Advanced Matching Techniques for High Precision Surface and Terrain Models

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Introduction

- **Comeback of image matching for DTM & DSM generation**
  - Very few professional tools for DSM generation from image matching
  - Several interesting research approaches, partly 10 years old
  - MATCH-T DSM can produce very dense point clouds – specially designed for urban areas
- **Competition to LiDAR point clouds**
  - Big potential in urban areas
- **Digital filmless cameras offer new potentials for matching**

Overview

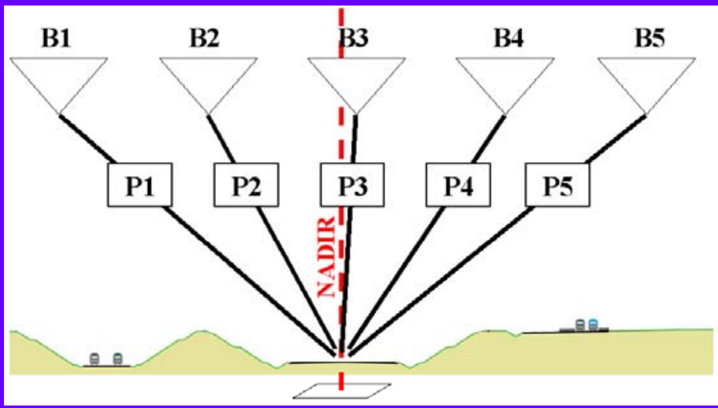
- **Topics**
  - Top 1: MATCH-T DSM – Advanced matching features
  - Top 2: Quality of DTM/DSM from MATCH-T DSM
  - Top 3: Change detection in open pit mining using MATCH-T DSM and SCOP-Poly
  - Top 4: Building extraction with point clouds & ground plans using Building Generator
  - Top 5: Improved point cloud classification by image support
- **Conclusions**

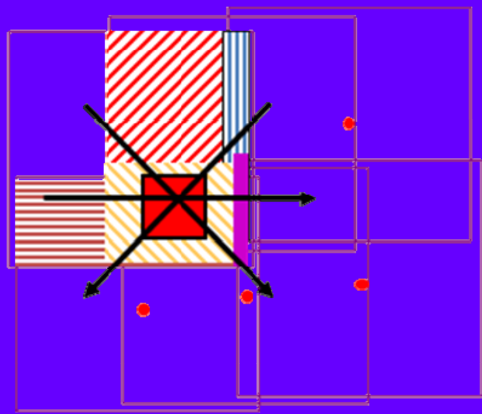
Top 1: MATCH-T DSM - Features

- **Improved „Model“- selection**
  - Individual model search for each “computation unit”
  - Sort sequence according to suitability
    - Angle of incidence
    - Model area
  - Sequential multi-image matching
- **Robust filtering in 3D**

MATCH-T DSM - Model selection

- Angle of incidence
- Model area

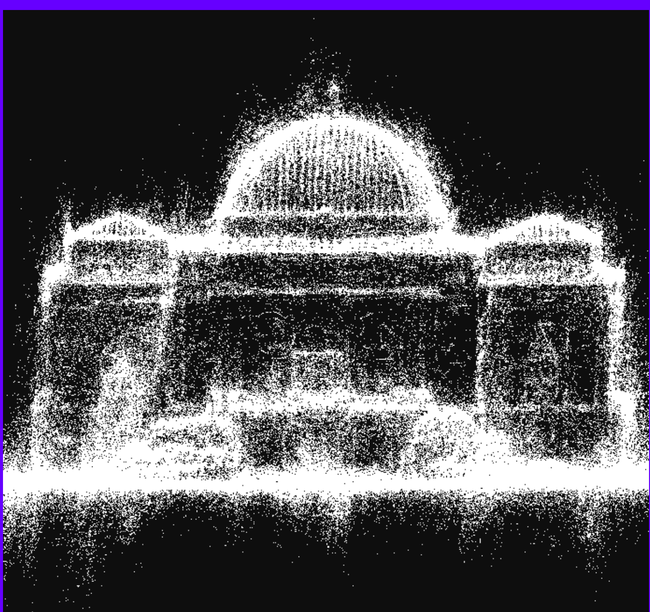




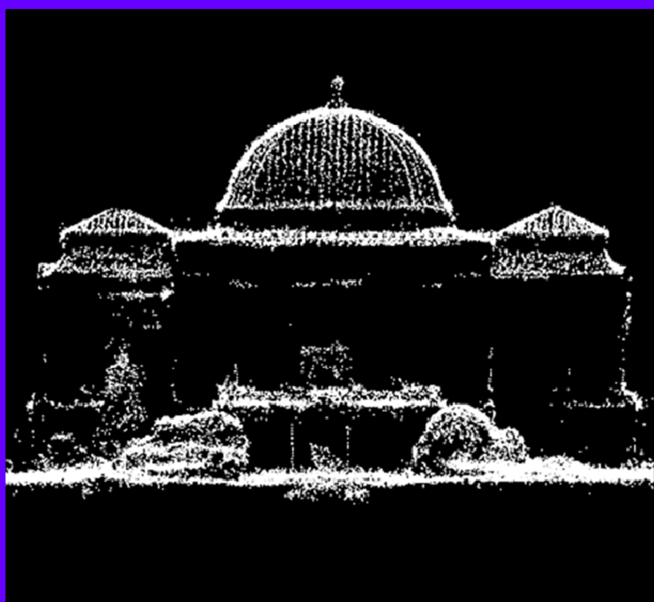
(Lothhammer, 2008)

MATCH-T DSM - Robust 3D filtering

Raw point cloud



Filtered point cloud



(Lothhammer, 2008)

Top 2: Quality of matched DTM/DSM

- Application in open pit mining
- Images + reference data by courtesy MIBRAG mbH
- 4 standard flights + 2 special flights
- Comparison to (manual) reference data

(Zheltukhina, 2009)

Test data sets – Courtesy MIBRAG

4 Standard data sets June-September '08

Number of strips	4
Number of images	98
Photo scale	10 000
Basis along the flying direction	375 m
Basis across the flying direction	1275 m
Forward overlap	60 %
Side overlap	23 %
Extension of the area West-East	12 500m
Extension of the area North-South	7700m
Mean terrain height	150 m

2 Special data sets October + November '08

Number of strips	7
Number of images	351
Basis along the flying direction	180 m
Basis across the flying direction	625 m
Forward overlap	80 %
Side overlap	62 %

Typical AT result by MIBRAG:
RMS at check points
X: 0,052 m
Y: 0,045 m
Z: 0,094 m
$\sigma 0$ = 0.2 pixel (1 pixel = 0.12m)

Reference data

- **MIBRAG**
  - Manual stereo DTM
    - Break-lines
    - Spot heights
  - Check points
- **HFT**
  - Manual stereo DTM
    - Single points
    - Break-lines

Example of reference data by MIBRAG overlayed on orthophoto (June 08)

(Zheltukhina, 2009)

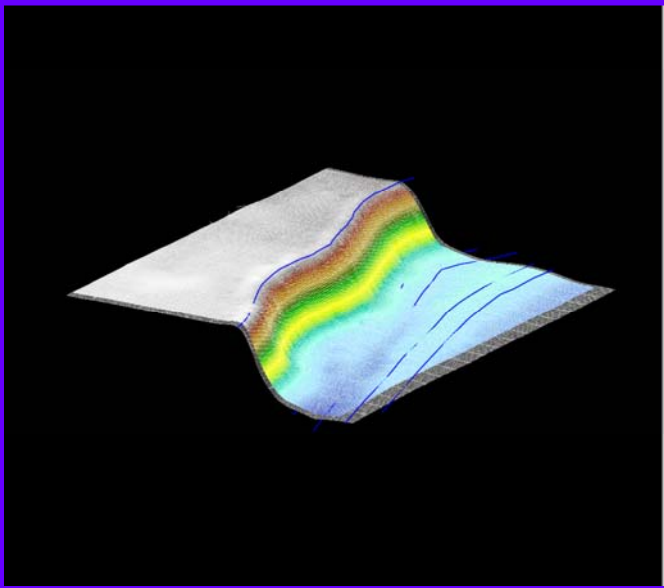
Examined: shadowed steep slope with overlayed check points

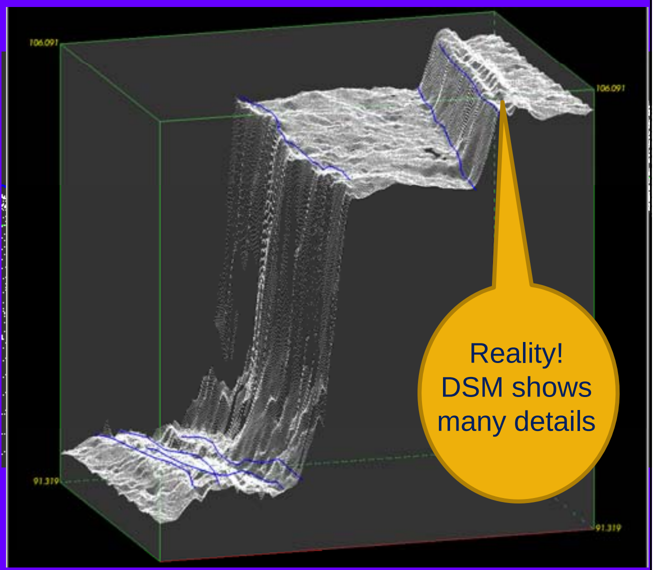
- **Analysis of parameter selection**
- **Quality analysis**
- **DTM and DSM results**

(Zheltukhina, 2009)

MATCH-T DSM – DTM/DSM

- DTM grid size 15cm undulating
- MIBRAG break-lines overlayed
- DSM grid size 15 cm Profile view with MIBRAG reference break-lines





(Zheltukhina, 2009)

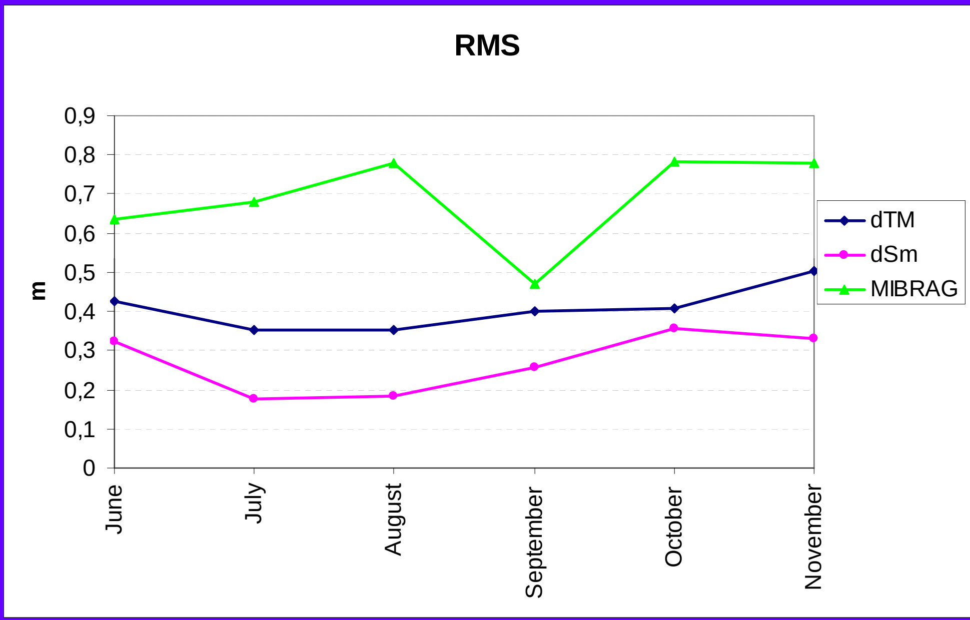
Investigations on accuracy for different parameter settings

- Default settings for DTM and DSM very suitable
- Customization did not really improve

General Information	Generating Strategy	RMS [m]	Max [m]	Min [m]
June, 2008 40 check points grid 0.15m	MIBRAG DTM	(0,945)	(3,480)	(-0,826)
	dTm_extreme	0,286	0,741	-0,717
	dTm_customized	0,342	0,931	-0,972
	dSm_undulating	0,213	0,530	-0,615
	dSm_customized	0,192	0,682	-0,531

Remark: MIBRAG result not representative for this part due to generalization effects

RMS (height) of derived DEMs compared to manual HFT check points – all flights



Number of check points from 1988 to 3036.
Manual measurement about 0.12m height accuracy.
DTM: 1.8m grid size, DSM 0.45m grid size

Influence of overlap parameters

Standard flight (60%/23%)

- Mostly matching unit determined from 1 model only
- 24.9 3D points per mesh

```
Number of not processed MU (no model)   :      220
Number of processed MU                  :     7556 / 100.0 [%]
Number of  1 - fold determined MU       :     7482 /  99.0 [%]
Number of  2 - fold determined MU       :       60 /   0.8 [%]
Number of  3 - fold determined MU       :       12 /   0.2 [%]
Number of  4 - fold determined MU       :        2 /   0.0 [%]
```

Special flight (80% / 62%)

- Many fold determined matching units
- 82.7 3D points per mesh

```
Number of processed MU              :   563698 / 100.0 [%
Number of  1 - fold determined MU   :        5 /   0.0 [%
Number of  2 - fold determined MU   :        5 /   0.0 [%
Number of  3 - fold determined MU   :        4 /   0.0 [%
Number of  4 - fold determined MU   :   410169 /  72.8 [%
Number of  5 - fold determined MU   :    39816 /   7.1 [%
Number of  6 - fold determined MU   :    46618 /   8.3 [%
Number of  7 - fold determined MU   :    22938 /   4.1 [%
Number of  8 - fold determined MU   :    13804 /   2.4 [%
Number of  9 - fold determined MU   :     6910 /   1.2 [%
Number of 10 - fold determined MU   :     4017 /   0.7 [%
Number of 11 - fold determined MU   :     2600 /   0.5 [%
Number of 12 - fold determined MU   :     1838 /   0.3 [%
Number of 13 - fold determined MU   :     1244 /   0.2 [%
Number of 14 - fold determined MU   :      848 /   0.2 [%
Number of 15 - fold determined MU   :      633 /   0.1 [%
Number of 16 - fold determined MU   :      495 /   0.1 [%
Number of 17 - fold determined MU   :      410 /   0.1 [%
Number of 18 - fold determined MU   :      304 /   0.1 [%
Number of 19 - fold determined MU   :      263 /   0.0 [%
Number of 20 - fold determined MU   :      232 /   0.0 [%
Number of 21 - fold determined MU   :      222 /   0.0 [%
Number of 22 - fold determined MU   :      168 /   0.0 [%
Number of 23 - fold determined MU   :      196 /   0.0 [%
Number of 24 - fold determined MU   :      772 /   0.1 [%
Number of 25 - fold determined MU   :      855 /   0.2 [%
```

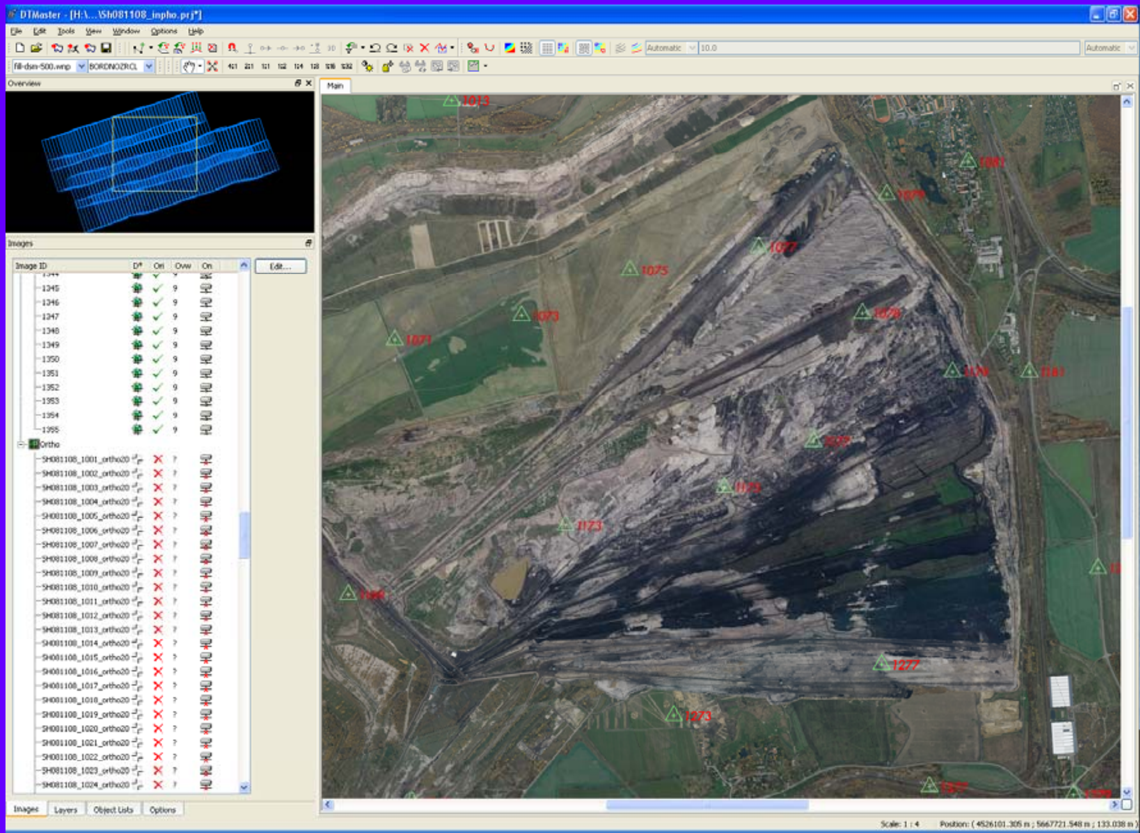
Discussion of Top 2 - Quality

- **DTM/DSM**
  - Quality compares to manual measurements
  - DSMs partly more detailed than reference data
  - DSM performs slightly better than DTM parameters in the examined cases
- **Matching parameters**
  - Customization does not bring real advantages
  - Standard parameter settings can be used
- **Higher redundancy by**
  - Multi-image matching
  - Usage of 12 bit information (Heuchel 2005)

Top 3: Detection of changes

- **Input**
  - **Assessing accuracy of DSM** (cf. above)
  - **Sequence of 2 DSMs (using 45cm grid spacing)**
- **Workflow**
  - **Calculate difference model (SCOP++ 5.4)**
  - **Accuracy of DSM used to detect significant changes (SCOP Poly)**
    - **Cutting/Filling threshold +/- 0.3m**
    - **Area threshold >4500m²**
- **Results**
  - **Polygons around changed areas**
  - **Difference DSM and volume determination (cutting/filling)**
  - **Statistical reports and visualization**

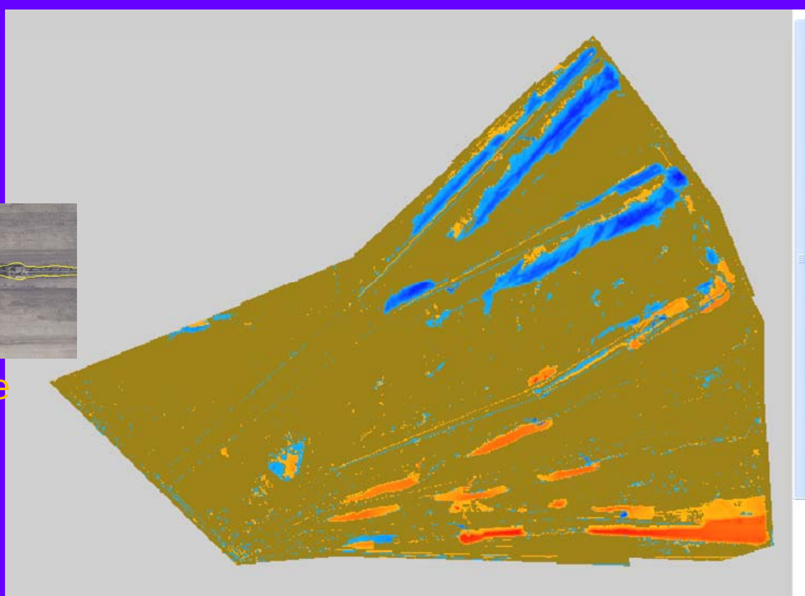
Selected working area for evaluation

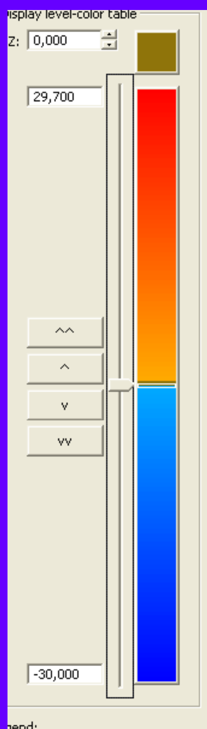


Difference model (Oct-Nov 80%/62%)

- **Automatically created DSMs**
  - Unchanged (green) between -0.3m and 0.3m
  - Cutting (orange) and Filling (blue)

Polygon of change

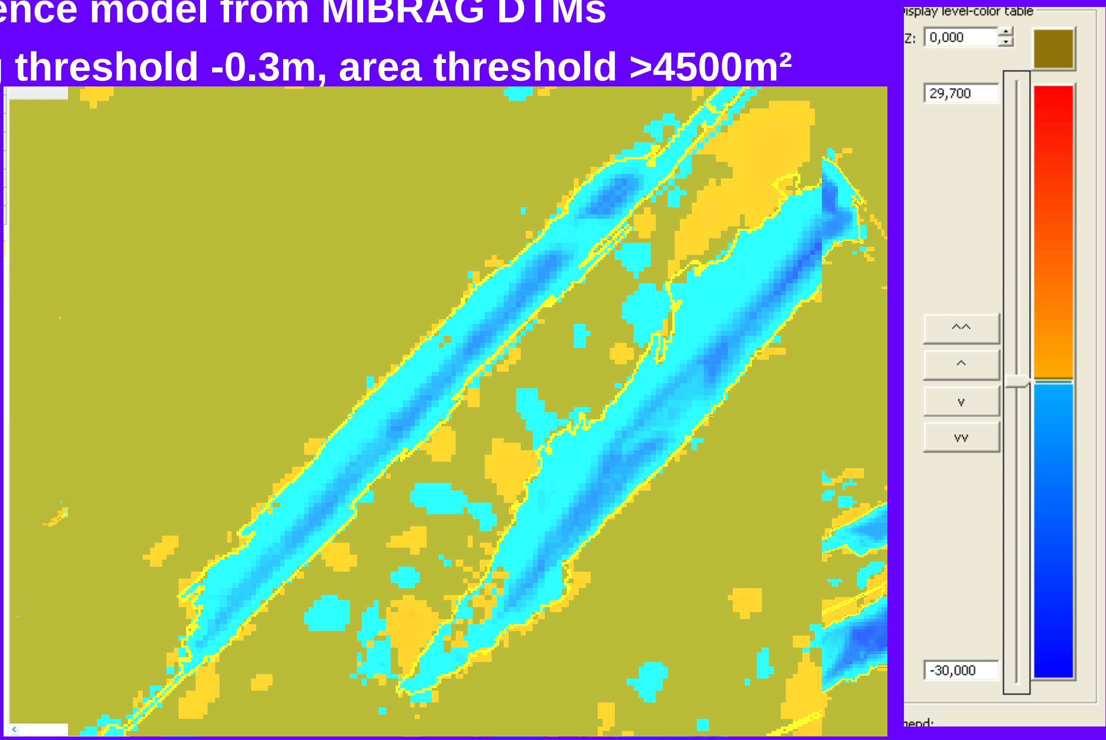




(Zheltukhina, 2009)

Polygons of changes – <u>Filling</u> (Oct.-Nov.)

- **Polygons generated from difference DSMs and overlayed on difference model from MIBRAG DTMs**
- **Filling threshold -0.3m, area threshold >4500m²**



(Zheltukhina, 2009)

Analysis of Cutting and Filling (Oct.-Nov.)

- MIBRAG – DTMs
  - Manual measurement and manual exclusion of machines
- Automatically generated DSMs
  - Manual deletion of 5 polygons indicating single machines.
  - Results still contain machines moving during/inbetween flights

	Volume m³	Volume m³	Volume m³	Volume in %
	MIBRAG DTMs (manual)	HFT MATCH-T DSMs (automatic)	Difference MIBRAG-HFT	Difference (MIBRAG=100%)
Filling	4296235	4287573	8662	0.2%
Cutting	5198767	5135589	63178	1.2%

Top 3: Discussion

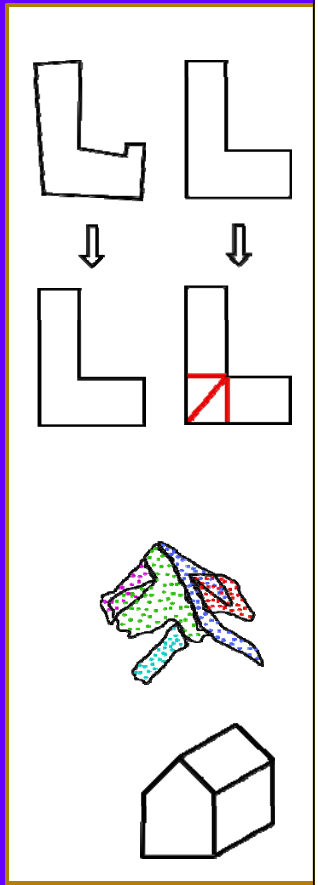
- **Simplicity of workflow**
  - Definition of 1 working area
  - Running Match-T DSM on whole area for 2 periods
  - Compute difference DSM
  - Running Scop Poly on difference DSM
  - Editing single polygons
  - Computation of volumes
- **SCOP Poly (Add-on) assists in detecting changes in difference DSMs**
  - Simple editing of automatically generated polygons
  - No manual digitization and exclusion from matching

Top 4: Building extraction

- **Objective: building models for large areas**
  - Focus on LoD 2 (and LoD 1) (cf. CityGML)
  - Model driven approach
  - Modelling by pre-defined parameter sets
- **Input**
  - Match-T DSM and LiDAR point clouds
  - Building ground plans
- **3 Step procedure**

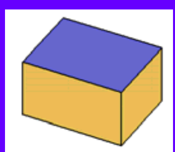
Building Generator – 3 steps

- **Ground plan generalization**
  - Analysis of ground plan structure
  - Division: Rectangle, L, T, U, complex shape
- **Segmentation**
  - Surface points in a ground plan polygon
  - Adjustment of points to plane segments
- **Modelling**
  - LoD 2 (basic primitives) or LoD 1

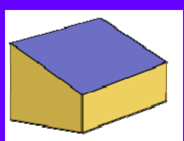


(Grau, 2008)

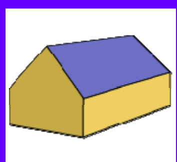
Building Generator - Building models for LoD2



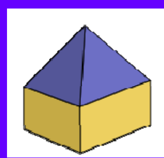
Flat roof



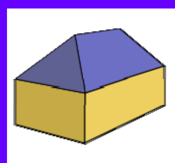
Lean-to-roof



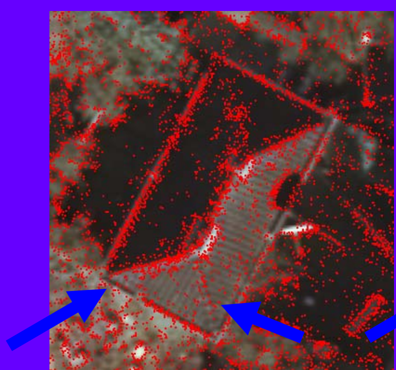
Saddleback roof



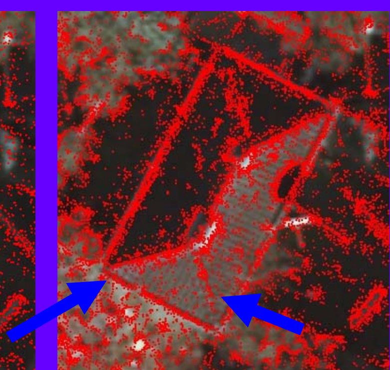
Tent roof



Hip roof



Sparse point cloud

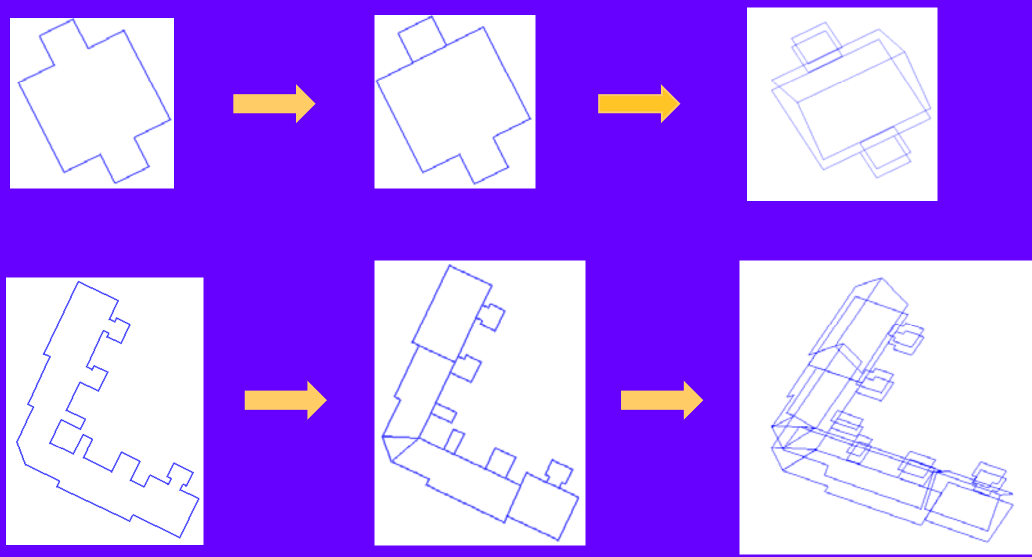


Dense point cloud

(Grau, 2008)

Building Generator - Subdivision of complex boundaries

2D boundary | **Subdivision of 2D boundary** | **Resulting models**



(Grau, 2008)

Building Generator - Test areas

- **Graz**
  - Dense
  - Complex roof types and ground plans


- **Toulouse**
  - Sparse, single houses
  - Simple structures


(Grau, 2008)

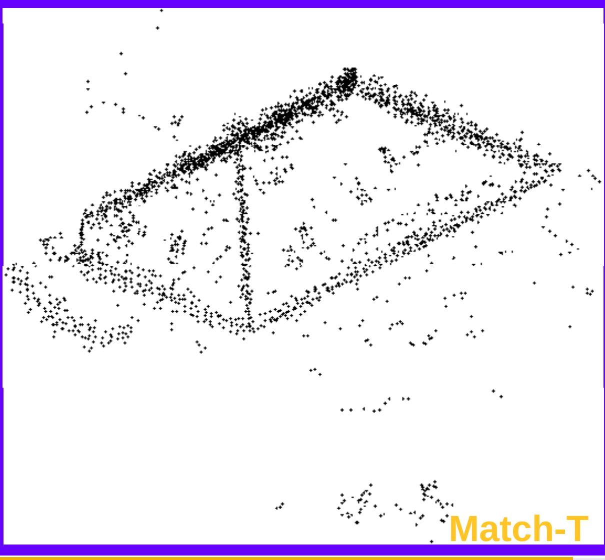
- **Bautzen**
  - Dense
  - Complex roof types and ground plans

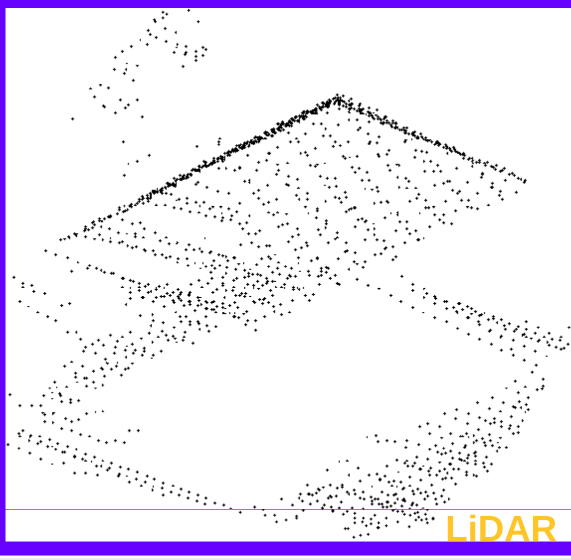

Building Generator – Ground plans

- Manual measurement of 334 buildings (map data not accessible)
- Classification into shapes:

	Shape categories				
Test data	Rectangle	Complex	L	T	U
Graz (Match-T)	39	9	28	9	17
Toulouse (Match-T)	92	12	19	5	2
Bautzen (LiDAR) ⟸	59	7	28	5	3
Bautzen (Match-T)	39	5	20	2	2

Building Generator - Point cloud structure





Test area	Graz	Toulouse	Bautzen	
Point cloud	Match-T	Match-T	LiDAR	Match-T
SDEV in height [m]	0,20	0,09	0,06	0,22
Relative point density [points/m²]	76	11	5	11

Building generator - Success rates

Test area	Graz	Toulouse	Bautzen	
Point cloud	Match-T	Match-T	LiDAR	Match-T
Rectangle shape	66,67%	95,65%	76,27%	60,26%
L-shape	25,00%	94,74%	42,86%	27,50%
T-shape	77,78%	100,00%	60,00%	50,00%
U-shape	17,65%	100,00%	33,33%	25,00%
Complex shape	11,11%	66,67%	28,57%	20,00%
Time/Building [sec]	44,45	2,20	1,96	4,41

Mean values (Median) of the LoD2 results in percent based on investigations of 40 different parameter combinations and average extraction time

Building generator - Discussion of parameter settings

- **Segmentation step:**
  - Essentially only 3 parameters are important
  - Parameter value selection needs knowlege on the structure of the point cloud
- **Generalisation step:**
  - Not very sensitive to parameter changes
  - Subdivision of very complex shapes necessary
- **General observation:**
  - Building complexity decisive for parameter selection

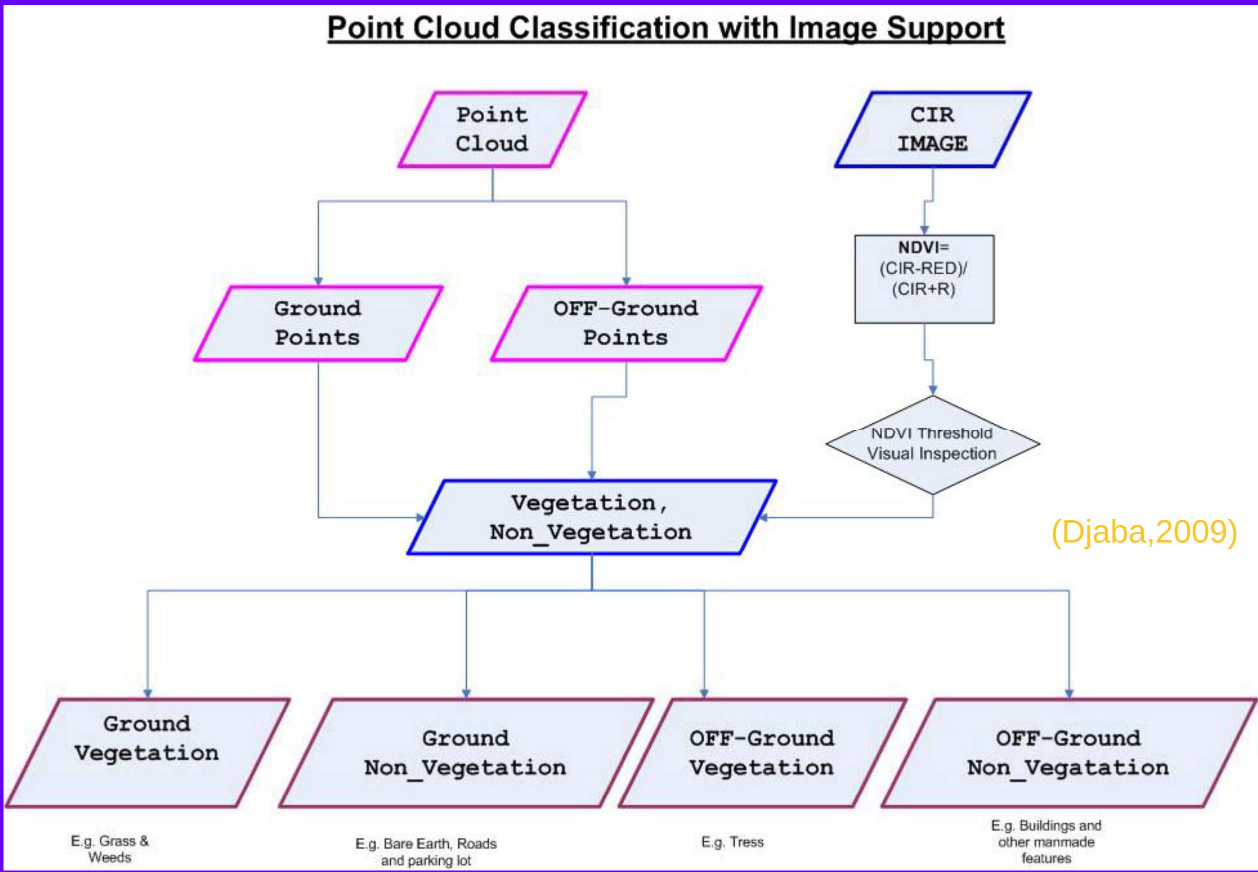
Top 4: Discussion

- **Match-T point cloud well suited for building modeling**
- **Success rates can reach level of building generation using LiDAR point cloud**
- **Parameter selection reduced to few decisive ones; still needs improvements**
- **Dependencies on ground plans should be reduced**

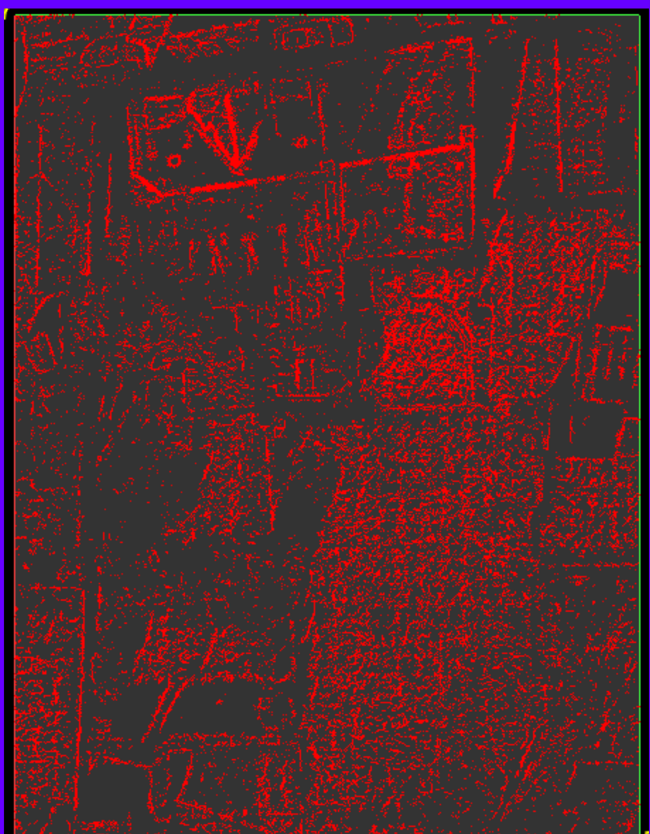
Top 5: Potentials

- **MATCH-T DSM point cloud classification using image support**
  – Use improved radiometric features of digital filmless cameras
  – Test area Graz

Methodology

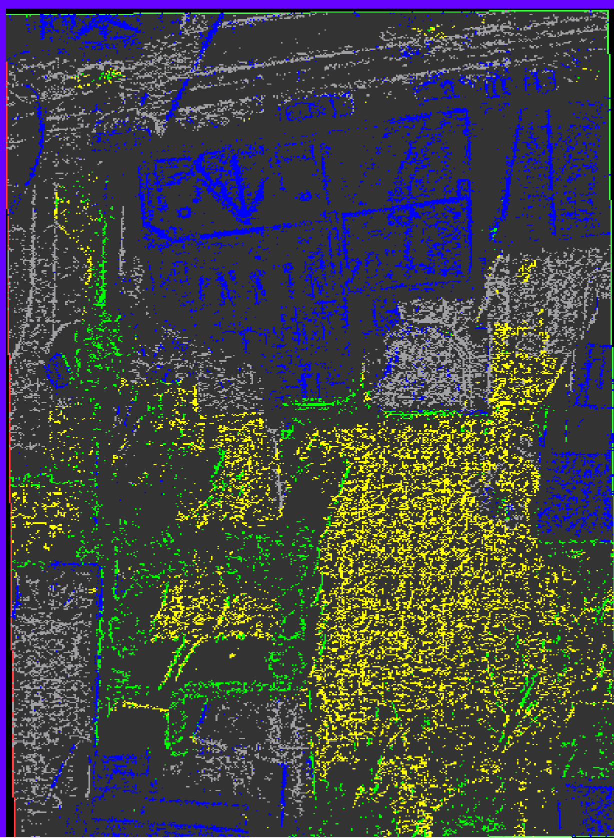


UnClassified PointCloud



Classified Point Cloud

(Djaba, 2009)



Red=Unclassified, **Blue=Off_terrain not_Veg**, **Green=Off_terrain Veg**, **Grey= Terrain not_Veg**, **Yellow= Terrain Veg**

Acknowledgements

- **inpho GmbH, Germany**
  - MATCH-T DSM 5.2 (Beta)
  - Building Generator
  - Add-on SCOP Poly
  - Image data
- **MIBRAG mbh, Germany**
  - Image data,
  - Reference data
- **HFT Graduates**
  - MSc. H. Djaba, Dipl.-Ing. (FH) S. Grau, MSc. N. Zheltukhina

Conclusions

- **MATCH-T DSM provides high quality DTMs/DSMs**
  - Good results in a very challenging area
  - Exploitation of multi-image matching and filmless digital cameras
  - Change detection results very promising
  - First research results show a clear improvement of point cloud classification by image support
- **Building Generator**
  - High potential for automated building extraction for LoD1 and LoD2 with given ground plan