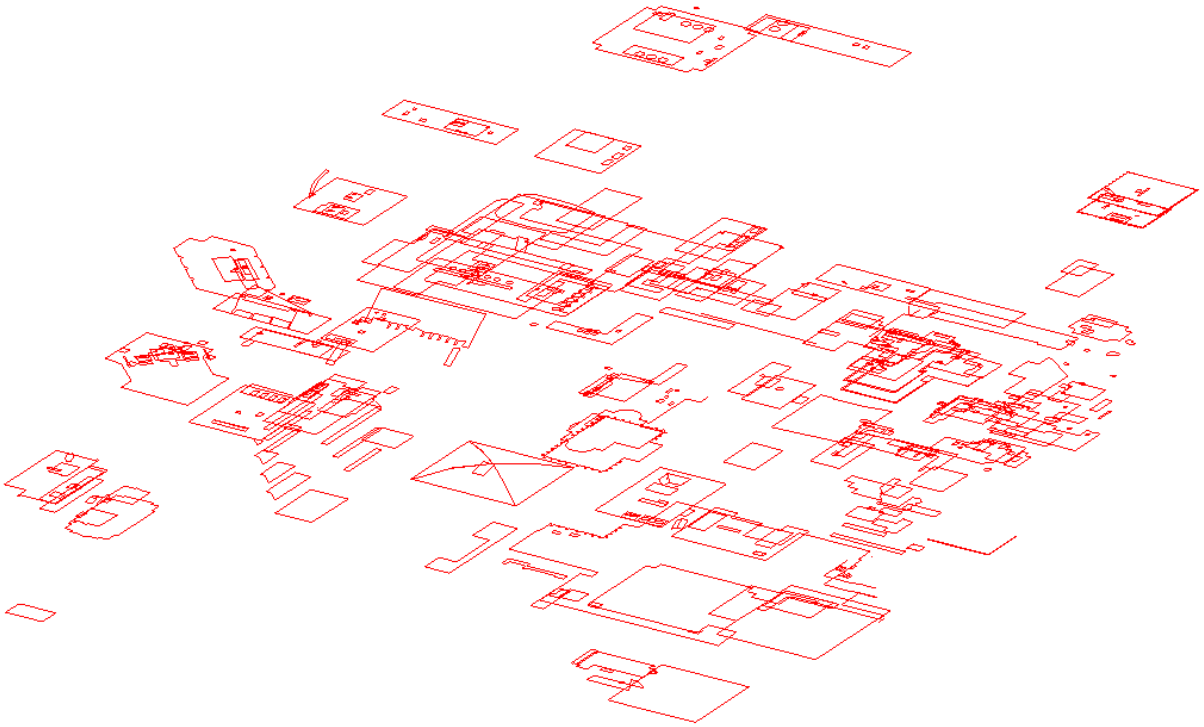


Area 5: 530 m x 600 m

Reference
38 building outlines
accuracy: ± 20 cm

Downtown Toronto: Test Area 5

- Downtown area, high-rise buildings



Area 5: 530 m x 600 m

Reference (roofs)
accuracy: ± 20 cm (X / Y)
± 15 cm (Z)

Outline

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

Task of the Participants

- Detection of urban objects:
  - Buildings
  - Trees
  - (...)
- Deliverables: one of the following per object class
  - Object outlines as (2D or 3D) polygons in object space
  - Label image of objects + georeferencing information
  - (binary mask of object pixels) + georeferencing information

Evaluation Methodology

- Evaluation of thematic accuracy:

  Completeness = TP / (TP + FN)

  Correctness = TP / (TP + FP)

  Quality = TP / (TP + FN + FP)

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

- Evaluation of geometrical accuracy (TP objects only):
  - RMS error of distances

    … from extracted outlines to reference outline (buildings), no considering points with distance > 3 m

    … from extracted centres of gravity to reference (trees)

Evaluation Methodology

- Completeness / Correctness / Quality are determined for three entities:
  - per-area: based on counting TP/FP/FN pixels in a raster image (buildings only)
  - per-object: an object is counted as a TP if at least 50% of its area coincide with an object in the other data set
  - per-object (50 m^2): These measures show the performance for the most relevant objects (covering an area > 50 m^2)
- Mayer et al, 2006: Requirements for practical relevance:
  - Completeness ≥ 70%
  - Correctness ≥ 85%

Results Submitted by Participants

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

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

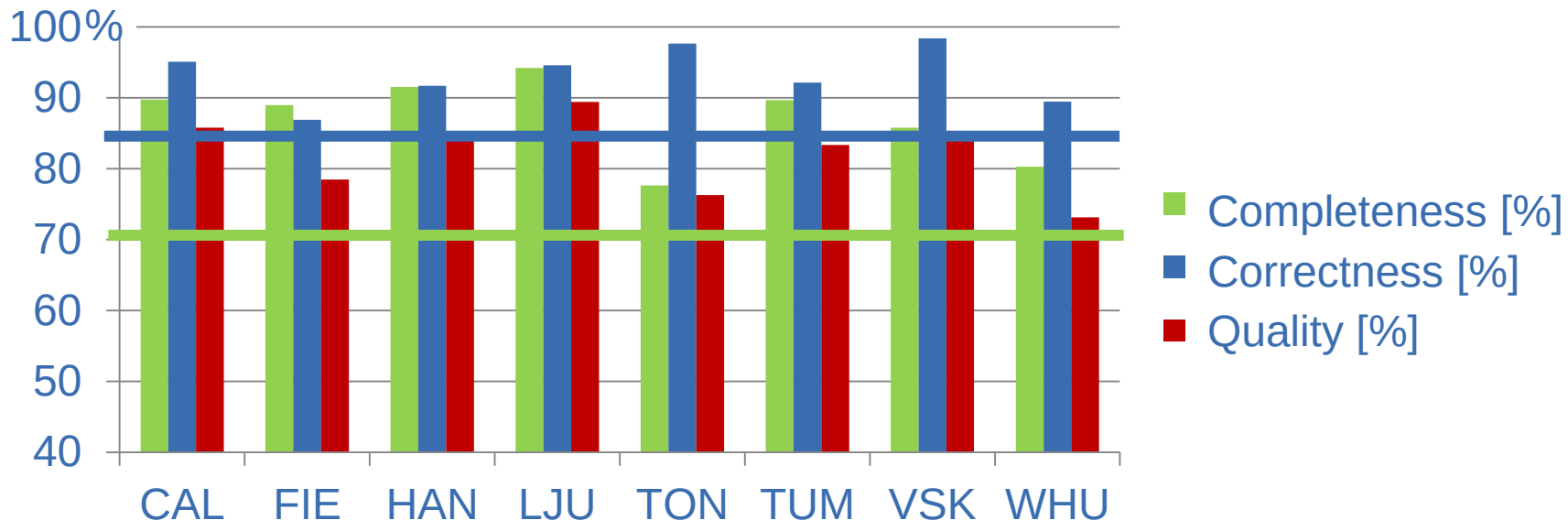
Processing Strategies

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

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

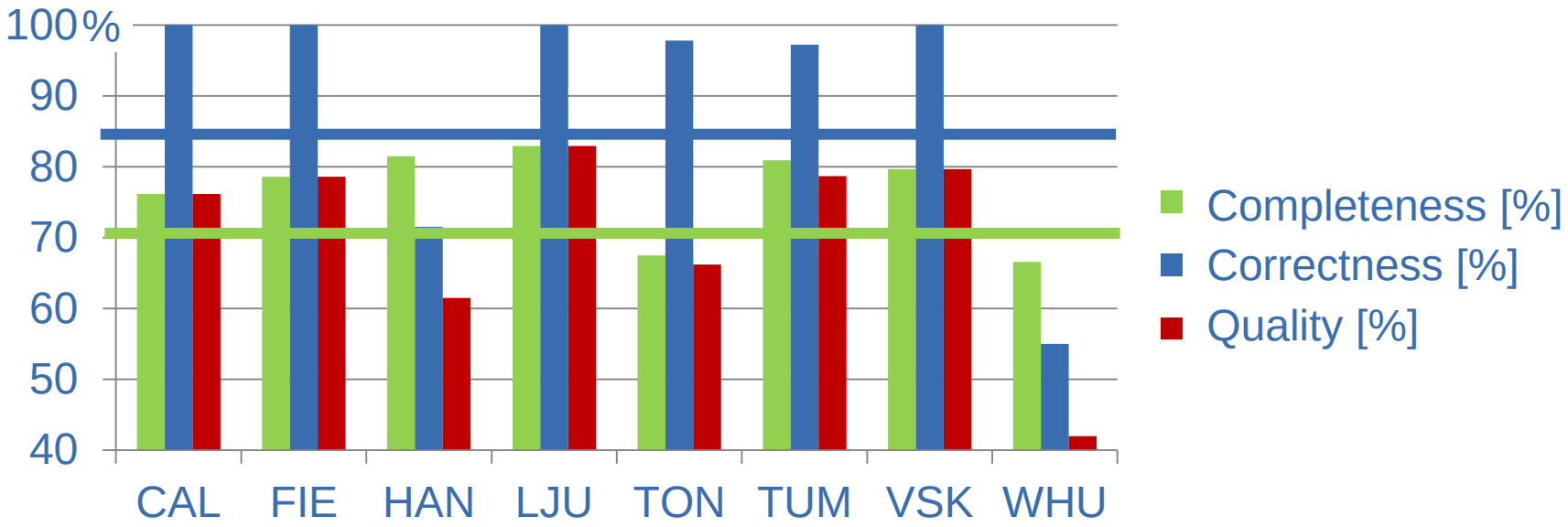
Evaluation of Building Detection - Vaihingen

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



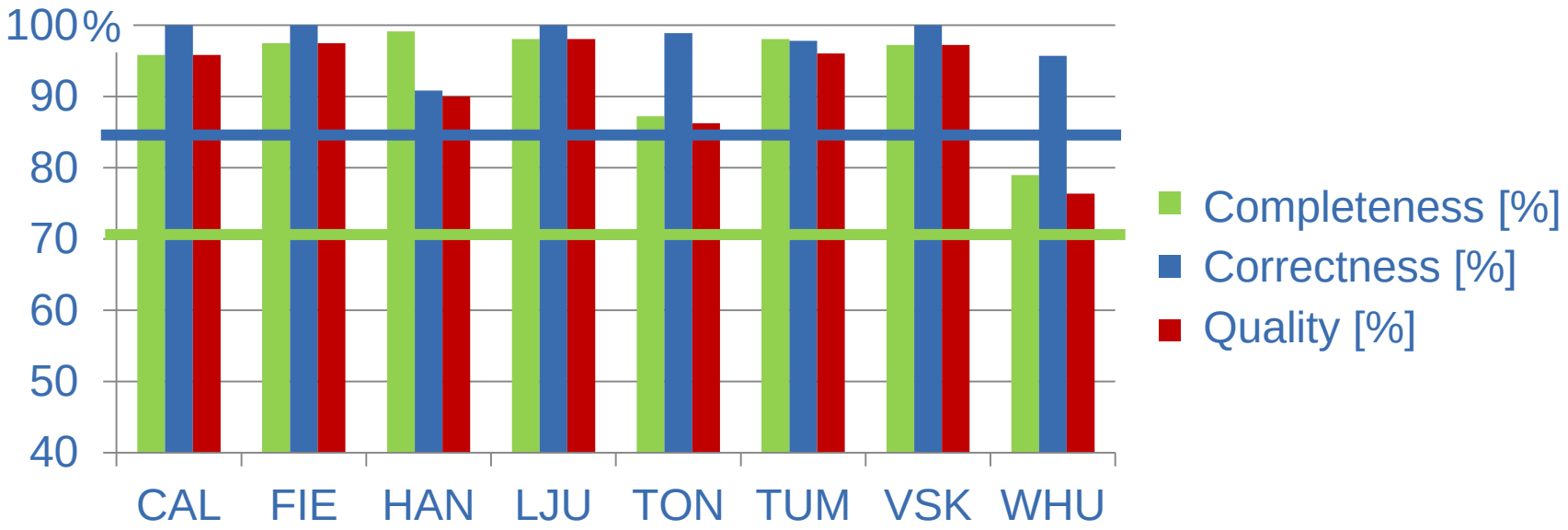
Evaluation of Building Detection - Vaihingen

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



Evaluation of Building Detection - Vaihingen

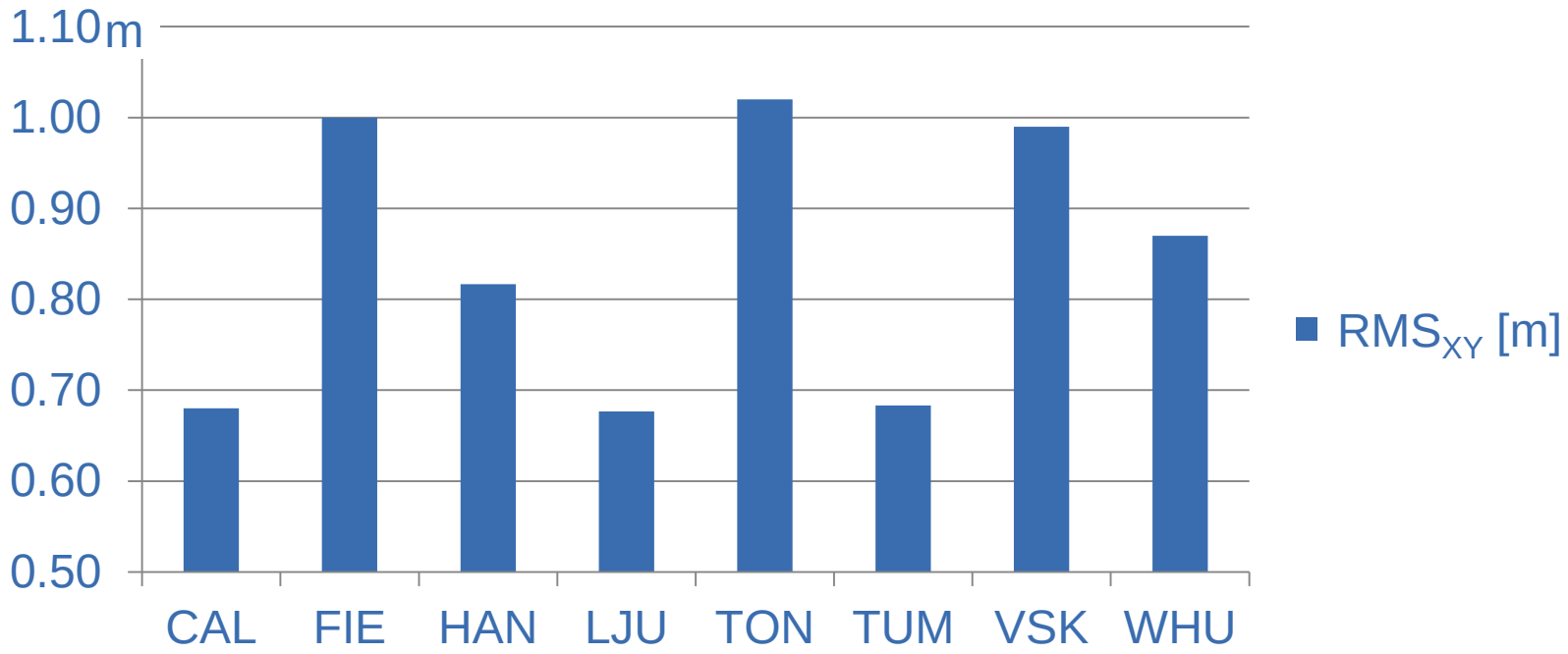
- Object-based evaluation for objects ≥ 50 m² (average Areas 1-3)



- Large structures can be detected reliably by most methods
- All methods except WHU fulfill the requirements by (Mayer et al., 2006) for large buildings

Evaluation of Building Detection - Vaihingen

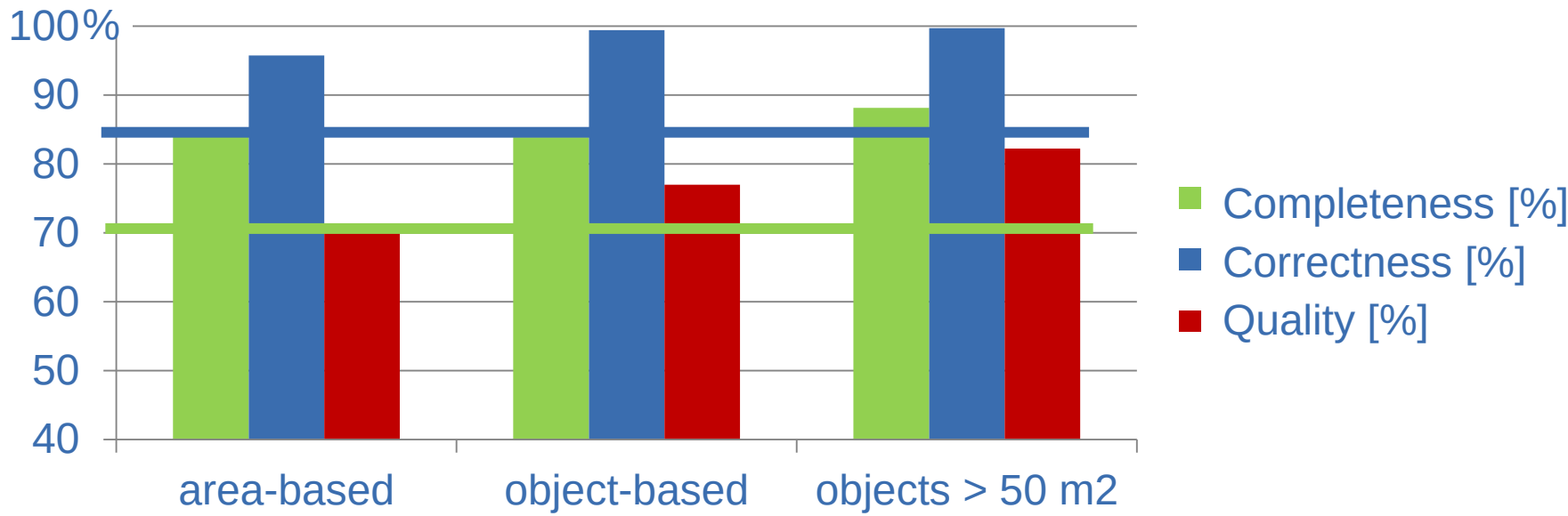
- RMS_{XY}: error of planimetric distances (average Areas 1-3)



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

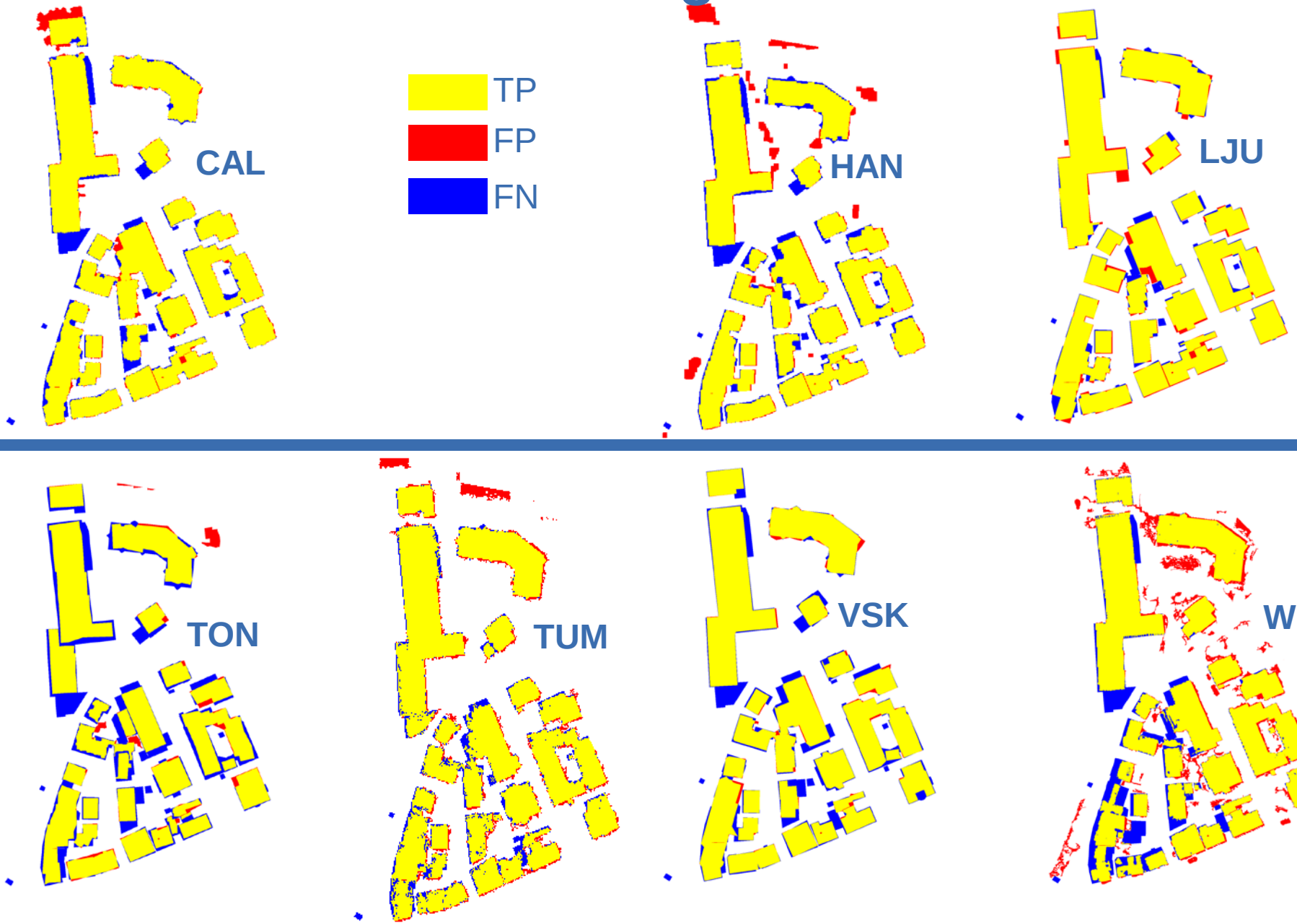
Evaluation of Building Detection - Toronto

- Evaluation for TUM (average of Areas 4 and 5) (RMS_{XY} = 1.5 m)

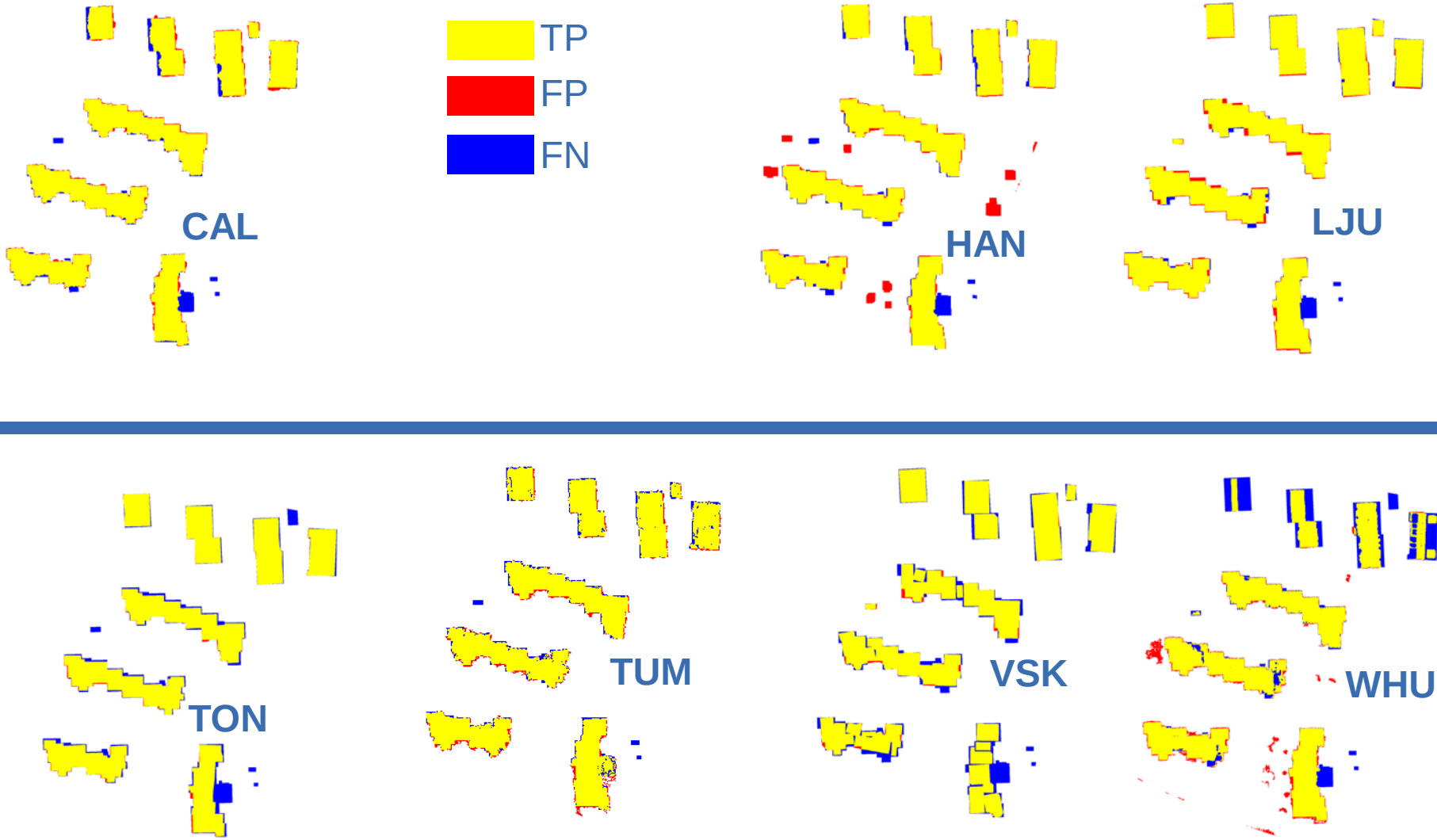


- More difficult scenario than Vaihingen
  - No Infrared band
  - Occlusions, extremely high-rising buildings
- Nevertheless, requirements by (Mayer et al., 2006) fulfilled

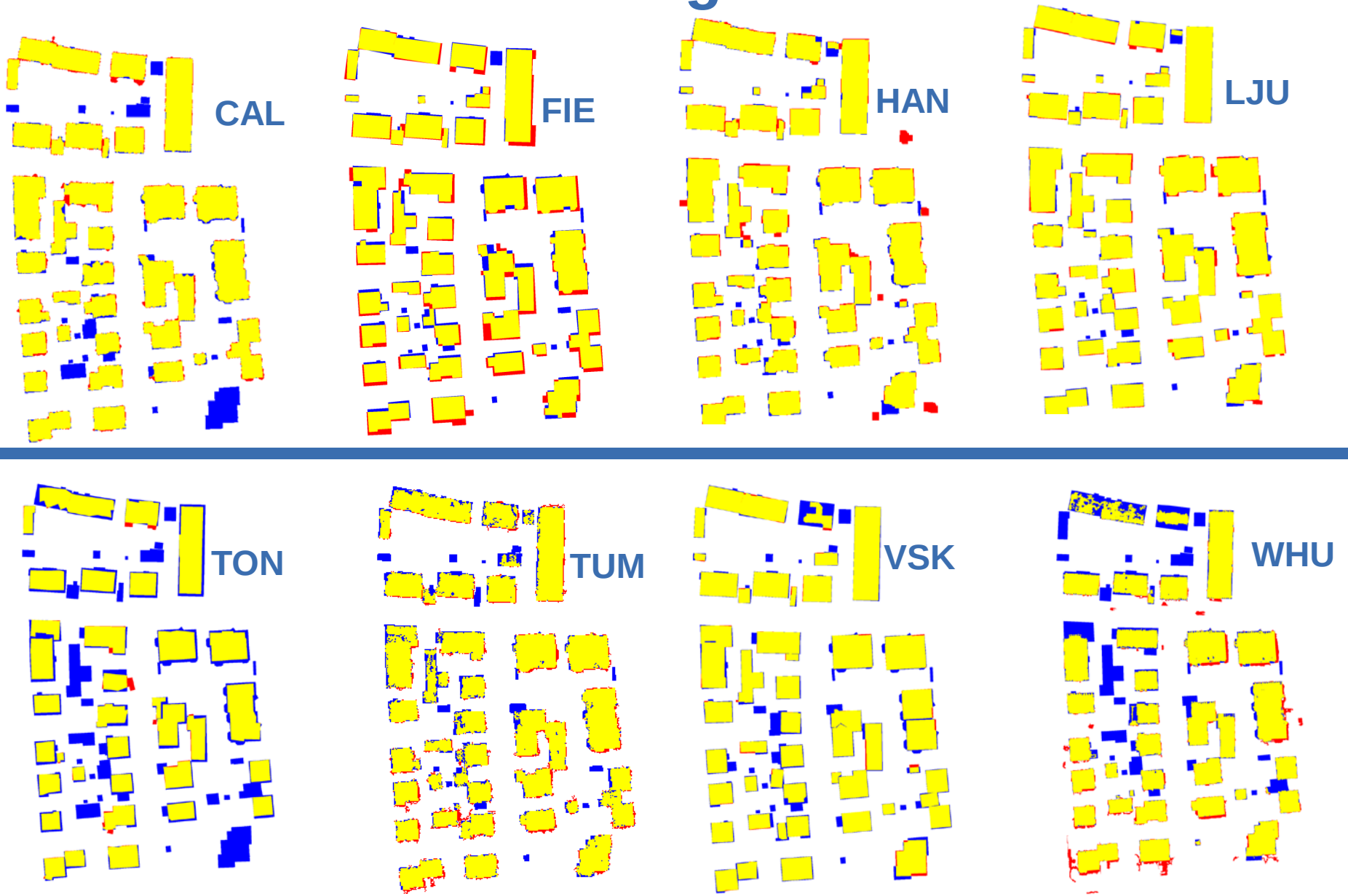
Evaluation of Building Detection – Area 1



Evaluation of Building Detection – Area 2

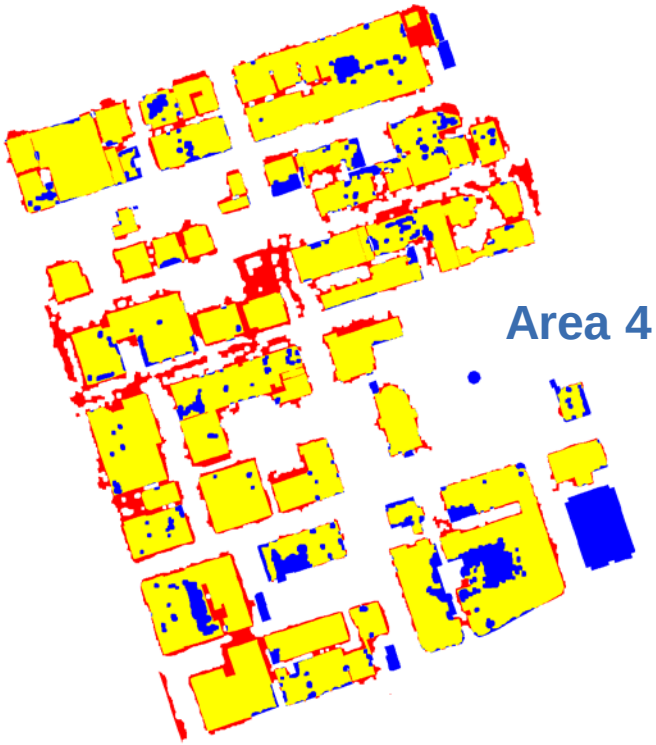


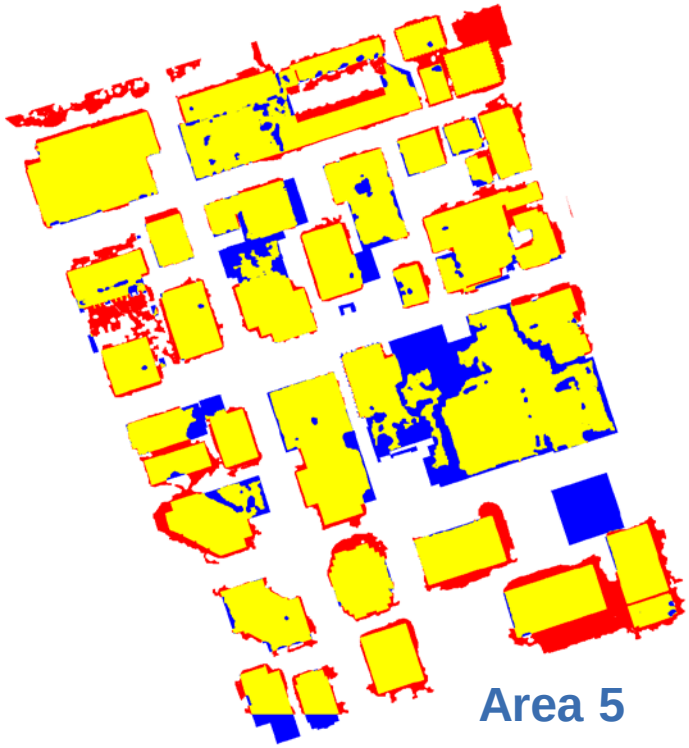
Evaluation of Building Detection – Area 3



Evaluation of Building Detection – Areas 4 & 5

- Results by TUM



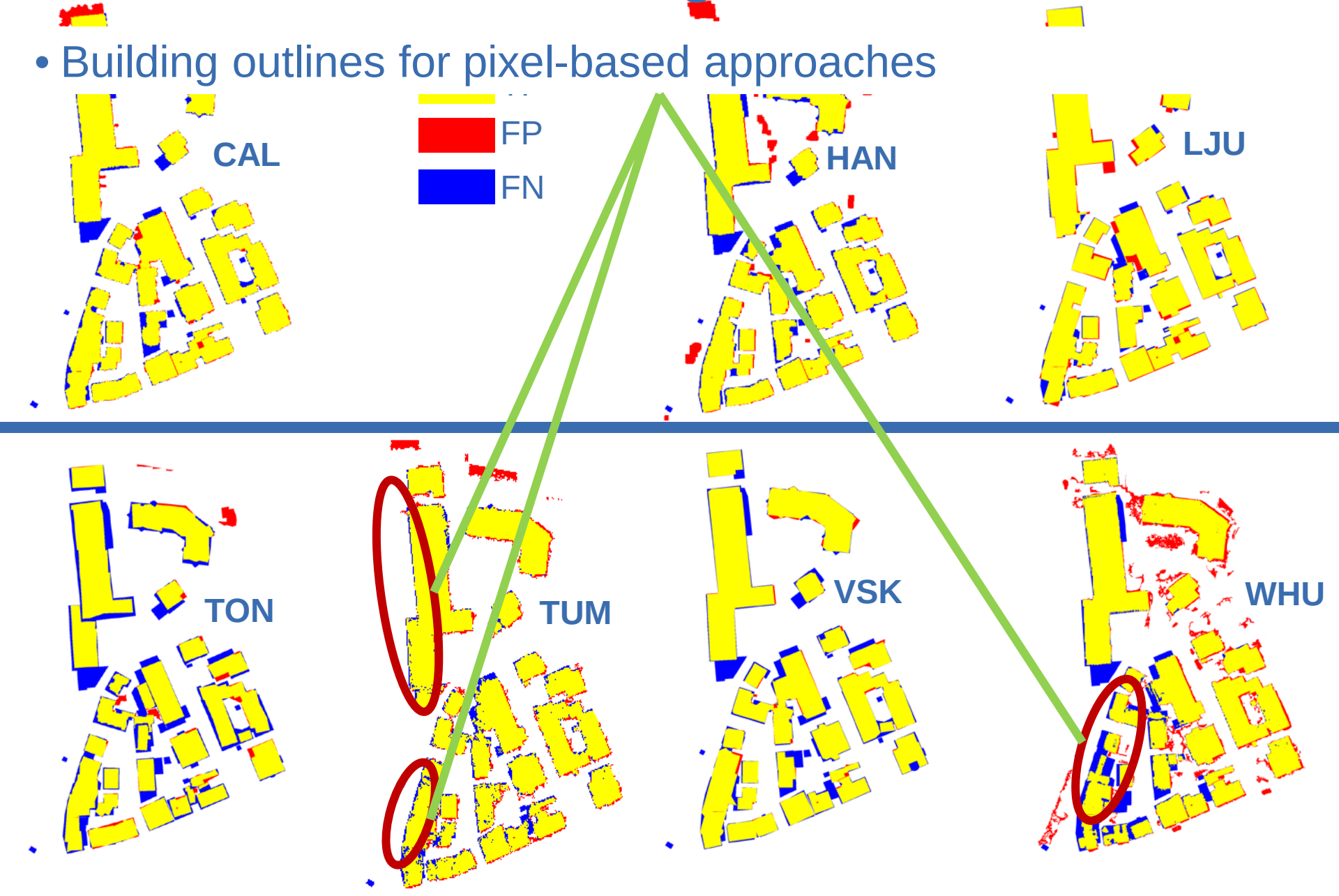


Common Problems in Building Detection

- Building outlines for pixel-based approaches

Evaluation of Building Detection – Area 1

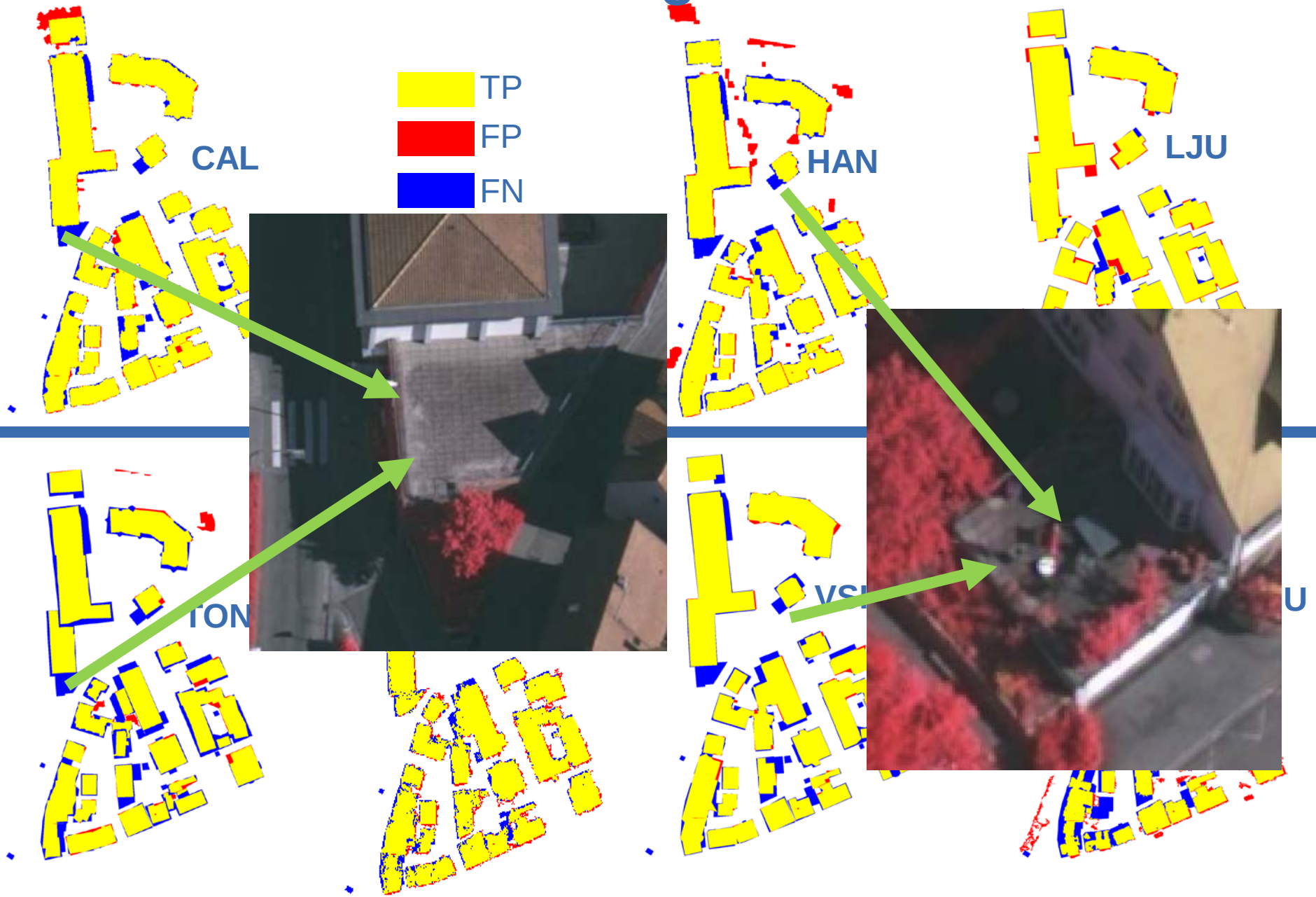
- Building outlines for pixel-based approaches



Common Problems in Building Detection

- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain

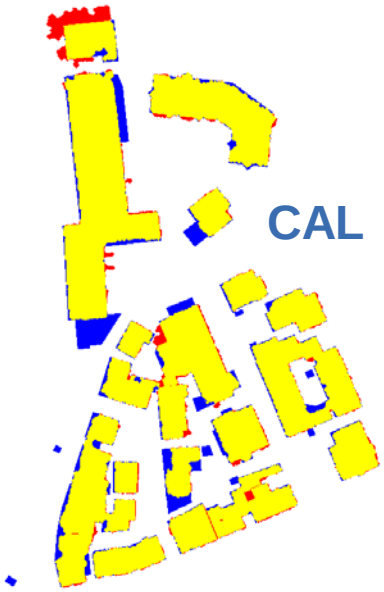
Evaluation of Building Detection – Area 1



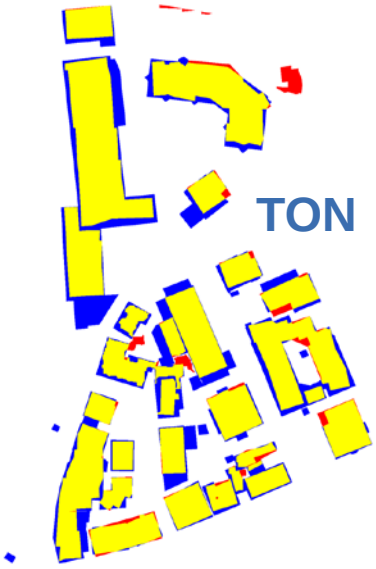
Common Problems in Building Detection

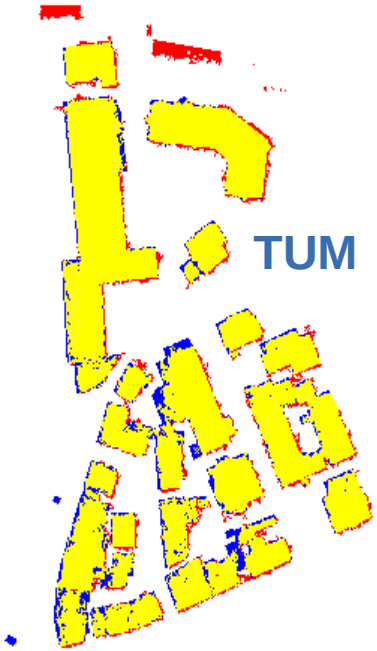
- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain
- Dense tree canopies → Problems for ALS-based methods

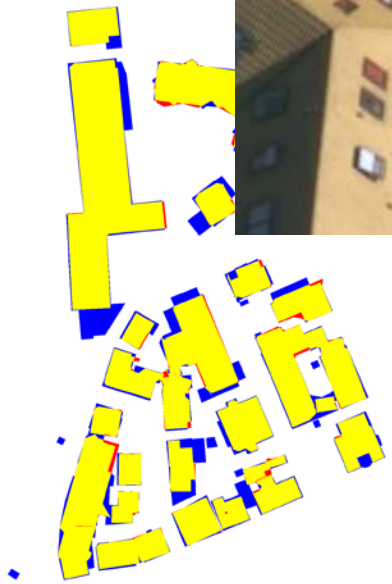
Evaluation of Building Detection – Area 1

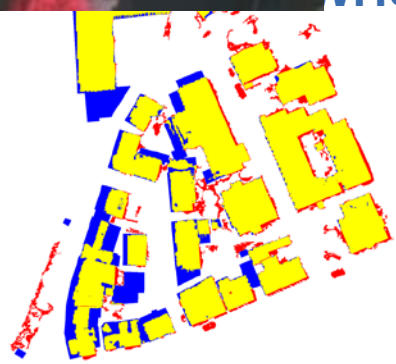


TP
FP
FN





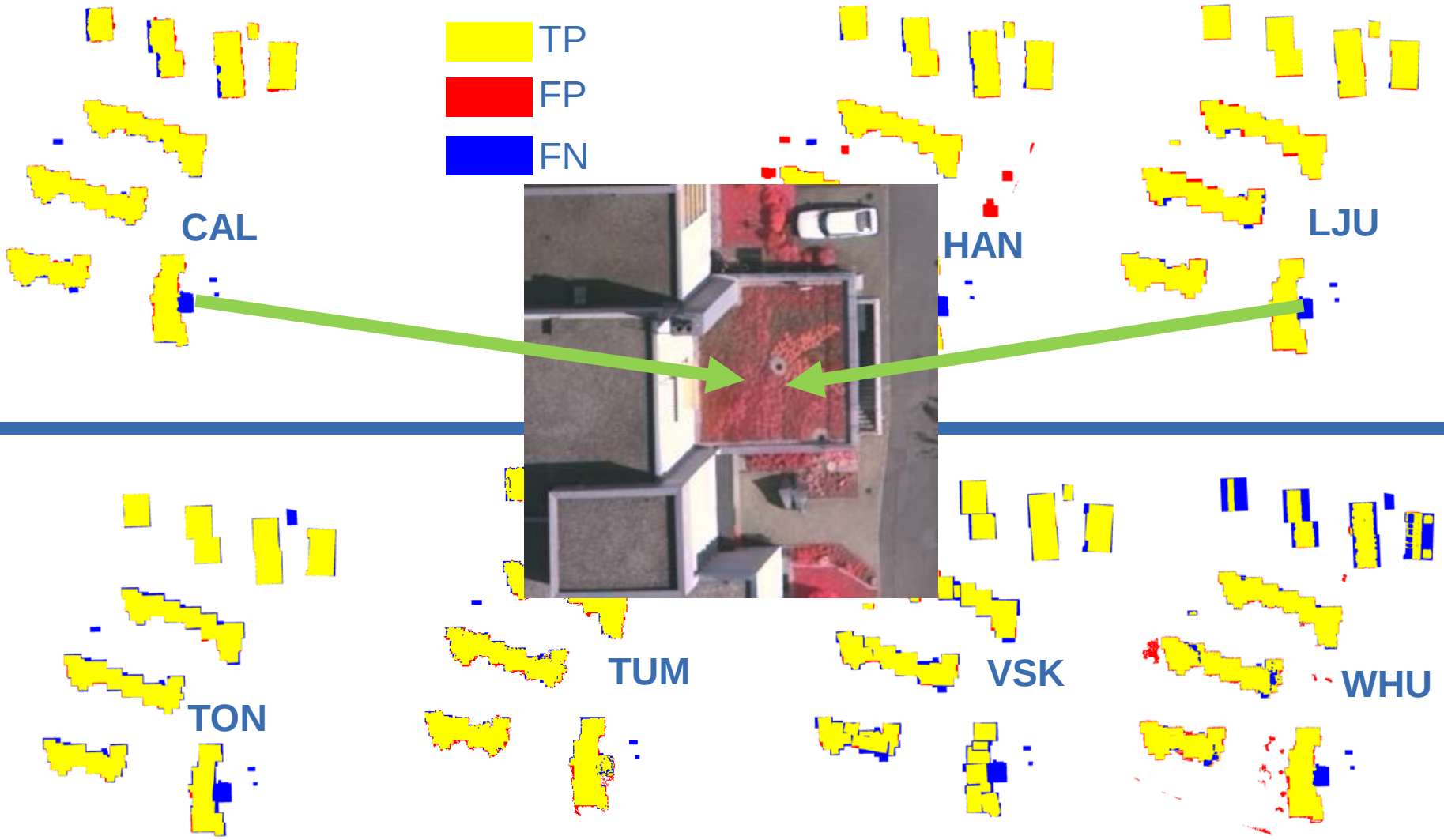




Common Problems in Building Detection

- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain
- Dense tree canopies → Problems for ALS-based methods
- Roofs covered by grass

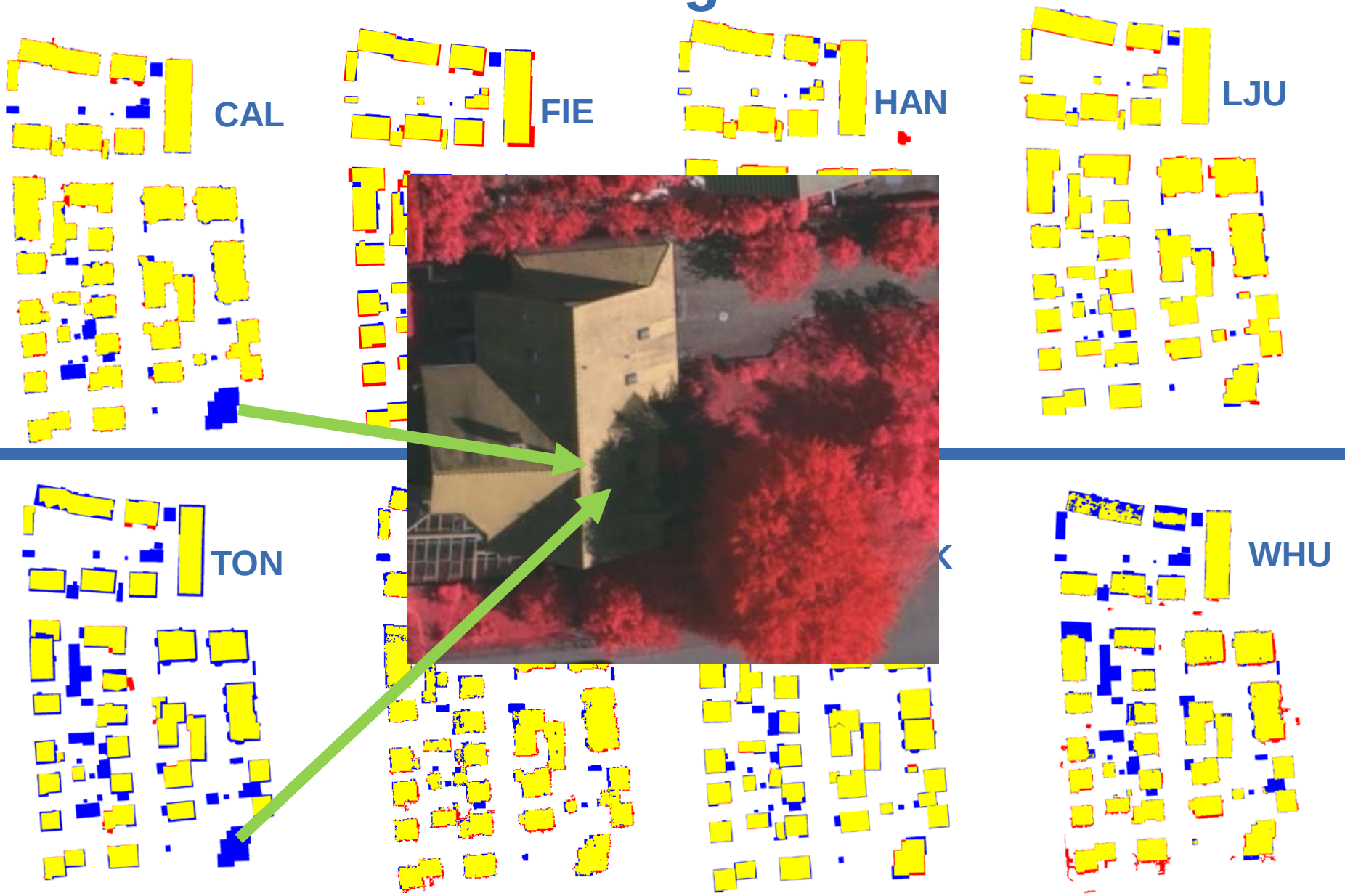
Evaluation of Building Detection – Area 2



Common Problems in Building Detection

- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain
- Dense tree canopies → Problems for ALS-based methods
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods

Evaluation of Building Detection – Area 3



Common Problems

- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain
- Dense tree canopies → Problems for ALS-based methods
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods
- Small building structures

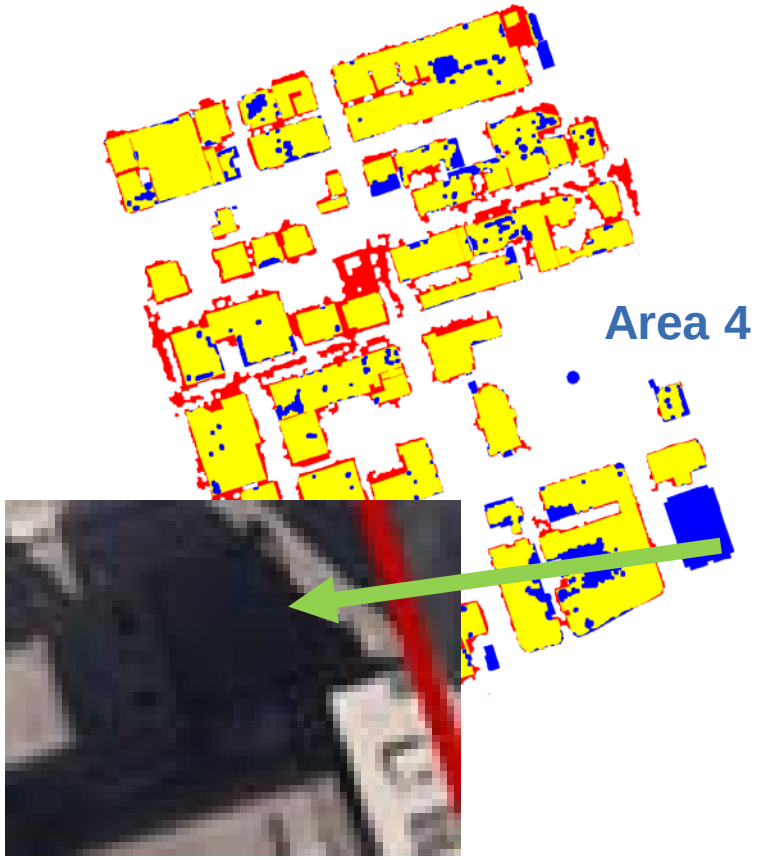
Evaluation of Building Detection – Area 3

Common Problems in Building Detection

- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain
- Dense tree canopies → Problems for ALS-based methods
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods
- Small building structures
- Occlusion / perspective distortion with high-rise buildings

Evaluation of Building Detection – Areas 4 & 5

- Results by TUM



Common Problems in Building Detection

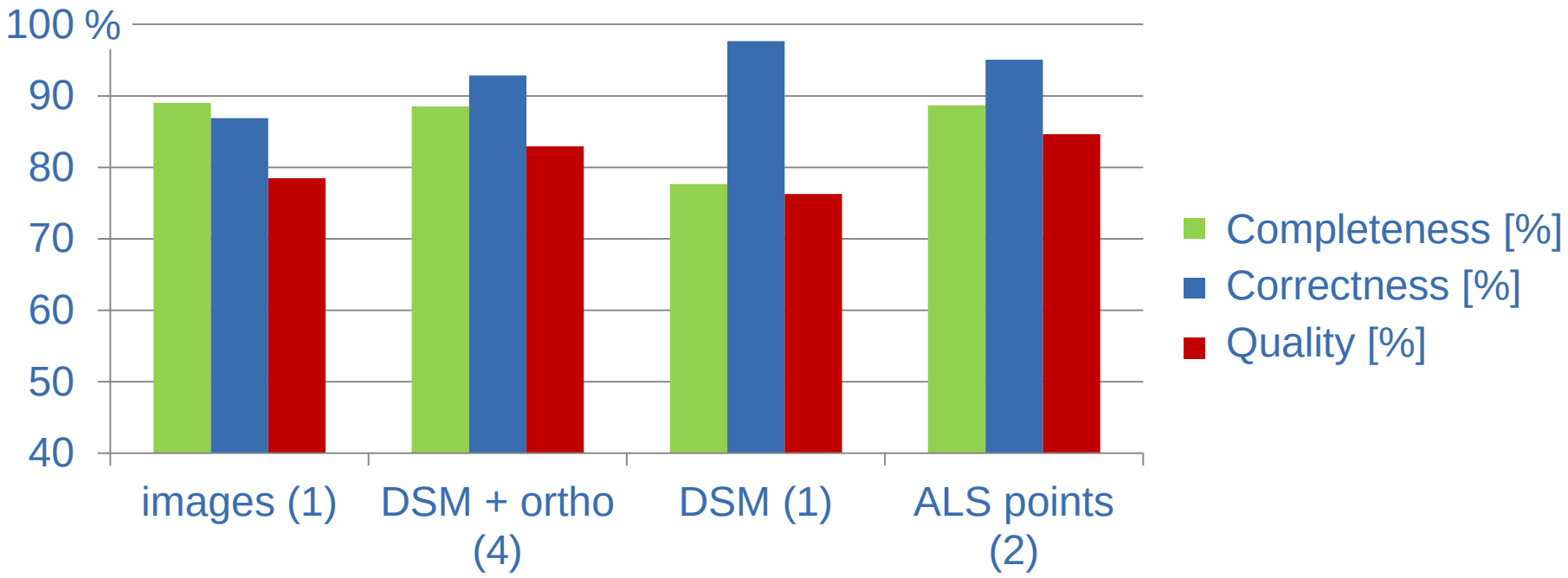
- Building outlines for pixel-based approaches
- Complex structures in combination with steep terrain
- Dense tree canopies → Problems for ALS-based methods
- Roofs covered by grass
- Large trees next to buildings for segmentation-based methods
- Small building structures
- Occlusion / perspective distortion with high-rise buildings
- Shadow
- Uncommonly low buildings in a CBD environment

Evaluation of Building Detection – Areas 4 & 5

- Results by TUM

Evaluation of Building Detection - Vaihingen

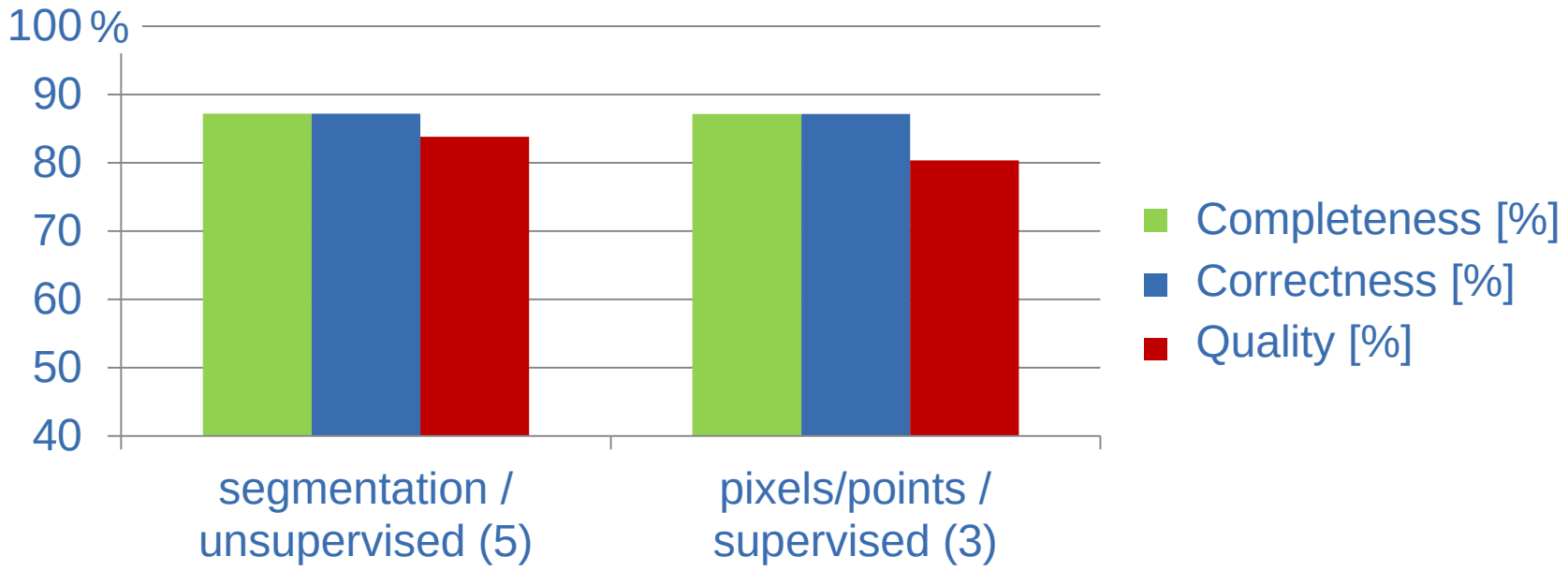
- Influence of used input data (area-based, average Areas 1-3)



- Observed differences are not conclusive due to small number of samples

Evaluation of Building Detection - Vaihingen

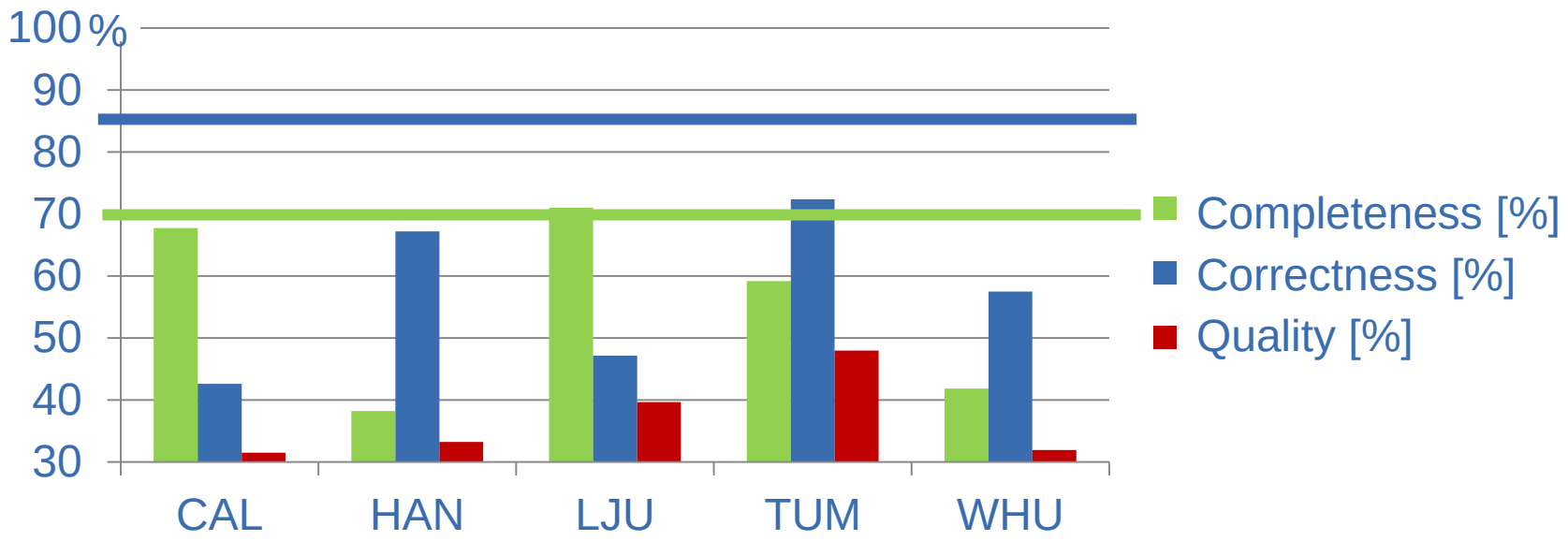
- Influence of processing strategy (area-based, average Areas 1-3)



- No significant difference

Evaluation of Tree Detection - Vaihingen

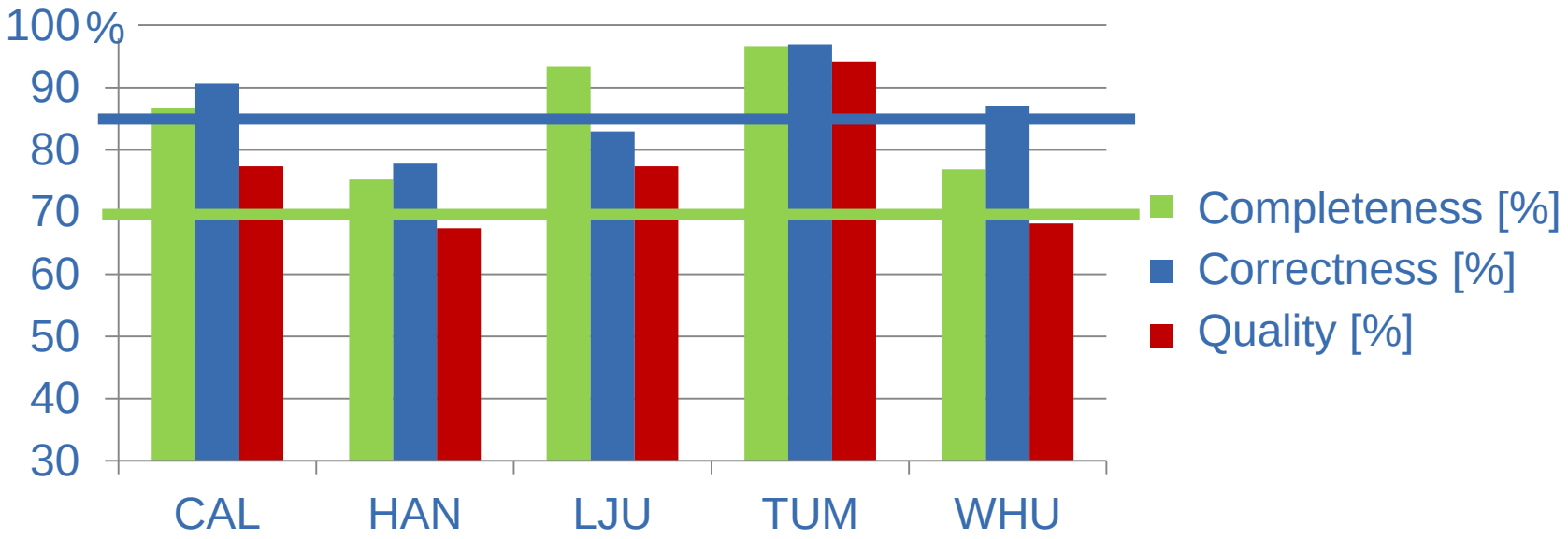
- Object-based evaluation (average Areas 1-3)



- Very low performance for all methods compared to building detection

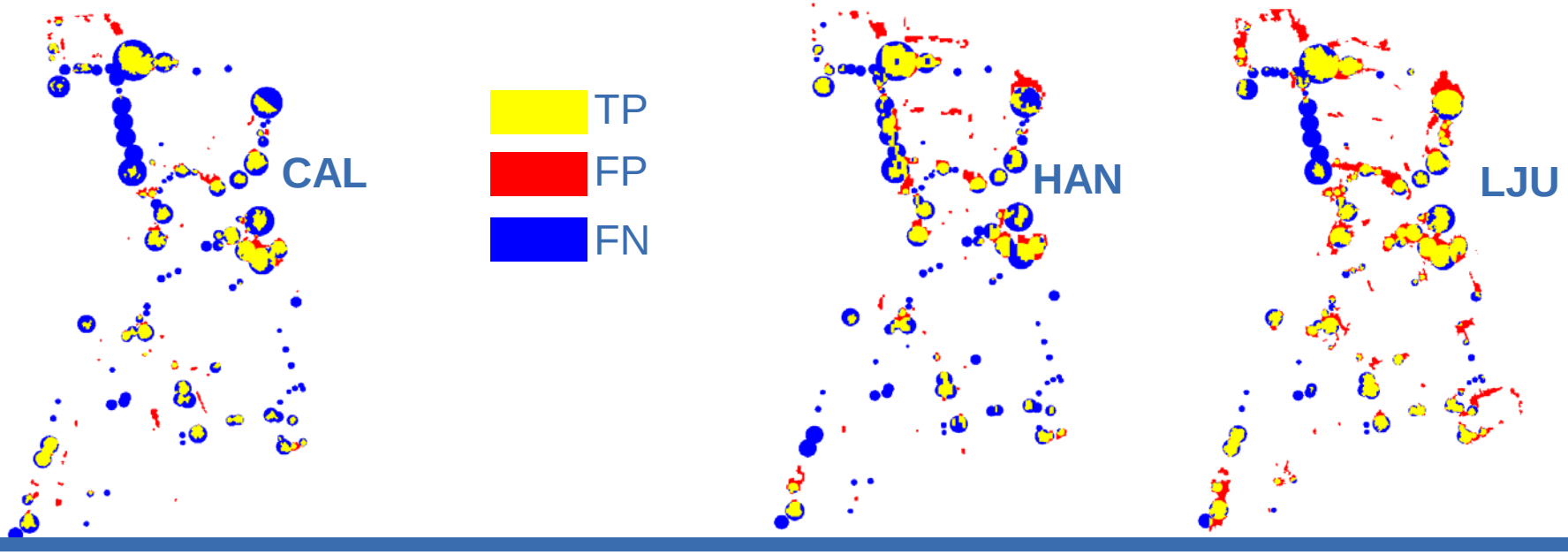
Evaluation of Tree Detection - Vaihingen

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

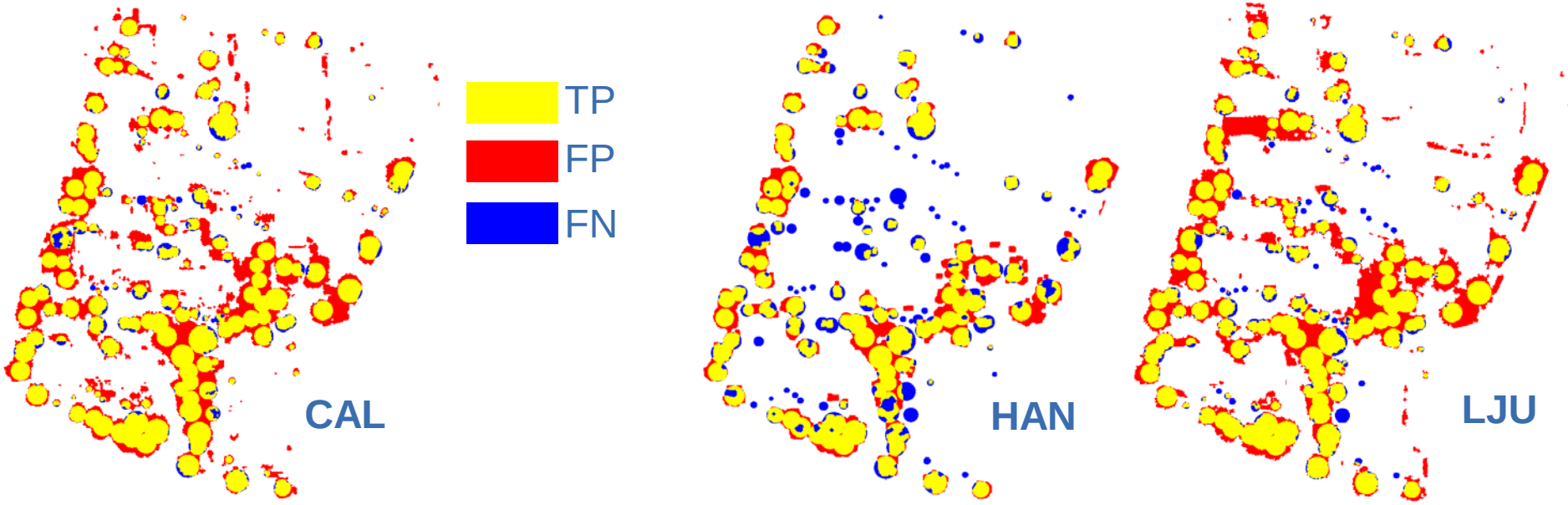


- 50 m^2 corresponds to a crown diameter of about 8 m
- Only CAL and TUM fulfill the requirements by (Mayer et al, 2006)

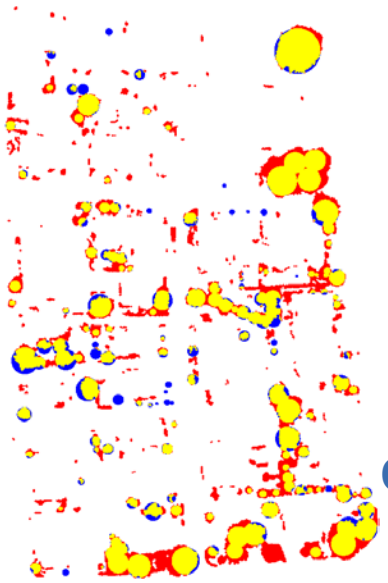
Evaluation of Tree Detection– Area 1



Evaluation of Tree Detection– Area 2

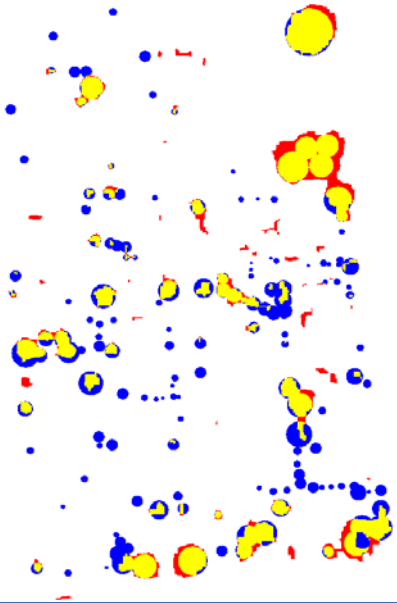


Evaluation of Tree Detection– Area 3

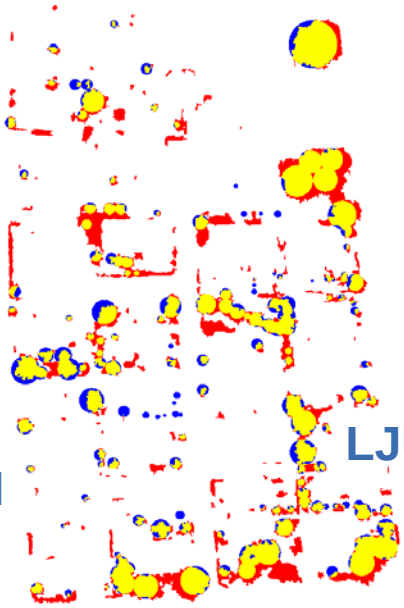


CAL

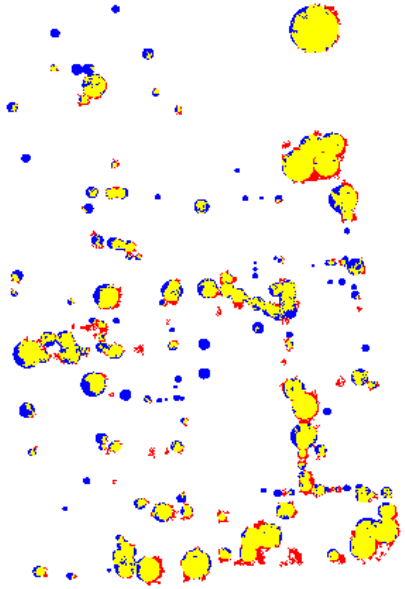
TP
FP
FN



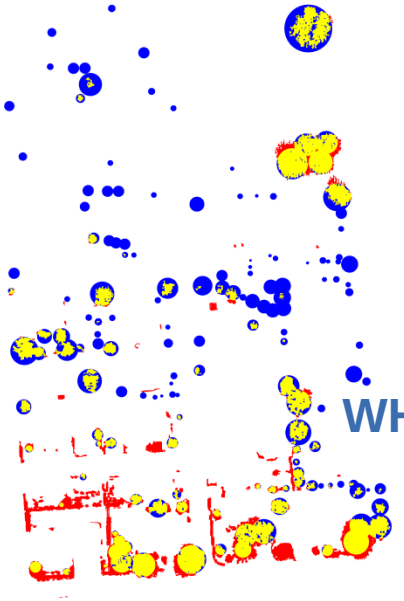
HAN



LJU



TUM

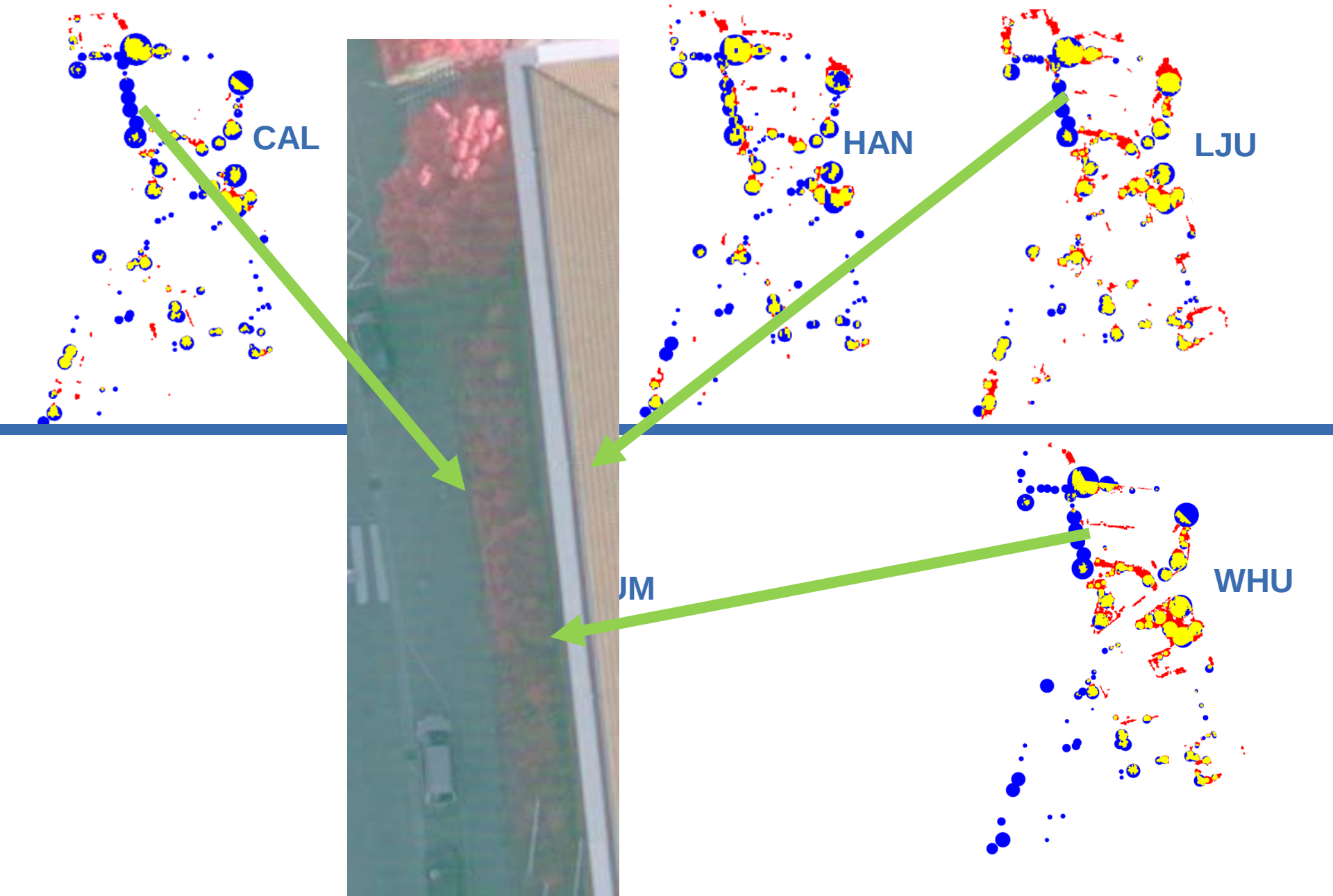


WHU

Common Problems in Tree Detection

- Similar problems as for buildings
- Complex scene content in combination with shadow

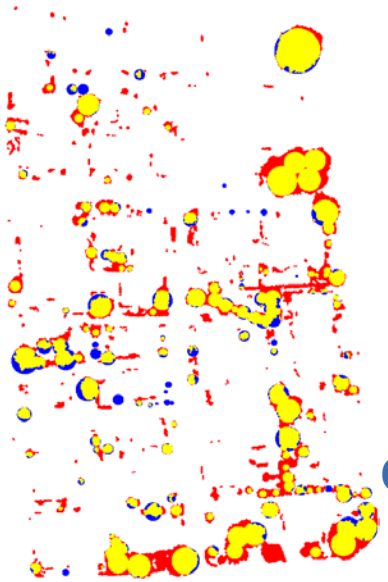
Evaluation of Tree Detection– Area 1



Common Problems in Tree Detection

- Similar problems as for buildings
- Complex scene content in combination with shadow
- Small trees

Evaluation of Tree Detection– Area 3

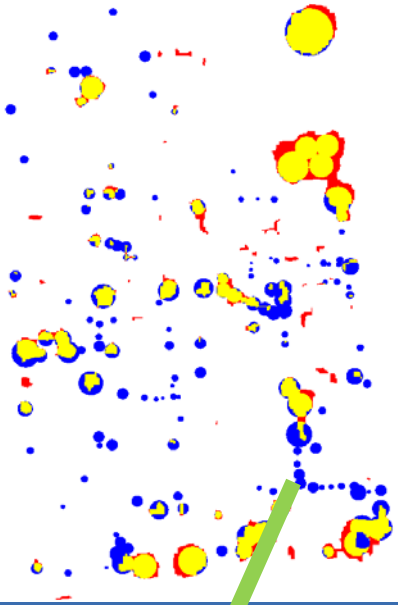


CAL

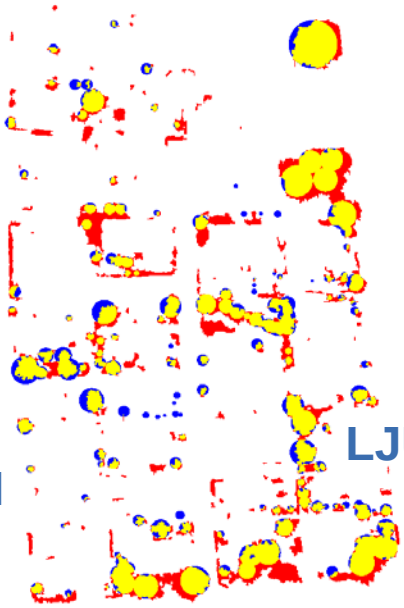
TP

FP

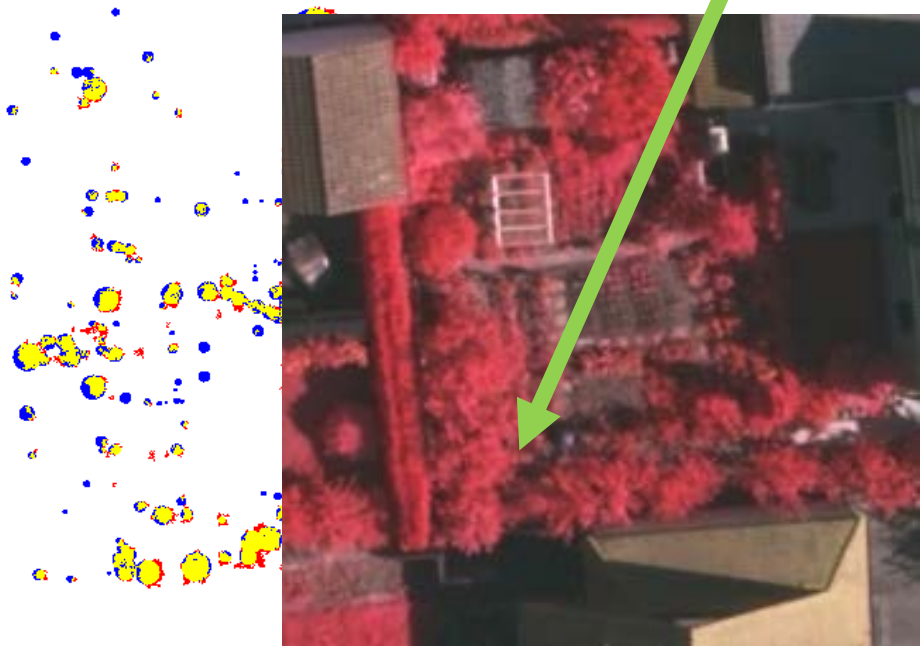
FN

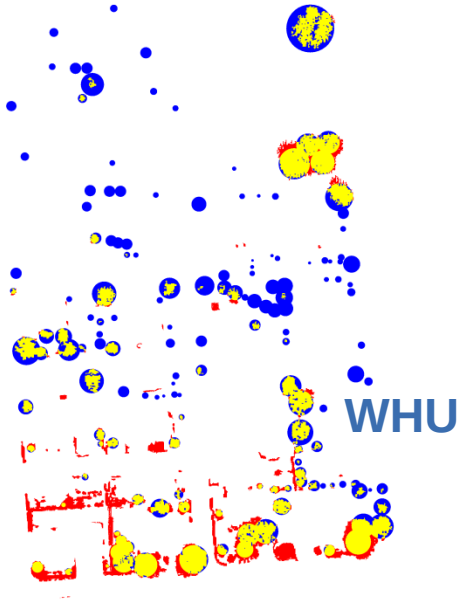


HAN



LJU





WHU

Object Detection: Discussion

- Main buildings per plot can be detected rather reliably by most methods, most methods can be practically relevant
- Small buildings remain a problem
- Occlusions in CBD scene → Multiple overlap required?
- Comparison of data sets and processing strategies remains inconclusive
- Full geometrical accuracy potential of images not yet exploited
- Trees are more problematic than buildings, practical relevance questionable for most methods
- Area 2 (high-rise residential) offers most favourable conditions for automation

Outline

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

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 all roof planes (50% overlap required for TPs)
    - of roof planes larger than 10 m^2
  - (Topological parameters: not reported here)
- 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			X		
J.-Y. Rau	CKU	Cheng Kung Univ. Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen			X		
S. Oude Elberink	ITCE1	ITC, Enschede	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede	X	X	X		
B. Xiong	ITCX	ITC, Enschede	X	X	X		
P. Dorninger	VSK	TU Vienna	X	X	X		
G. Sohn	YOR	York University	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			X		
J.-Y. Rau	CKU	Cheng Kung Univ. Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen			X		
S. Oude Elberink	ITCE1	ITC, Enschede	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede	X	X	X		
B. Xiong	ITCX	ITC, Enschede	X	X	X		
P. Dorninger	VSK	TU Vienna	X	X	X		
G. Sohn	YOR	York University	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			X		
J.-Y. Rau	CKU	Cheng Kung Univ. Taiwan	X	X	X	X	X
D. Bulatov	FIE	Fraunhofer Inst., Ettlingen			X		
S. Oude Elberink	ITCE1	ITC, Enschede	X	X	X		
S. Oude Elberink	ITCE2	ITC, Enschede	X	X	X		
B. Xiong	ITCX	ITC, Enschede	X	X	X		
P. Dorninger	VSK	TU Vienna	X	X	X		
G. Sohn	YOR	York University	X	X	X	X	X

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

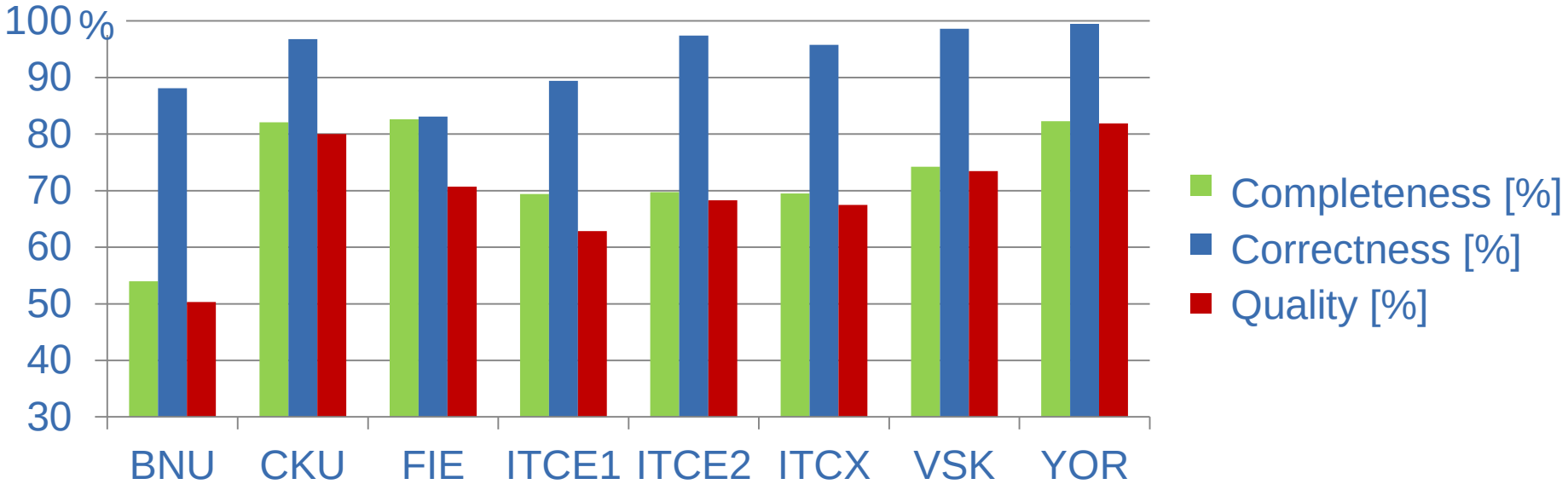
Building Models

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

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

Evaluation of Building Reconstr. - Vaihingen

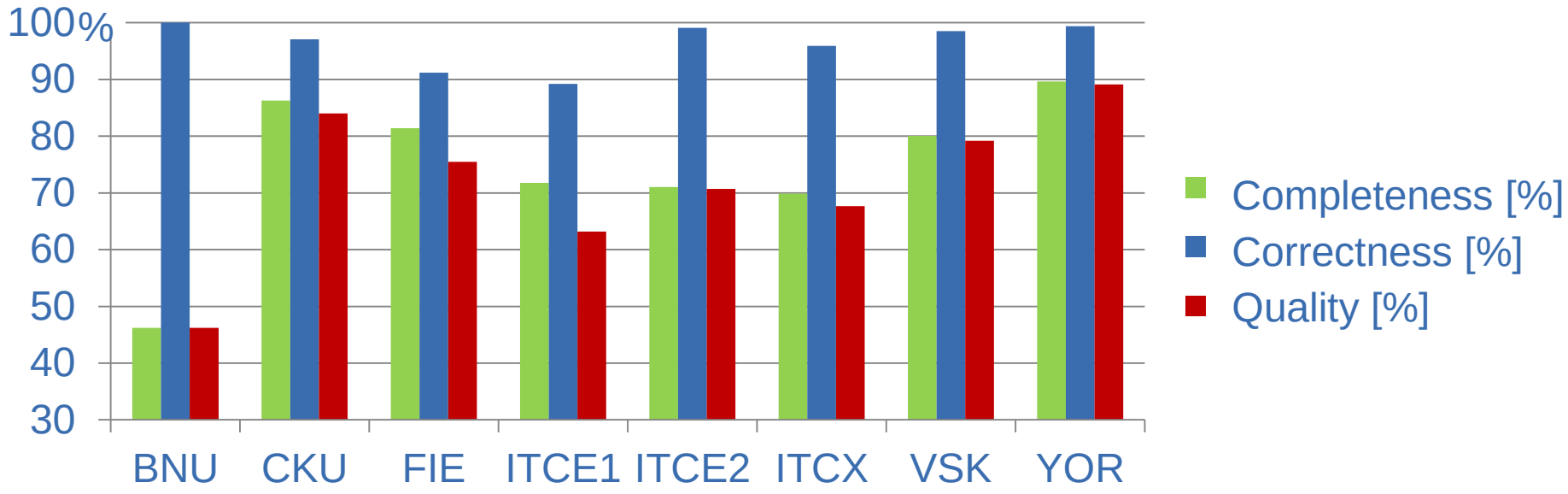
- Evaluation for all roof planes (average Areas 1-3)



- Correctness > 80% for all methods
- Many undetected roof planes

Evaluation of Building Reconstr. - Vaihingen

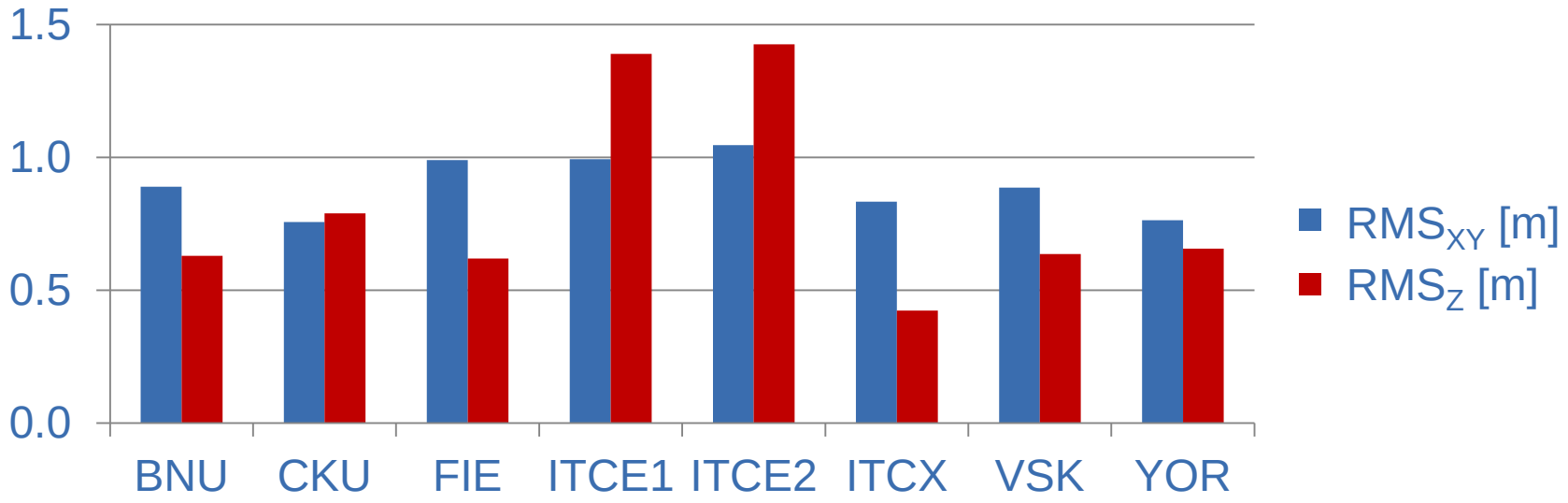
- Evaluation for roof planes >10 m^2 (average Areas 1-3)



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

Evaluation of Building Reconstr. - Vaihingen

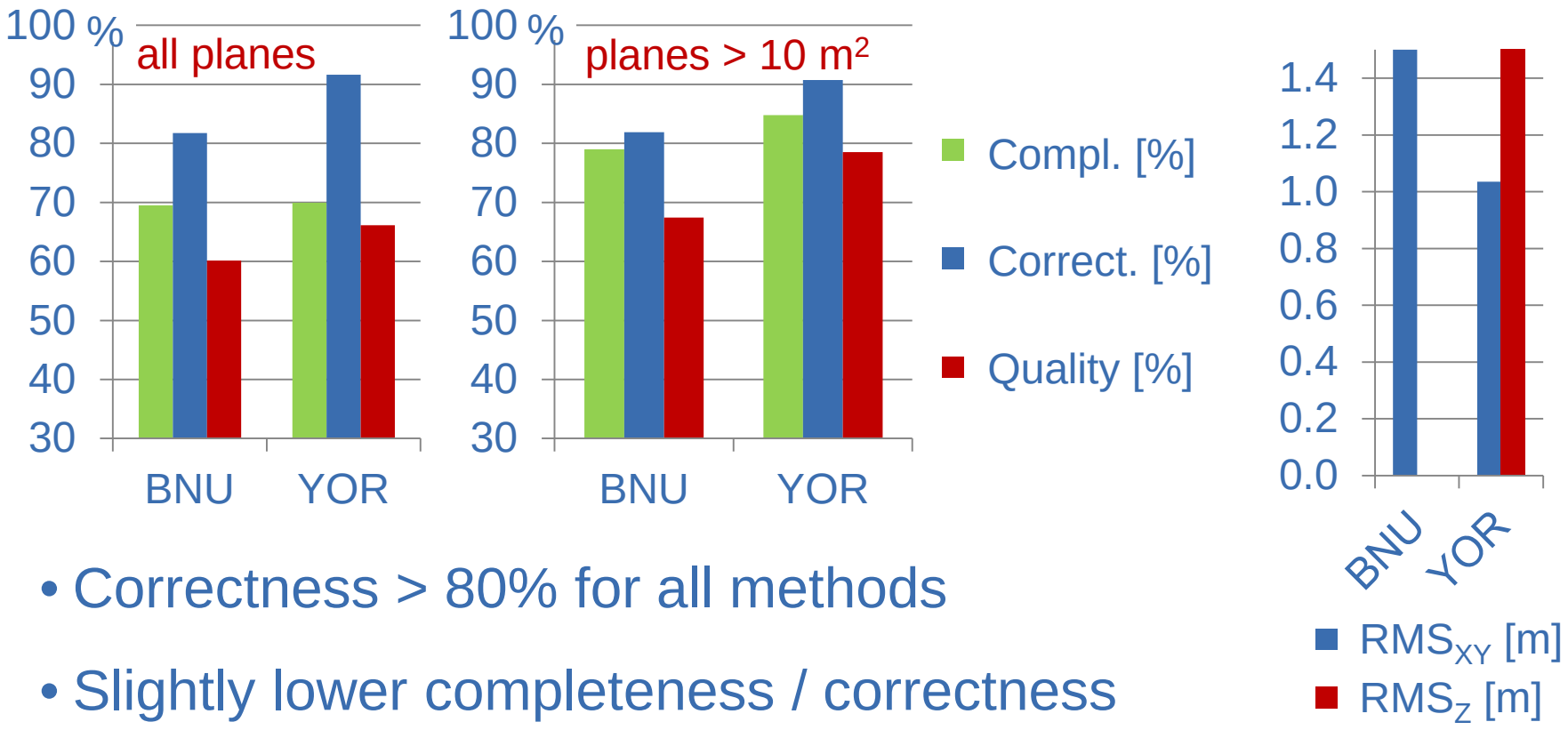
- Geometrical errors(average Areas 1-3)



- Order of magnitude (planimetry): 2 – 4 x point spacing
- Height errors are relatively high, but also have influence of segmentation errors
- Full accuracy potential not exploited

Evaluation of Building Reconstr. - Toronto

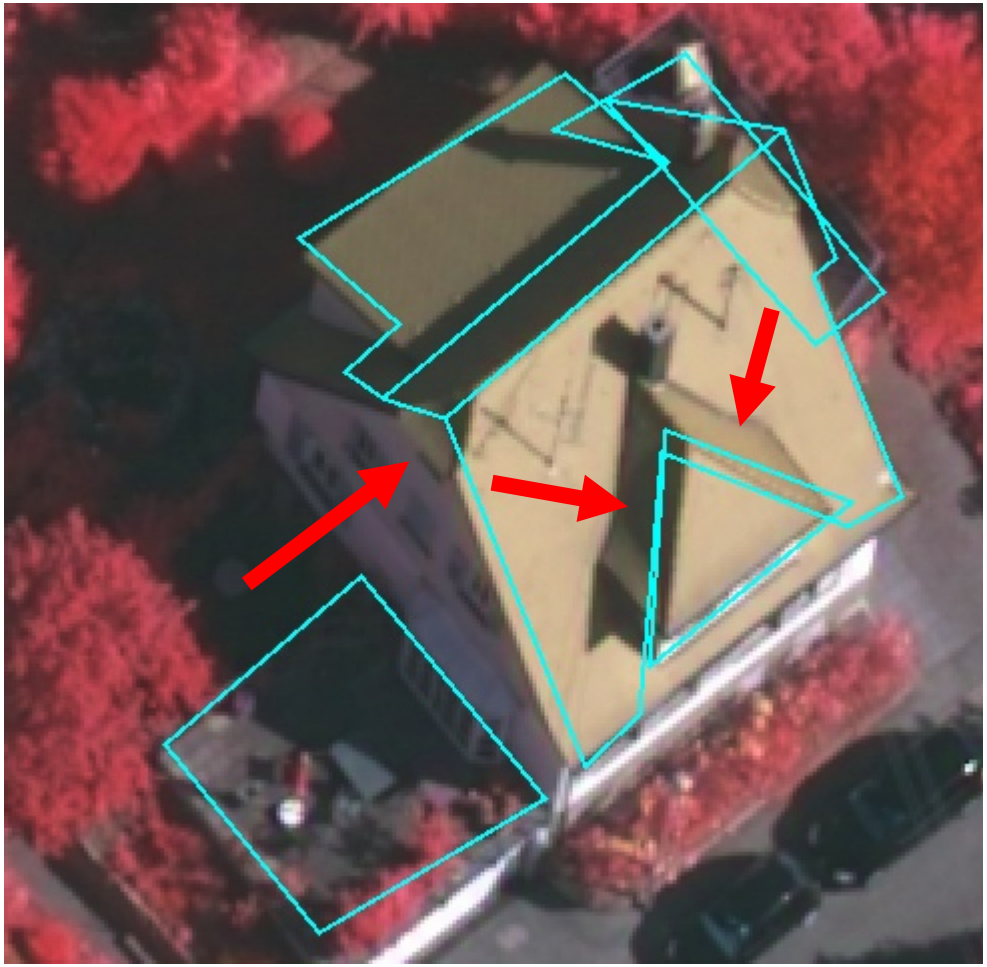
- Evaluation for roof planes (average Areas 4 & 5)



- Correctness > 80% for all methods
- Slightly lower completeness / correctness values than in Vaihingen
- RMS errors larger than Vaihingen

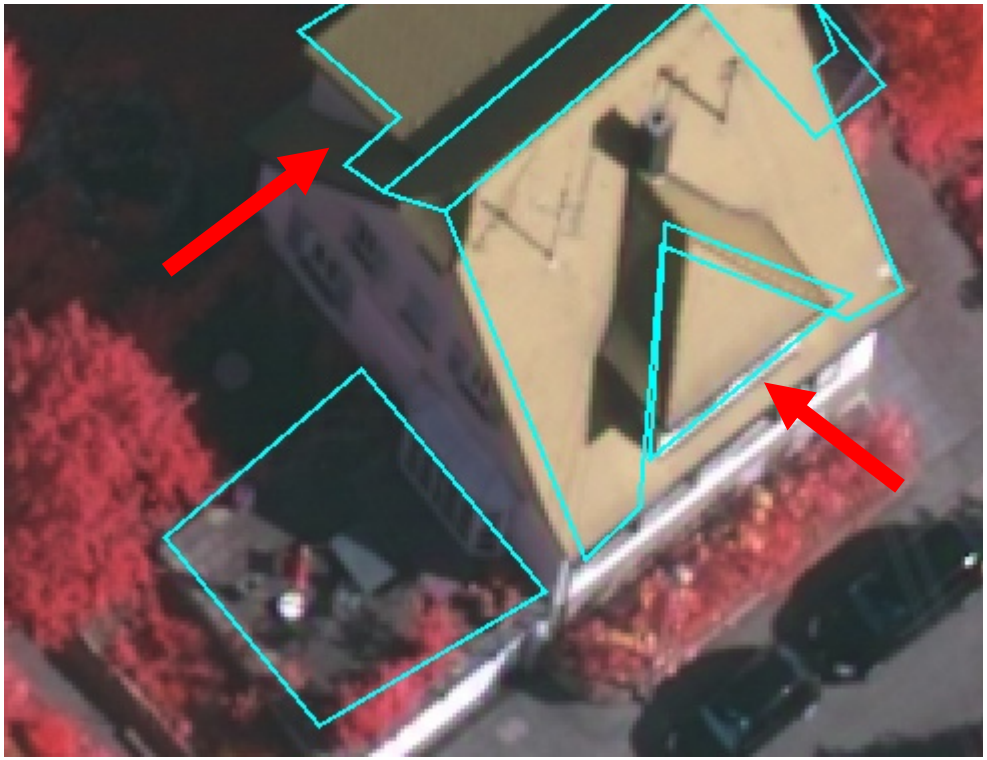
Common Problems

- Small roof planes (YOR)



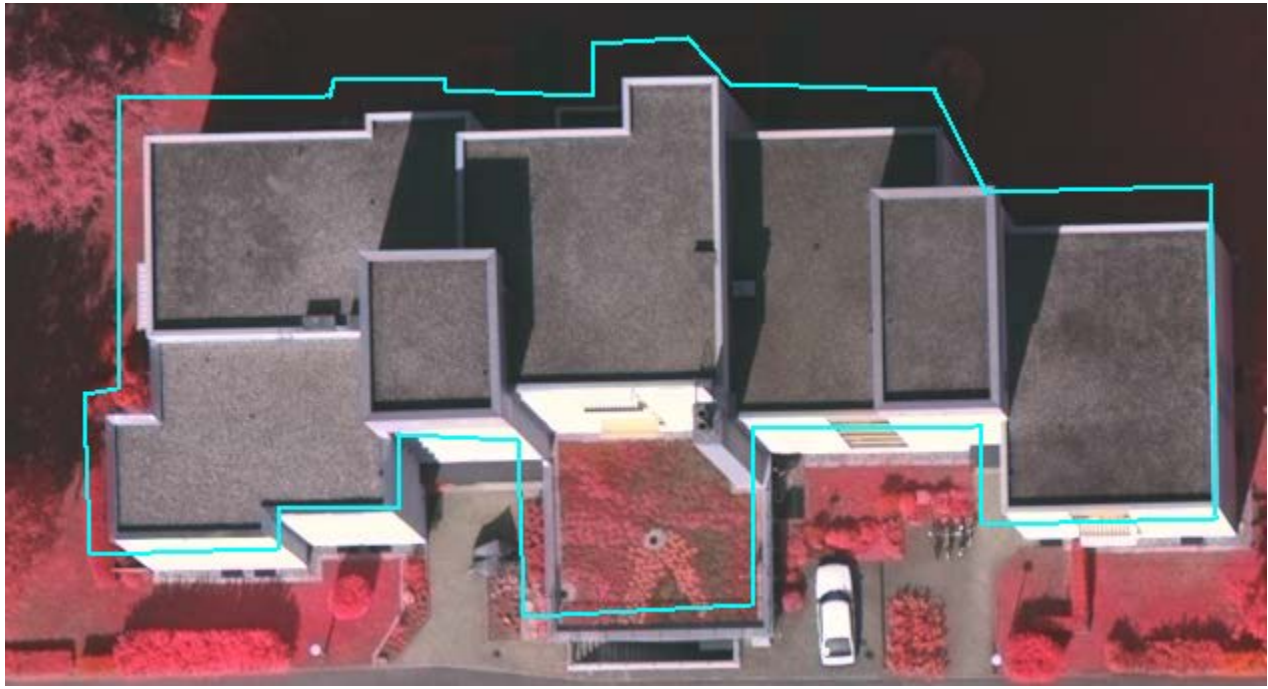
Common Problems

- Small roof planes (YOR)
- Small appendices to larger roof planes (YOR)



Common Problems

- Small roof planes (YOR)
- Small appendices to larger roof planes (YOR)
- Undersegmentation (ITCE1)



Common Problems

- Small roof planes (YOR)
- Small appendices to larger roof planes (YOR)
- Undersegmentation (ITCE1)
- Wrong segmentation (VSK, FIE)

Common Problems

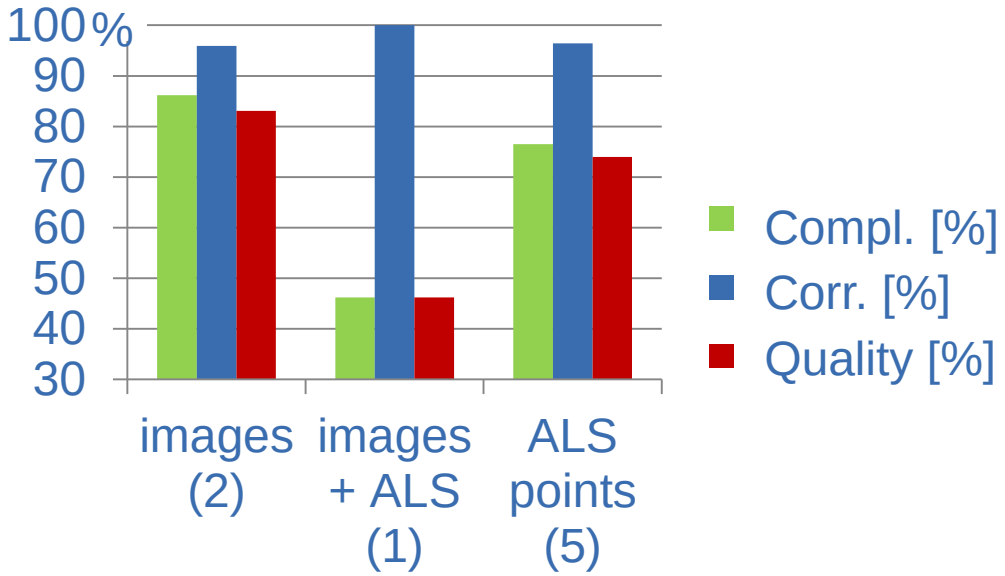
- Small roof planes (YOR)
- Small appendices to larger roof planes (YOR)
- Undersegmentation (ITCE1)
- Wrong segmentation (FIE)
- Missing regularisation (YOR)

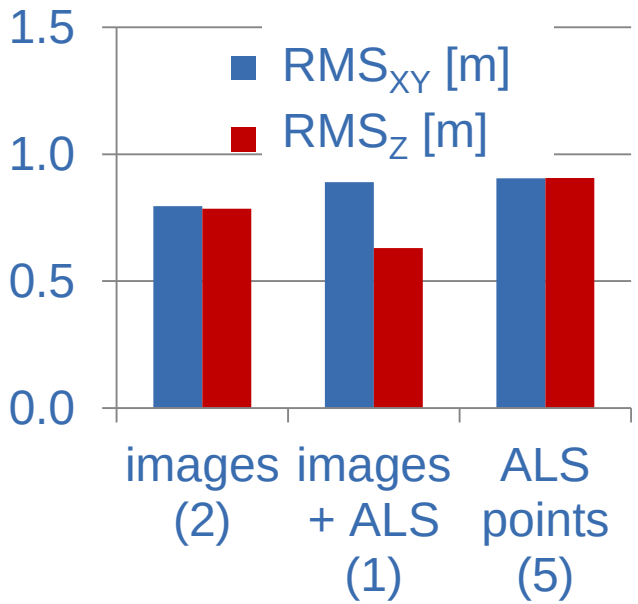
Common Problems

- Small roof planes (YOR)
- Small appendices to larger roof planes (YOR)
- Undersegmentation (ITCE1)
- Wrong segmentation (FIE)
- Missing regularisation (YOR)
- Incorrect combination of planes (VSK)

Evaluation of Building Reconstr. - Vaihingen

- Impact of used data (average Areas 1-3, roof planes > 10 m^2)

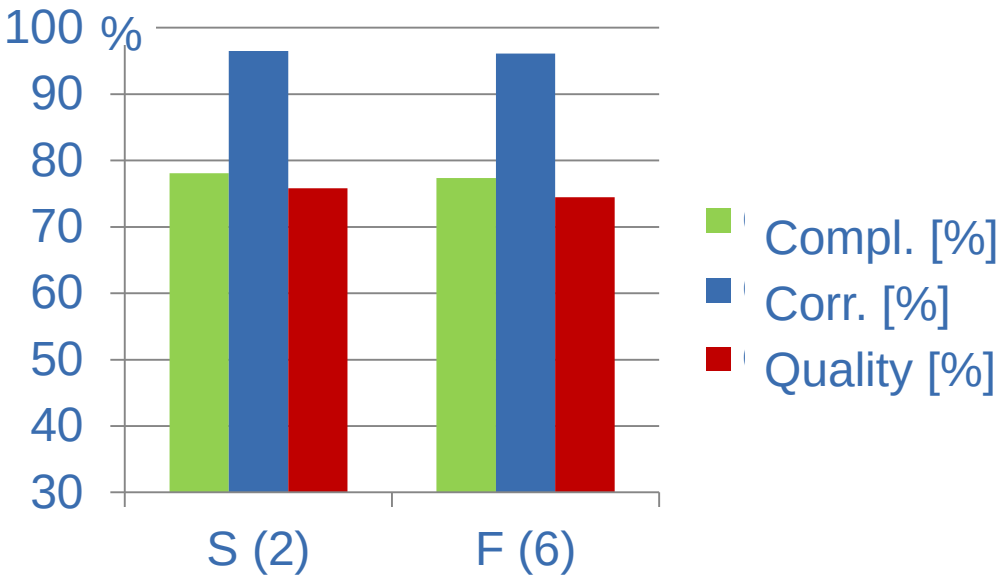


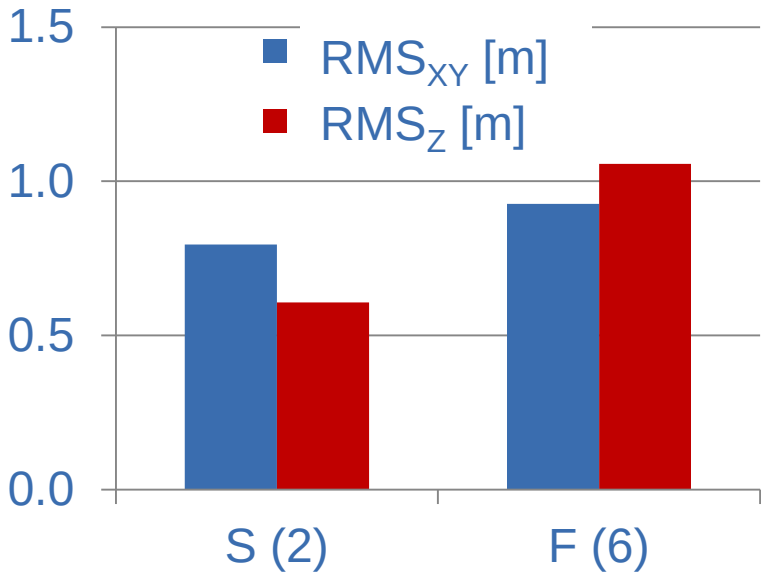


- Comparison not conclusive:
  - Image-based methods only available for area 3 (FIE) or semi-automatic
  - Only one method combining ALS + images

Evaluation of Building Reconstr. - Vaihingen

- Impact of degree of automation (average Areas 1-3, roof planes > 10 m^2): Semi-automatic (S) vs. Fully-automatic (F)

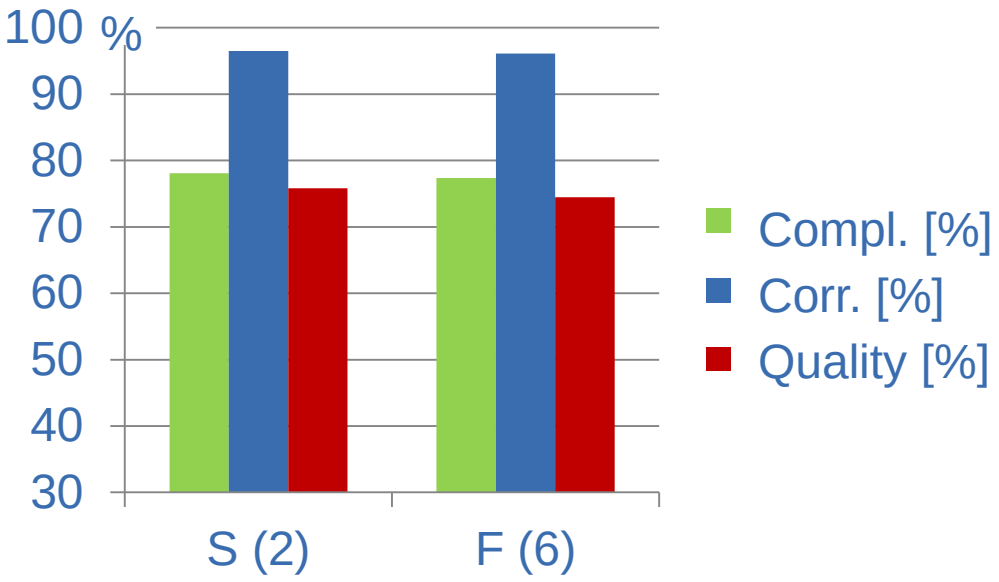


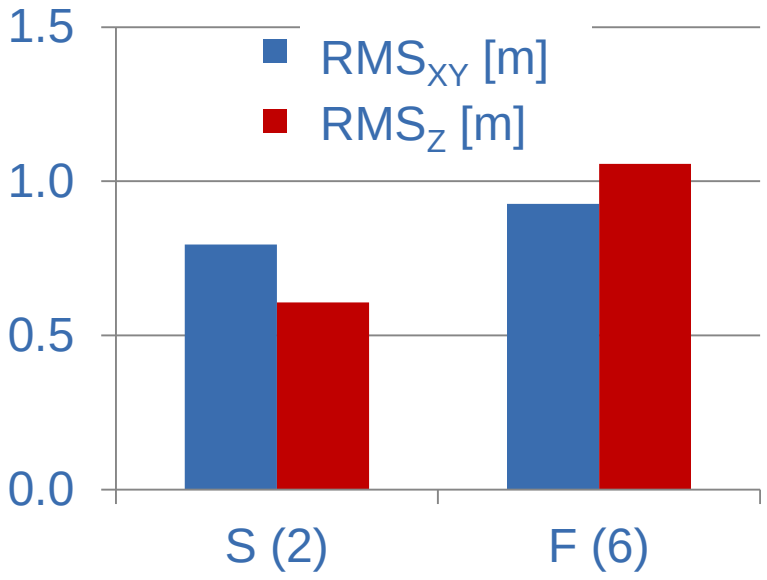


- Semi-automatic processing can achieve a better accuracy both in planimetry and height

Evaluation of Building Reconstr. - Vaihingen

- Impact of degree of automation (average Areas 1-3, roof planes > 10 m^2): Semi-automatic (S) vs. Fully-automatic (F)

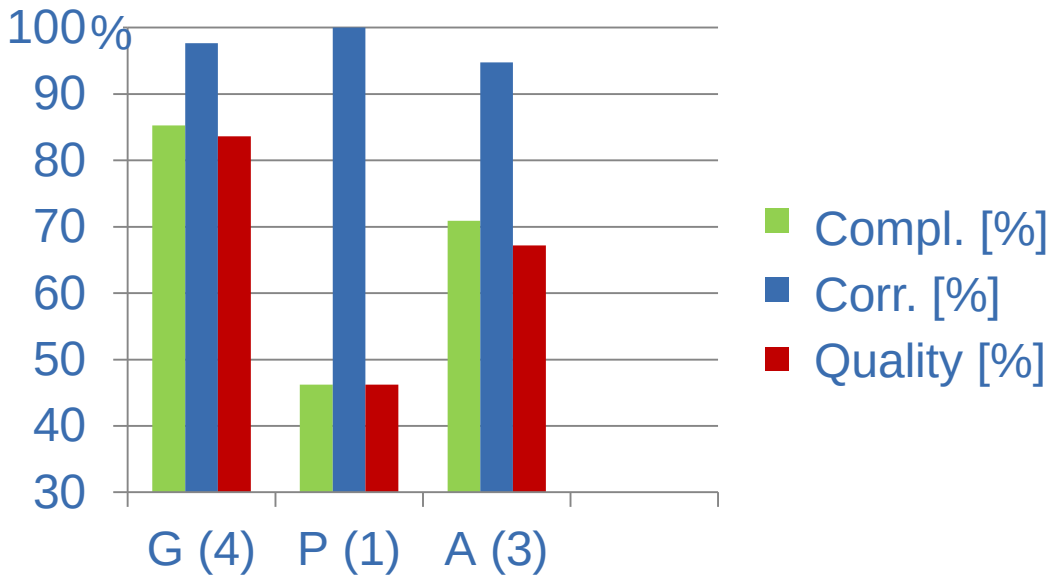


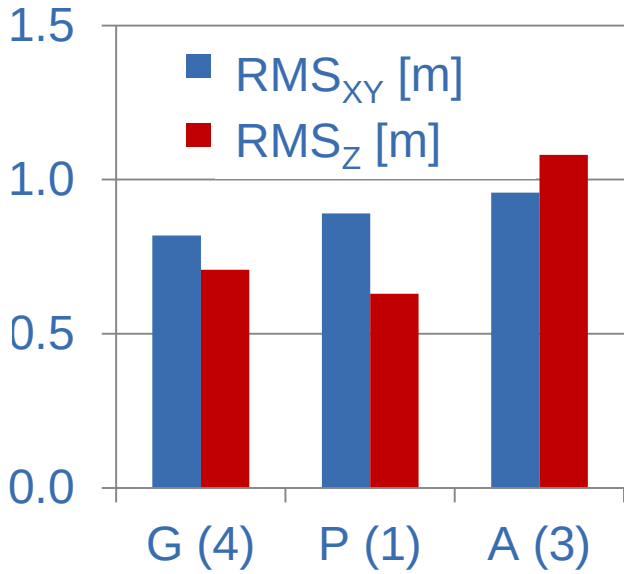


- Semi-automatic processing can achieve a better accuracy both in planimetry and height

Evaluation of Building Reconstr. - Vaihingen

- Impact of building models (average Areas 1-3, roof planes > 10 m^2): Generic (G) vs. Primitives (P) vs. Adaptive (P)





- Comparison is not really conclusive
  - Three adaptive methods are variant of the same algorithm
  - Only one method based on primitives

Discussion

- Building reconstruction works well for simply-shaped buildings
  - Generally simple shape
  - Dormers are small compared to dominant roof planes
- Complex shapes and small objects do not simply lead to more generalized models
- Accuracy potential of the sensors not yet fully exploited
- Results are generally sufficient for a ‘nice’ visualisation
- Fully automatic generation of topologically and geometrically correct models in complex environments
- Most favourable conditions: area 2 (high-rise residential bld.)

Outline

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

Conclusion

- Comparison of state-of-the-art methods
- Interested in individual methods?
  → See sessions on the ISPRS benchmark
- Benchmark for urban object extraction is still on-going
- The data may still be obtained via the WWW
- Results are made available via the WWW
- Changed conditions of use: **DGPF has allowed the use of the Vaihingen data for any scientific purpose**

Future Work

- The data set should remain a standard data set for making different methods comparable
- We are contemplating an online evaluation system
- Expansion of the data set:
  - New data (incl. reference!) ?
  - Provide DSM from matching and true orthophoto
  - Provide reference for labelling (rather than object detection)
- Special issue on the outcomes of the ISPRS benchmark
  - Journal still to be negotiated
  - We will announce this soon

Acknowledgements

- The Vaihingen data set was provided by the German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF) (Cramer, 2010): http://www.ifp.uni-stuttgart.de/dgpf/DKEP-Allg.html.
- The reference for Vaihingen was generated by RAG Steinkohle AG and SIRADEL (www.siradel.com).
- The Toronto data set was provided by Optech Inc., First Base Solutions Inc. and York University.
- The reference for Toronto was created by York University.

References

- Bulatov D., Solbrig P., Gross H., Wernerus P., Repasi E., Heipke C., 2011. Context-based urban terrain reconstruction from UAV-videos for geoinformation applications. *IAPRSIS* XXXVIII-1-C22 (on CD-ROM)
- Cramer, M., 2010. The DGPF test on digital aerial camera evaluation – overview and test design. Photogrammetrie – Fernerkundung – Geoinformation 2(2010):73-82.
- Champion, N., Rottensteiner, F., Matikainen, L., Liang, J., Hyyppä, J., Olsen, B., 2009. A test of automatic building change detection approaches. *IAPRSIS* XXXVIII-3/W4:145-150.
- Dorninger, P., Pfeifer, N., 2008. A comprehensive automated 3D approach for building extraction, reconstruction, and regularization from airborne laser scanning point clouds. Sensors 8(11):7323-7343.
- Everingham, M., Van Gool, L., Williams, C., Winn, J., Zisserman, A., 2010. The Pascal Visual Object Classes (VOC) Challenge. International Journal of Computer Vision 88(2): 303-338.
- Griffin, G., Holub, A., Perona, P., 2007. Caltech-256 Object Category Dataset. Technical report 7694, California Institute of Technology, http://authors.library.caltech.edu/7694.
- Grigillo, D., Kosmatin Fras, M., Petrovič, D., 2011. Automatic extraction and building change detection from digital surface model and multispectral orthophoto. Geodetski vestnik 55: 28-45.
- Gröger, G., Kolbe, T. H., Czerwinski, A., Nagel, C. 2008. OpenGIS city geography markup language (CityGML) encoding standard, Version 1.0.0, OGC Doc. No. 08-007r1 http://www.opengeospatial.org/standards/citygml (10/01/2012).

References

- Jwa, Y., Sohn, G., Cho, W. and Tao, V., 2008. An implicit geometric regularization of 3D building shape using airborne LiDAR Data. *IAPRSIS* XXXVII-B3A:69-76.
- Kaartinen, H., Hyyppä, J., Gülch, E., Hyyppä, H., Matikainen, L., Hofmann, A. D. Mäder, U., Persson, A., Söderman, U., Elmqvist, M., Ruiz, A., Dragoja, M., Flamanc, D., Maillet, G., Kersten, T., Carl, J., Hau, R., Wild, E., Frederiksen, L., Homgaard, J., Vester, K., 2005. Accuracy of 3D city models: EuroSDR comparison. *IAPRSIS* XXXVI-3/W19:227–232.
- Liu, C., Shi, B., Xuan, X., Nan, L., 2012. LEGION segmentation for building extraction from LiDAR data. Accepted for publication in *IAPRSIS* XLIX-B3.
- Liu, X., Wang, D. L., 1999. Range image segmentation using a relaxation oscillator network. IEEE Transactions on Neural Networks 10 (3):564-573.
- Mayer, H., 2008. Object extraction in photogrammetric computer vision. ISPRS J. Photogrammetry & Remote Sens. 63(2):213-222.
- Mayer, H., Hinz, S., Bacher, U., Baltsavias, E., 2006. A test of automatic road extraction approaches. *IAPRSIS* XXXVI-3: 209–214.
- Moussa, A., El-Sheimy, 2012. A new object based method for automated extraction of urban objects from airborne sensors data. Accepted for publication in *IAPRSIS* XLIX-B3.
- Niemeyer, J., Wegner, J.D., Mallet, C., Rottensteiner, F., Soergel, U., 2011. Conditional random fields for urban scene classification with full waveform LiDAR data. U. Stilla et al. (Eds.): PIA 2011, LNCS 6952, pp. 233-244.

References

- Oude Elberink, S., Vosselman, G., 2009. Building reconstruction by target based graph matching on incomplete laser data: analysis and limitations. Sensors, 9(8):6101-6118.
- Oude Elberink, S., Vosselman, G., 2011. Quality analysis on 3D building models reconstructed from airborne laser scanning data. ISPRS J. Photogrammetry & Remote Sens. 66(2) 157-165.
- Rau, J.-Y., Lin, B.-C., 2011. Automatic roof model reconstruction from ALS data and 2D ground plans based on side projection and the TMR algorithm. ISPRS J. Photogrammetry & Remote Sens. 66 (6) (supplement):s13-s27.
- Rutzinger, M., Rottensteiner, F., Pfeifer, N., 2009. A comparison of evaluation techniques for building extraction from airborne laser scanning. IEEE J. Selected Topics in Applied Earth Observations & Remote Sens. 2(1):11-20.
- Scharstein, D., Szeliski, R., 2002. A taxonomy and evaluation of dense two-frame stereo correspondence algorithms. International J. Computer Vision, 47(1/2/3):7-42,
- Sohn, G., Huang X. and Tao, V., 2008. Using binary space partitioning tree for reconstructing 3D building models from airborne LiDAR data. PE & RS 74(11):1425-1440.
- Zhang, W., Grussenmeyer, P., Yan, G., Mohamed M., 2011. Primitive-based building reconstruction by integration of Lidar data and optical imagery. *IAPRSIS* XXXVIII-5/W12.