Evaluation of

# Building Extraction from Digital Elevation Models

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**Abstract:** *This note describes the basics of our approach towards building extraction using automatically derived high resolution Digital Elevation Models (DEMs), answers to the questionaire of the ISPRS WG III/3 questionaire for the test on image understanding, and shows results for the ISPRS test data sets.*

# Contents

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# 1 Why Building Extraction from Digital Elevation Models ?

Our investigations concerning building extraction from high resolution Digital Elevation Models (DEMs) have been motivated by the data sets for the ISPRS WG3 test on image understanding. A closer look on the distributed DEMs, which do not only contain information about the topographic surface, but also about the buildings, indicates the usefullness of such DEMs for the extraction of information about buildings with respect to height information. The resolution for ground plan extraction will always be limited due to the resolution of the used DEM. Therefore, our approach towards building extraction from DEMs originally aimed at gaining approximation values for other techniques (Lang and Schickler 1993, Lang 1995), which are directly based on the use of digital images. The extracted approximation values can be used to decrease the degree of interaction or, dependent on the quality of the approximation values, help for automation of the procedure as a long term goal. An approach quite close to this idea is Haala 1994, wheras Gabet *et al.* 1994 is close to our approach with respect to the use of DEMs.

Of course using DEMs as the only input has some disadvantages. The information about the buildings is not as dense as in digital images. Furthermore, only height information can be used, whereas digital images may also be exploited using e. g. texture or colour information, if available. On the other hand, a DEM is an intermediate geometric 2.5D description of the 3D objects to be extracted. Thus, a DEM is not able to describe e. g. vertical walls or passages through a building, but allows the application of object related geometric parameters during the extraction procedure. Furthermore, DEMs can be generated automatically and the results of building extraction seem to be sufficient for some applications, in which the requirements for ground plan resolution and details are not as strict as e. g. in architecture or town planning. An example for these applications is microclimate investigation. In order to compute e. g. wind fields, Navier-Stokes equations have to be solved. Due to the complexity of the algorithms used for it, they normally deal with a medium resolution for the underlying surface description.

In the following, section 2 replies to the questionaire of the ISPRS WG III/3 test, referring to the distributed data sets, for which parametric building models have been applied. Section 4 deals with results for other data sets using prismatic models, followed by the conclusions in section 5.

# 2 Answers to the Questionaire

## 2.1 Datasets

The data sets we used for our approach are the range images/DEMs of the data sets 3 (*flat*) and 4 (*suburb*).

## 2.2 Hardware

The program is hardware independent and runs on SUN and Silicon Graphics workstations.

## 2.3 Software

The software is selfmade.

## 2.4 Programming language

The software is implemented in C.

## 2.5 Publications

Publications about our approach are

- Weidner and Förstner 1995, submitted to ISPRS journal, describing the approach for parametric and prismatic building models,
- Brunn *et al.* 1995, submitted to DAGM'95, focussing on 2D shape recovery, which can be used to extract ground plan information, but also for a wider range of applications, and
- Weidner 1995, a technical report (in preparation).

## 2.6 Object models

The models we use for the detection and reconstruction of buildings are generic and specific. The generic models are based on generic knowledge about the buildings, including the knowledge that

- buildings are supposed to be higher than the surrounding topographic surface (vertical walls),
- the ground plan of buildings consists of straight lines, which form a closed polygon or a set of closed polygons,
- the edges of the polygons are likely to be orthogonal, parallel, and collinear.

Besides such generic model assumptions we use specific (parametric) building models, namely models of

1. rectangle buildings with flat roof, and
2. rectangle buildings with symmetrically sloped roof

## 2.7 Prior knowledge

For our approach we assume, that

- the minimal size of buildings and
- the minimal height of vertical walls (e.g. height of a floor)

is known. This knowledge is used to fix some control parameters, namely

- the area for minimum and maximum filter, which is related to the size of the buildings, and
- the height for the initial segmentation, which is related to the height of vertical walls.

For the application of parametric models, we furthermore assume that the buildings are rectangles in the $xy$-plane and that they are separated from each other.

## 2.8 Strategy

The strategy of our approach towards building extraction from DEMs consists of two steps

1. detection of buildings in the DEM and
2. reconstruction of a parametric or prismatic geometric description for each detected building.

The first step is the *detection* of buildings with the goal of focusing attention on areas where buildings can be expected. We first compute an approximation of the topographic surface using mathematical morphology. The difference between the measured DEM and the topographic surface contains the information about the buildings. The buildings are detected by thresholding the difference data set. The threshold is chosen according to prior knowledge about the buildings.

The second step is the *reconstruction* of the buildings. For this purpose different groups of models are used, dependent on the complexity of the detected buildings.

The first group of models consists of *parametric* models of the buildings. These models are used for simple buildings, which can be described using a few parameters.

Complex buildings and blocks of buildings are described using *prismatic* models, which constitute the second group. These models are based on generic knowledge about the buildings.

## 2.9 Pseudo code of the program

**Algorithm 2.1 (Building detection)**

1. Minimum filtering *of data*
2. Maximum filtering *of the minimum filtered data*
3. *Computation of the* difference *between the data and the filtered data*
4. *Computation of the* initial segmentation *by thresholding*
5. *Computation of* connected components *and* labelling
6. *Computation of the labels'* sizes *and* bounding boxes
7. *Selection of* valid labels
8. *Computation of the maximum and minimum height of each label*
9. *Computation of the threshold for the refined segmentation*
10. *Computation of the* refined segmentation *by thresholding within bounding box*

⊙

**Remark 2.1 (Step 1)** *Minimum filtering is an* erosion

$$\overline{z} = z \ominus w$$

*(cf. Figure 1 top row, middle).* •

**Remark 2.2 (Step 2)** *Maximum filtering is a* dilation.

$$\overline{\overline{z}} = \overline{z} \oplus w$$

•

**Remark 2.3 (Steps 1 + 2)** *Steps 1 and 2 form the opening of the set*

$$\overline{\overline{z}} = z \circ w$$

*(cf. Figure 1 top row, right).* •

**Remark 2.4 (Steps 1 + 2)** *Minimum and Maximum filtering is sensitive to noise and outliers in the data. In order to deal with both, a dual rank filter as described in Eckstein and Munkelt 1995 can be used.* •

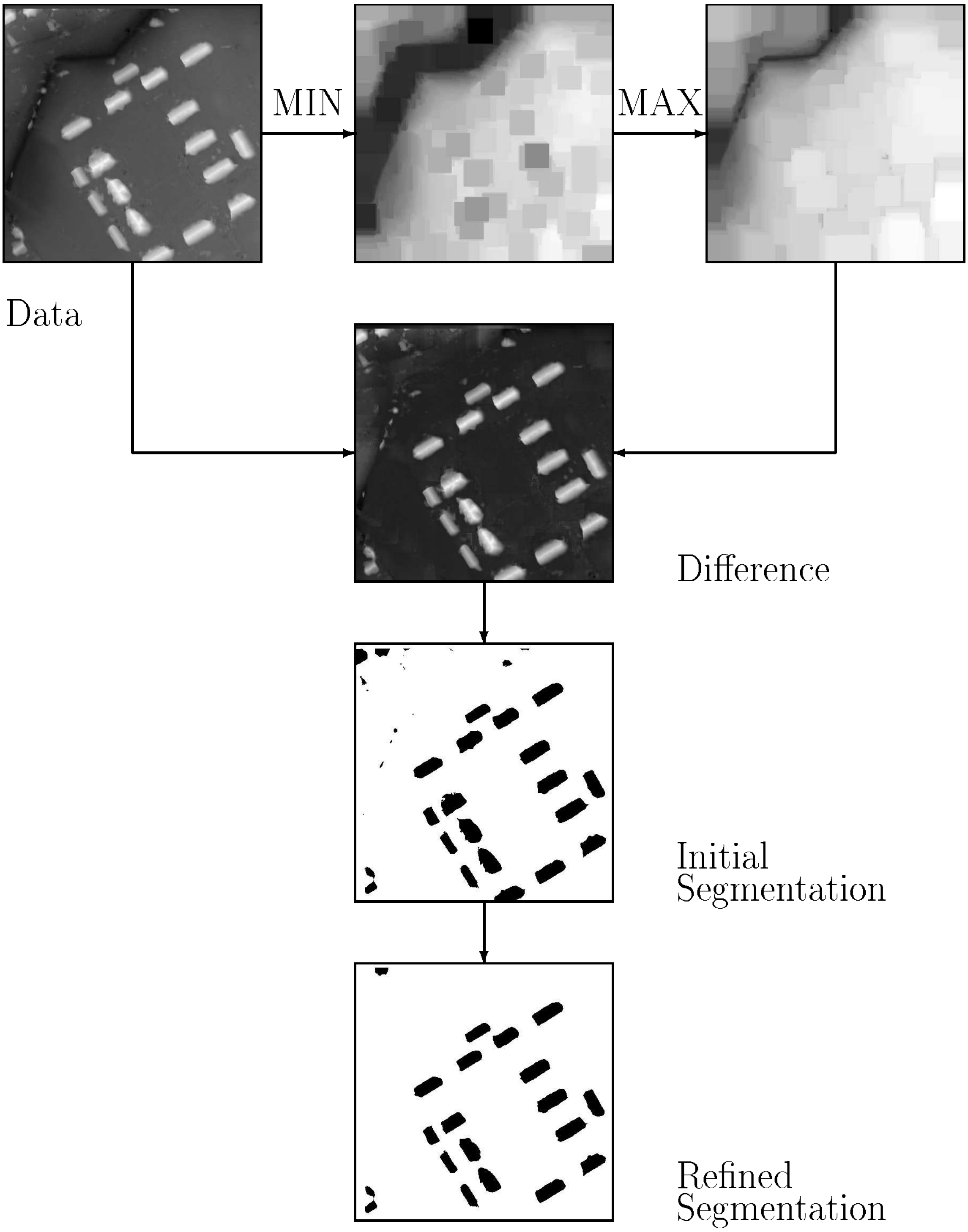



Figure 1: Building detection

**Remark 2.5 (Steps 1, 2)** *Both filters need the window size $m \times m$ as control parameter. $m$ is computed based on the control parameter* area for minimum and maximum filter*:*

$$m_0 = \sqrt{\frac{area\ for\ min/max\ filter}{\Delta x \Delta y}} \quad with \quad \Delta x,\, \Delta y\ :\ grid\ increments$$

*If $m_0$ is even, then $m = m_0 + 1$, else $m = m_0$.* •

**Remark 2.6 (Steps 1, 2)** *For the examples given in the figures we used a square window. Such a structural element has the disadvantage that the result is rotation variant. The use of a circle as structural element delivers a rotation invariant result. The influence of the use of the different structural elements has to be investigated.* •

**Remark 2.7 (Step 2)** *If* area for minimum and maximum filter *is chosen large with respect to the size of the buildings, the result of step 2 is an approximation of the DEM without buildings. On the other hand, a small window size is preferable in hilly regions, because the approximation of the topographic surface directly influences the result of step 4, i. e. thresholding for the initial segmentation. The* area for minimum and maximum filtering *should be chosen to be*

$$area\ for\ filter > k \cdot expected\ minimal\ size\ of\ buildings$$

*with $k = 5 \ldots 10$.* •

**Remark 2.8 (Step 3)** *If the approximation obtained in step 2 converges towards the measured DEM, step 3 delivers the data of the buildings (approximately) put on a plane. This holds if the topographic surface is smoother than the surface with buildings.* •

**Remark 2.9 (Steps 1, 2, 3)** *Negative values in the difference data set occur mainly at the margin of the data set, because the masks for minimum and maximum filtering are of a fixed size $m$ and are moved until the masks touch the border of the original data set. In order not to reduce the size of the data sets, the computed height values of the rows $(\frac{m}{2}+1)$ and $(\#rows - \frac{m}{2} - 1)$ and the columns $(\frac{m}{2}+1)$ and $(\#cols - \frac{m}{2} - 1)$ are transferred to the area of the margin.* •

**Remark 2.10 (Step 4)** *The threshold for the initial segmentation is given by the user. The* height for the initial segmentation *is related to the expected minimal height of the vertical walls of a building.* •

**Remark 2.11 (Step 6)** *In order to reduce the influence of errors during the first segmentation the bounding box is enlargened. This enlargement is predefined by the user with the control parameter* additional margin for bounding box. •

**Remark 2.12 (Step 7)** *The first criterion for the selection of valid labels is the size of the label by thresholding using the control parameter* expected minimal size of buildings, *in order to exclude spurious segments due to bushes and trees. This criterion is applied* *for both groups of models. The second criterion, which is only applied for parametric models, is the position of the bounding box. If the bounding box coordinates are at the margins of the data set, the labels are rejected, because in this case only parts of the buildings may be contained in the data set and the parameters would not be correct. In case of prismatic building models, at least the building parts within the dataset can be extracted.* •

**Remark 2.13 (Step 9)** *The threshold for the refined segmentation of each segment is computed using the difference between the maximum height of the initial segment and the minimum height of the related bounding box.* •

**Algorithm 2.2 (Building reconstruction: Parametric models)**

1. *Computation of the maximum and minimum height of each refined segment and the mean height of the background within the bounding box*
2. *Computation of the point of gravity* – position $x, y$ – *and the direction of the main axis* – orientation – *of each refined segment*
3. *Computation of the* shape parameters *for each segment*
4. *Computation of the* reference point coordinates *and the* orientation *of each segment in a reference coordinate system*
5. Selection *of the building model for each segment*
6. *Computation of the* height parameters *for each segment*

⊙

**Remark 2.14 (Step 2)** *In order to compute the point of gravity (position $x, y$) and the orientation of each refined segment, the heights within the segments are used as weights, i. e.*

$$r_g = \sum_{\mathcal{S}} r \cdot z(r,c) \; / \; \sum_{\mathcal{S}} z(r,c) \quad \textit{and} \quad c_g = \sum_{\mathcal{S}} c \cdot z(r,c) \; / \; \sum_{\mathcal{S}} z(r,c)$$

*where $\mathcal{S}$ denotes the segment.* •

**Remark 2.15 (Steps 2, 3)** *The shape parameters are computed as*

*length = length of the segment along the first main axis*

*width = width of the segment along the second main axis*

*Instead of using these simple techniques, the point of gravity, the lenght and the width can be computed via more sophisticated, model-based techniques (cf. Luo and Mulder 1993).* •

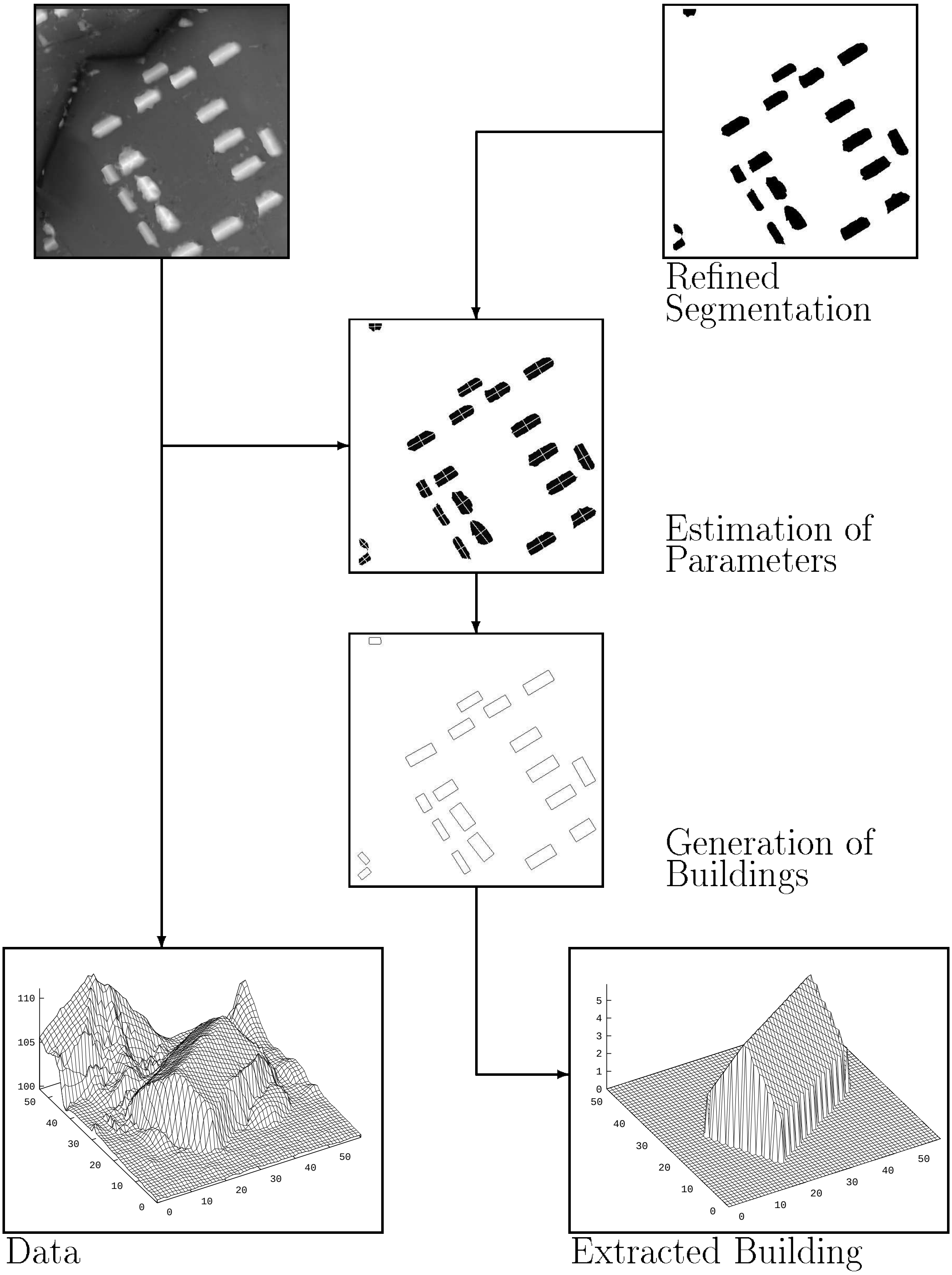



Figure 2: Reconstruction of parametric models

**Remark 2.16 (Step 5)** *For the selection of the models, i. e. building with a flat or a symmetric, sloped roof, the slope of the roof, i.e. difference between maximum and minimum of each refined segment devided by one half of the width, can be used as criterion. This is quite closely related to using the magnitude of the mean gradient. The threshold for the selection is the* minimal slope. •

**Remark 2.17 (Step 6)** *The algorithm distinguishes for the height parameters between two types of buildings:*

**Building with a flat roof**

- *height = difference between the mean height of the segment and the mean height of the background within the bounding box*

**Building with a symmetric, sloped roof**

- *height1 = difference between the minimum height of the segment and the mean height of the background within the bounding box*
- *height2 = difference between the maximum and minimum height of the segment*

*In order to improve the robustness of the computed parameters mean values for the k maximum or minimum heights could be used instead.* •

**Remark 2.18** *In order to improve the extraction of height information, heights might also be derived from the* opening *of the DEM, e. g.*

- *taking the height information for the bounding box without labels from the* opening *as described above, or*
- *intersecting the vertical walls with the surface given by the* opening,

*or a surface approximation for the bounding box without labels based on the heights of the original DEM by*

- *estimating the parameters of a tilted plane*

$$z(x, y) = a \cdot x + b \cdot y + z_0$$

*and computing the heights of the buttoms of the buildings as intersection of the vertical walls with this plane.*

*The estimation of the plane's parameters should be done using robust estimation techniques in order to reduce the influence of the round offs at the buildings' borders.* •

**Remark 2.19** *The direction of the ridge for buildings with a symmetric, sloped roof is assumed to be the direction of the first main axis. Instead of this assumption, the ridge line should be detected using gradients or curvatures and this information should be used.* •

For details concerning the extraction of prismatic models, please refer to Weidner and Förstner 1995.

## 2.10 Degree and type of interaction

During processing no interaction of an operator is needed. Interaction is reduced to editing of the control parameter file, starting the program, and control of the result.

### Example of control parameter file

```
# control parameter file BEX

flat05.dhm  # data
    0.5     # pixel_size in x-direction [m]
    0.5     # pixel_size in y-direction [m]
78909.0     # x-coordinate (lower left corner) [m]
44760.0     # y-coordinate (lower left corner) [m]
   50.0     # expected size of buildings [m^2]
  500.0     # area min/max filter
    4.0     # height for initial segmentation
    3.0     # minimal slope [degree]
    0.1     # resolution in height
    0.37    # threshold for polygon (triangle height) [m]
  100       # first label
    2       # additional margin for bounding box [pixel]
   51       # output data format for grid models of buildings
btestf      # name (without extension)
    1       # parametric models
    0       # prismatic models
    0       # write grid models
    0       # write data for each model
    1       # write additional data
    2       # show results
```

## 2.11 Computation time

The times [min.] given here are measured from starting the program to its end, and not only CPU times.

| data set | | SUN | | | Silicon | | |
|---|---|---|---|---|---|---|---|
| | | detection | reconstr. | total | detection | reconstr. | total |
| *flat* | 0.5 m | 1:15 | 0:40 | 1:55 | 0:45 | 0:10 | 0:55 |
| *flat* | 1.0 m | 0:20 | 0:10 | 0:30 | 0:10 | 0:05 | 0:15 |
| *suburb* | 0.5 m | 1:20 | 0:30 | 1:50 | 0:50 | 0:10 | 1:00 |
| *suburb* | 1.0 m | 0:20 | 0:10 | 0:30 | 0:10 | 0:05 | 0:15 |

## 2.12 Results

The result of the algorithm is a geometric description of buildings either using parametric or prismatic models.

# 3 Results for ISPRS Test Data Sets

## 3.1 Data Set *flat*

The DEM we used has a pixel size of $0.5\,m \times 0.5\,m$. Figure 3 displays the left digital image of the stereo pair and the overlay of the extracted ground plan information on the input DEM. A comparison between image and ground plan information indicates that only one building has not been detected. Note that no ground plan information about the buildings at the upper left corner and the building at the lower margin of the image was extracted, because they are at the margins of the DEM data set. They have been detected, but due to their position within the data set it is assumed that the related model parameters could not be extracted correctly. A closer look on the overlay indicates a plausible correspondence between input data and extracted ground plan information.

Figure 4 displays labelled ground plan information for the identification of buildings in Fig. 5, Fig. 6, and Fig. 7 and a visualization of the extracted building models put on the computed approximation of the topographic surface. Another visualization is given in Figure 8.

Figure 5 shows the extracted building models (white lines) projected into the left image of the stereo pair. A qualitative evaluation indicates that the orientations of the extracted models fit to the image information. Problems occur for the paramters *lenght* and *width*, although the overlay in Fig. 3 indicates a plausible fit to the DEM data. Therefore, the reasons for the discrepancies occur during the DEM generation. An explanation of the effects may be that during DEM generation, interest points are found at the borders of the roofs. Due to low texture (cf. label 113) or shadows (cf. label 134), no interest points are found close to the building. Therefore, the regularization term within the reconstruction algorithm leads to interpolation between points at the roofs' borders and points on the ground, which are more or less far away from the building, and thus elongating the buildings sytematically. Furthermore, the round offs at breaklines contribute to such effects, although we try to take these effects into consideration during the refined segmentation, and therefore the round offs only have minor influence.

A rough comparison of the height parameters compared to techniques directly based on digital images indicates that more sophisticated techniques as the implemented ones should be used in order increase robostness of the extraction procedure.

Figure 6 allows a closer look on the result of DEM-analysis and the use of the extracted models (label 115) for the semiautomatic tool described in Lang and Schickler 1993. The upper image displays the projected model. An operator has only to check the selection of the right parametric model, and also can move the model (middle), before he starts the automatic measurement procedure. The result of automatic measurement is displayed in the lower image, also showing the extracted image edges (black lines).

Figure 7 shows the approximate model derived by DEM-analysis and the result of the automatic measurement without user interaction (label 128).

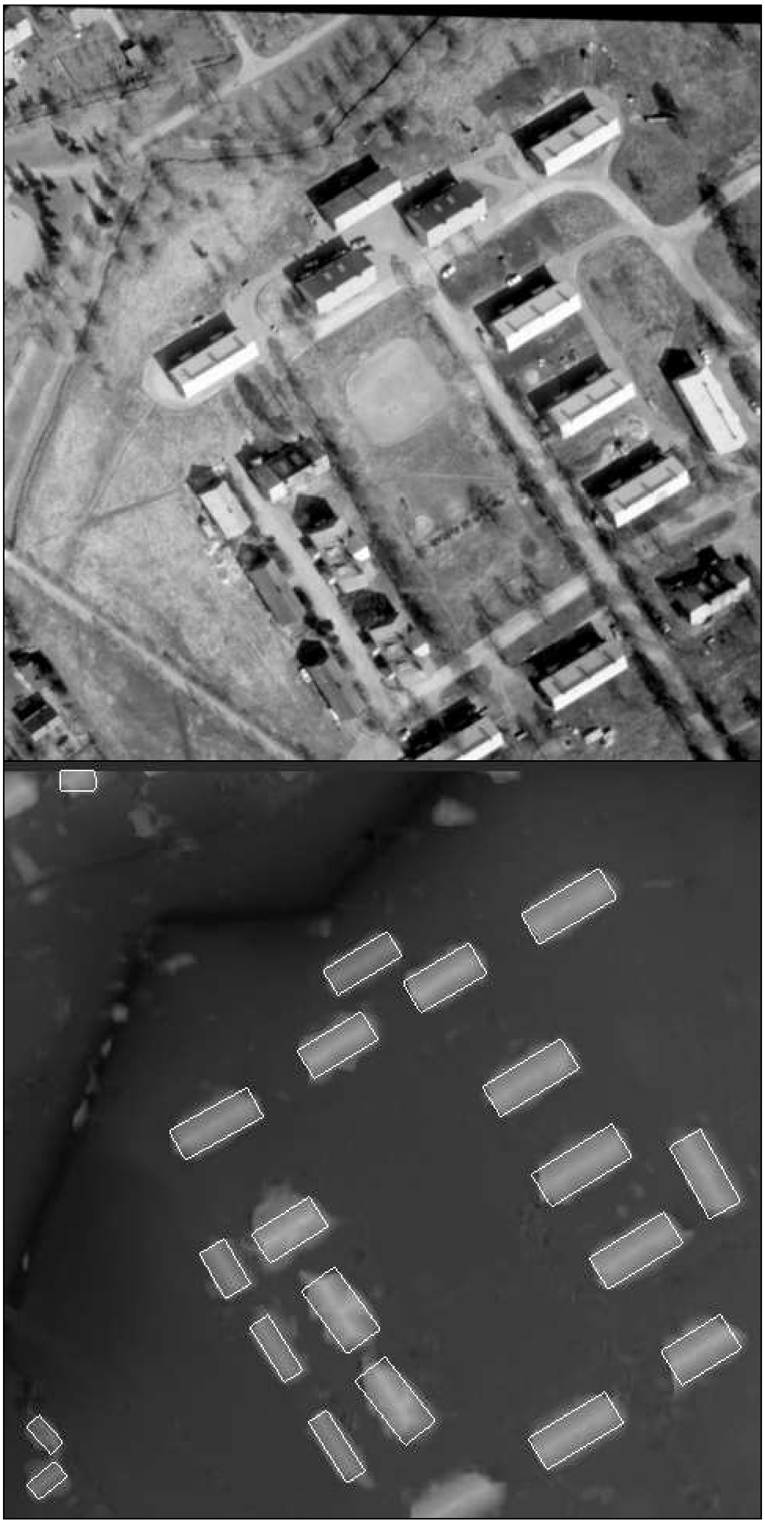


Figure 3: *flat*: digital image and overlay DEM – ground plan

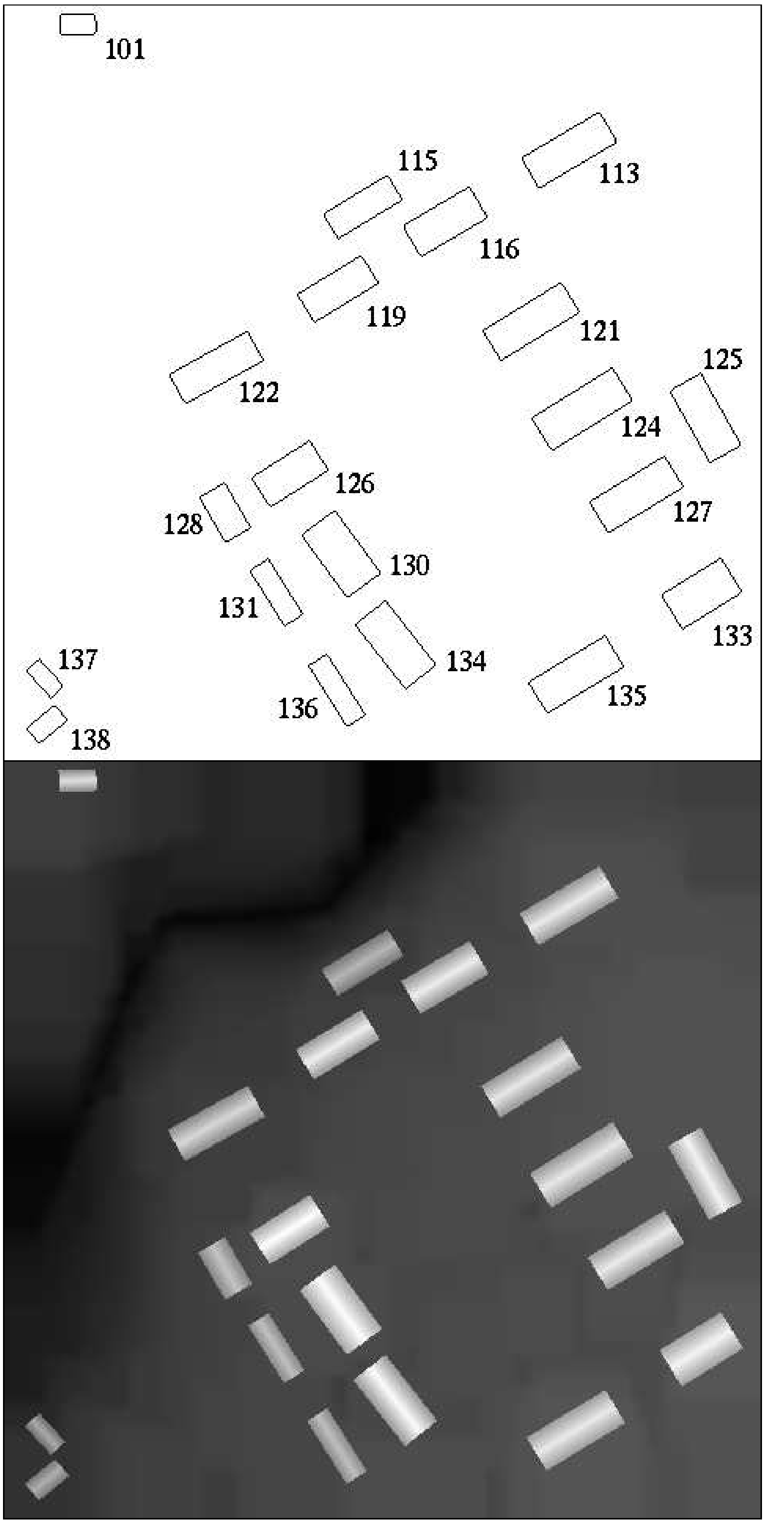
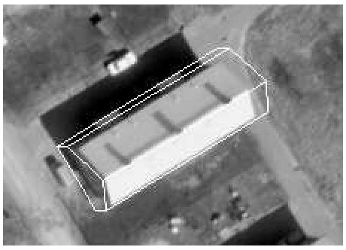
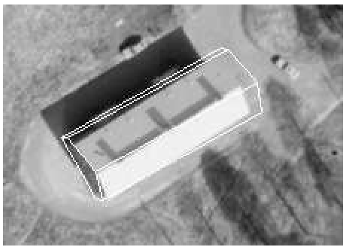



Figure 4: *flat*: labels and reconstructed buildings


Label 113

Label 116

Label 119

Label 121

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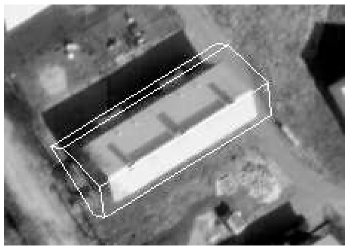
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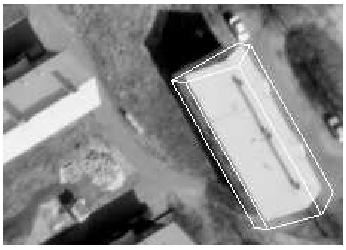
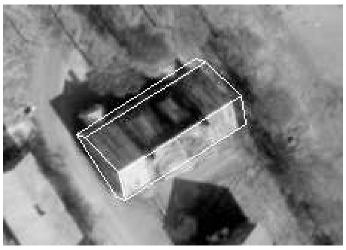

Label 125

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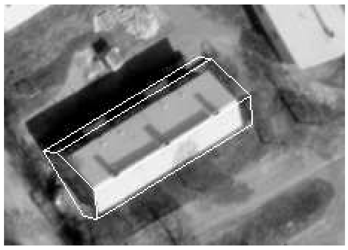
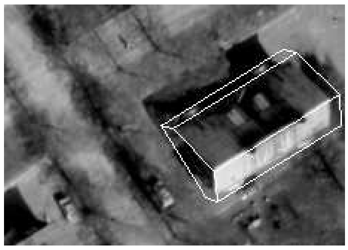

Label 127

Label 130

Label 131

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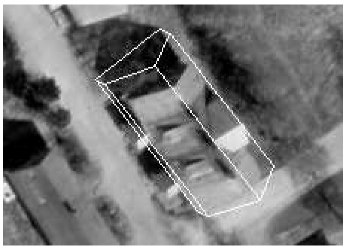
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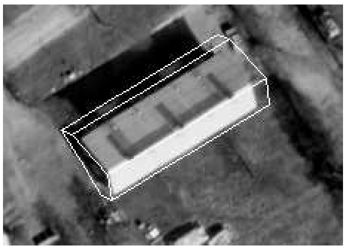
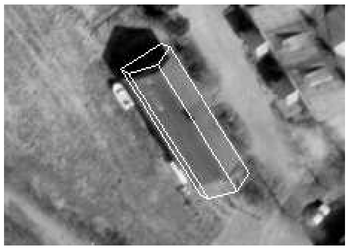
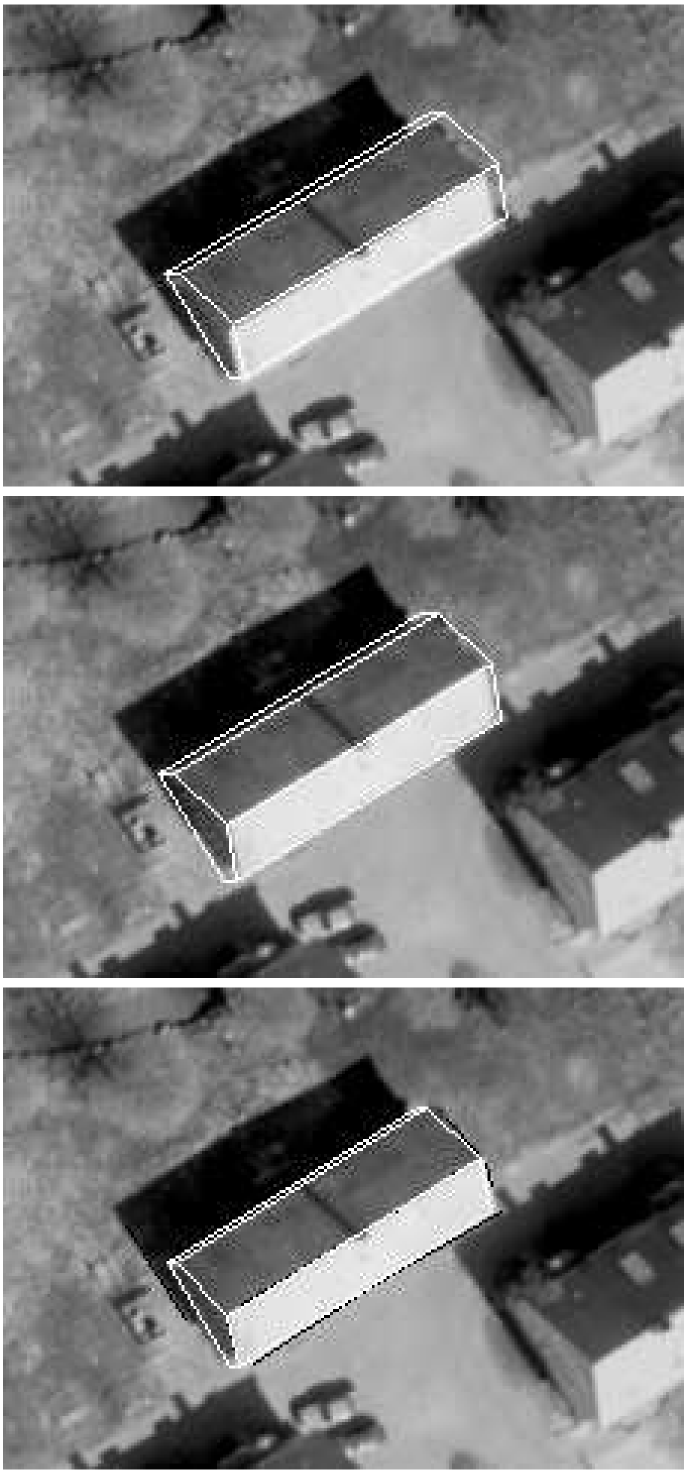

Label 135

Label 136

Figure 5: Other labels

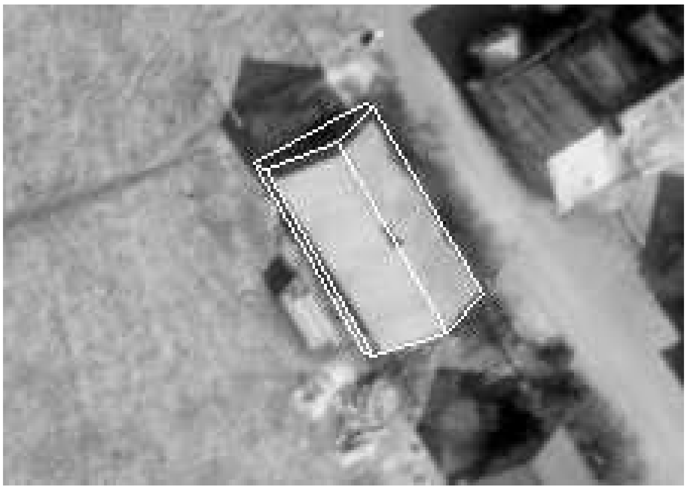


Model extracted by DEM-analysis

Model modified by user interaction

Model adjusted by matching

Figure 6: Label 115



Model extracted by DEM-analysis

Model adjusted by matching

Figure 7: Label 128

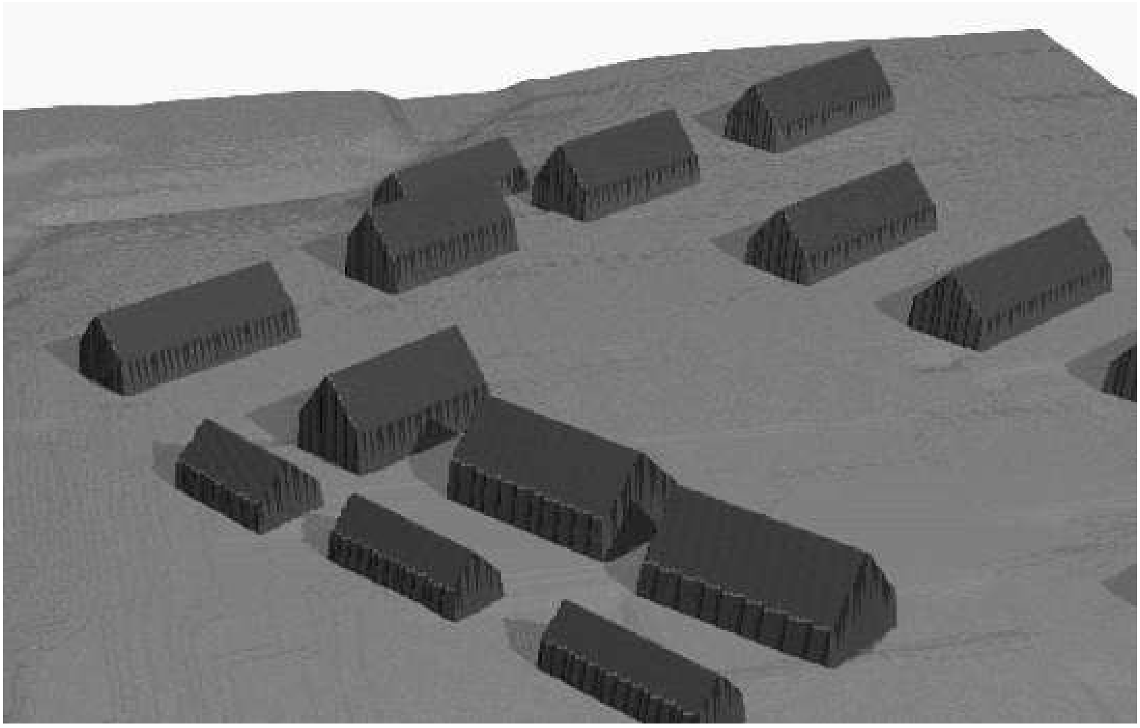


Figure 8: Ray shading of result

Figure 9 displays the result for the DEM *flat* with a grid resolution of 1 $m \times 1$ $m$. In this case two buildings have not been detected, and the parameters for one building are totally false due to the disturbed data in the DEM. Again, the other buildings have not been extracted due to their position within the data set.

## 3.2 Data Set *suburb*

Figure 10 displays results of our approach for the data set *suburb* with a grid resolution of 0.5 $m \times 0.5$ $m$. In this data set, the round offs due to regularization are more obvious compared to the data sets of *flat*. Therefore, detection and reconstruction of the buildings is a more difficult task, especially the determination of the model parameters. Furthermore, the data set includes buildings, which are not separate from each other. Thus, the data do not correspond to the models and assumptions we have incorporated in our approach. Therefore, the algorithm fails to correctly detect and reconstruct these buildings. In these cases, prismatic models should be used, but up to now the user has to define which kind of model group has to be applied. Future work will not only deal with the introduction of more parametric models in order to cope e. g. also with hip roofs, but also focus on automatic selection of model groups.

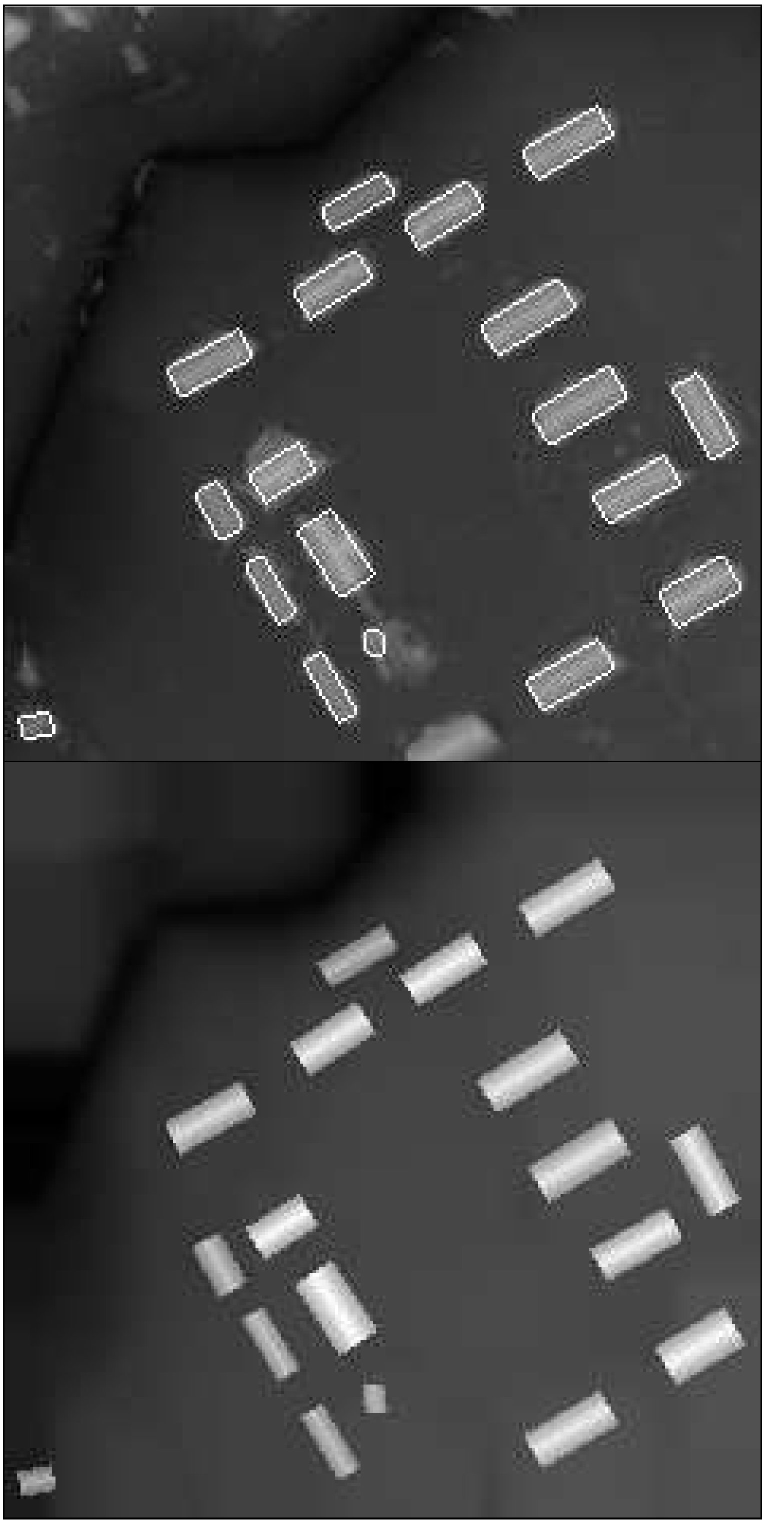


Figure 9: *flat*: overlay DEM – ground plan and reconstructed buildings (grid size $1\,m \times 1\,m$)

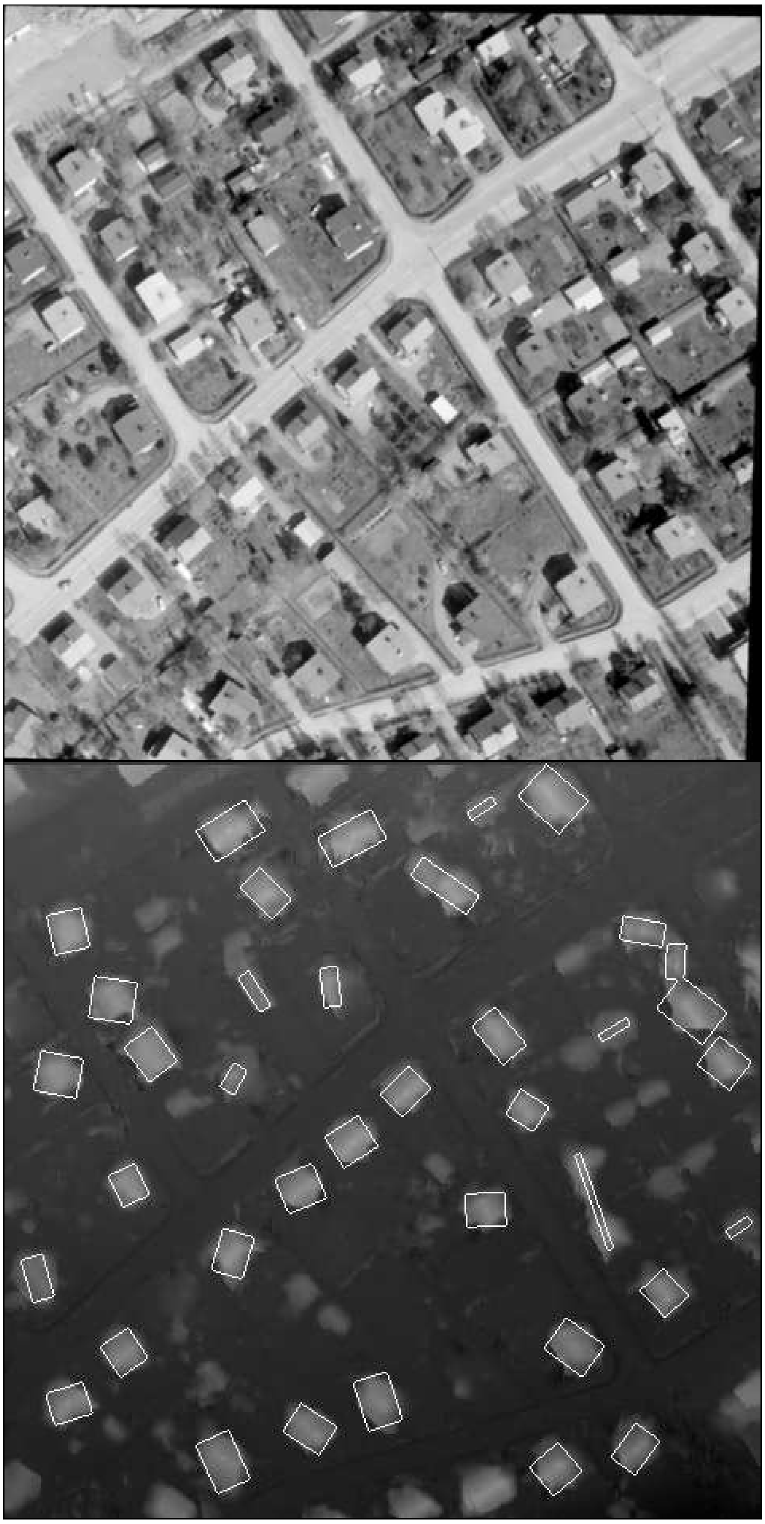


Figure 10: *suburb*: digital image and overlay DEM – ground plan

# 4 Results for Other Data Sets

A detailed description of the approach for prismatic building models is given in Weidner and Förstner 1995, and the principle of 2D-shape recovery behind our algorithm is elucidated in Brunn *et al.* 1995. The basic idea is to use MDL in order to find an appropriate description with respect to the given 2D data, i.e. a polygon or a set of polygons describing the ground plan of a building.

The examples given in the following show results of our approach applied to range data and aerial images. Fig. 11 displays original range data[1], acquired by airborne laser scanning, and the result of a segmentation. The outlines of this segmentation are used as starting point for the vectorization. Fig. 12 shows results of the shape recovery for three building ground plans. From left to right, the polygons are displayed after preprocessing, local MDL–analysis, and global robust adjustment. For these data sets the local MDL–application leads to a reduction of points from 36 to 7, 134 to 29, and 98 to 36 rsp. The hypothesis about geometric relations between edges of the polygons, which are introduced in the robust estimation, put constraints onto the edges, which results in the final polygons. These polygons are also displayed in Fig. 13 superimposed on the original range data. A qualitative evaluation shows little discrepancies, whereas the overall performance seems to be acceptable. The discrepancies are due to considering only the data in each iteration and not the originally observed polygons.

Fig. 14 displays the results for a building with court yards, indicating the ability of our approach to deal with multiple polygons belonging to an object.

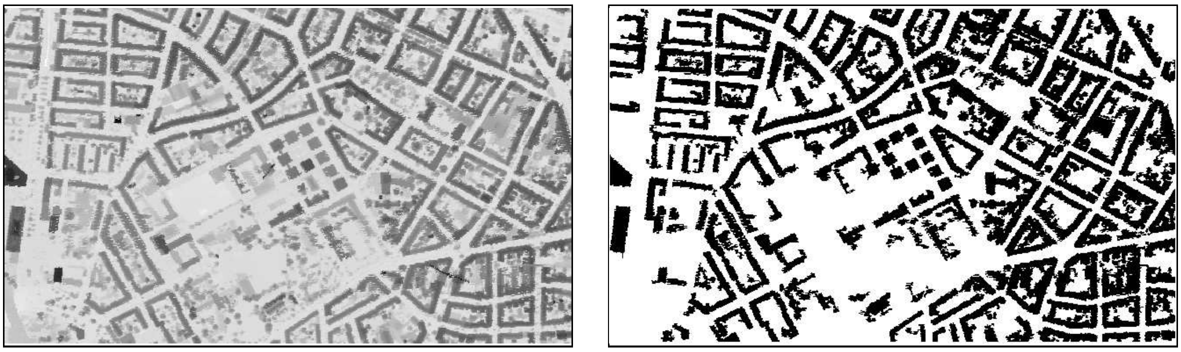


Figure 11: Range data from airborne laser scanner and segmentation (Weidner and Förstner 1995)

[1]The range data of Hannover was supplied by Dornier, Friedrichshafen.

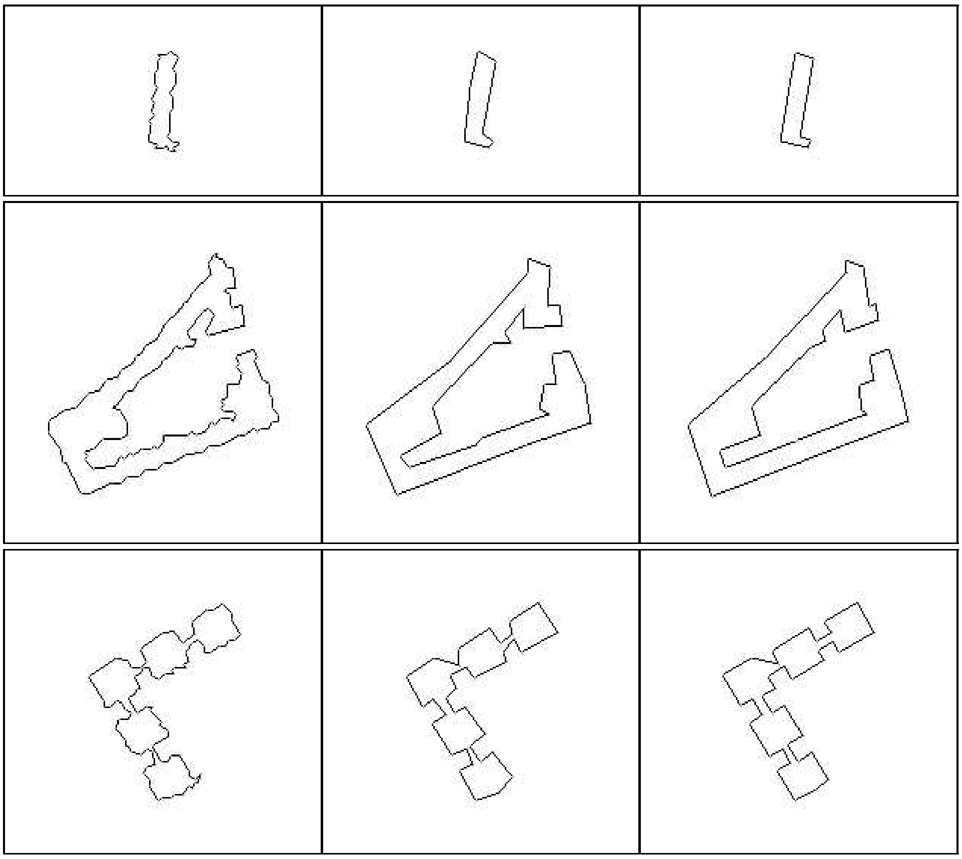


Figure 12: Three examples for range data – left: original boundary from segmentation; middle: result of local MDL–analysis; right: recovered final shape

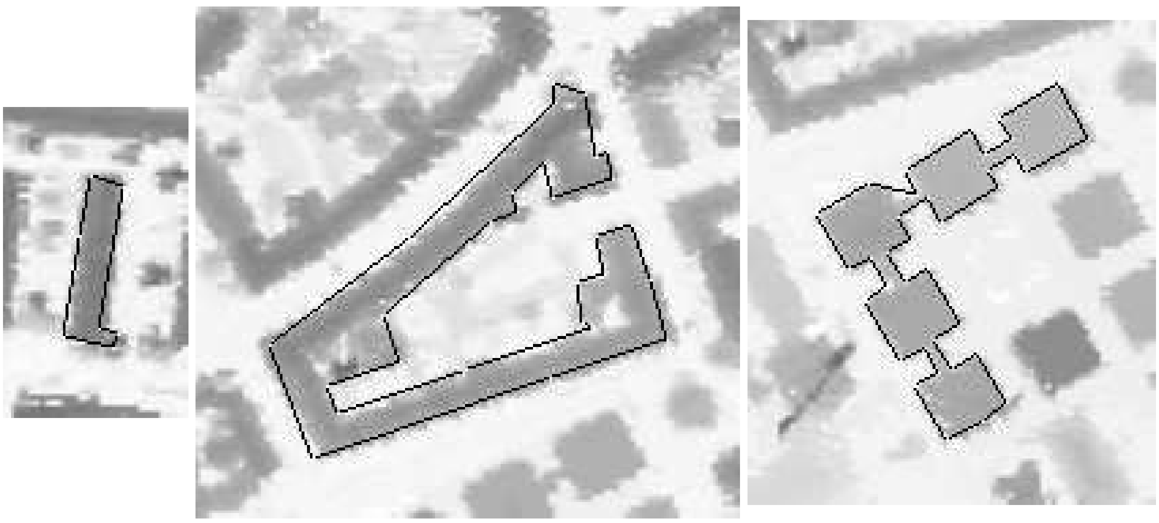


Figure 13: Overlay of recovered final shapes on original data

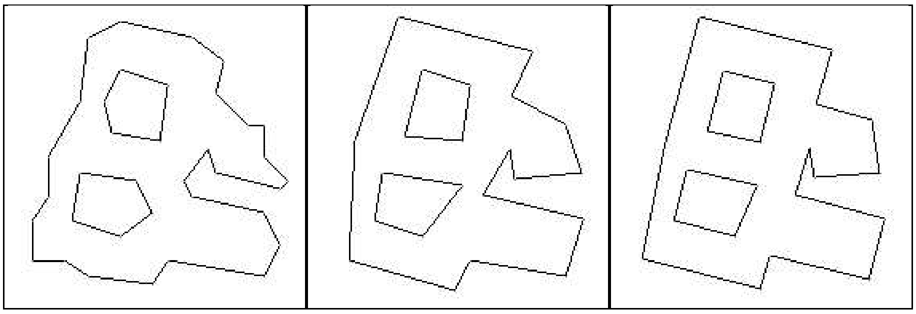


Figure 14: Example for a set of polygons

# 5 Conclusion

We discussed some results of building extraction from high resolution Digital Elevation Models. The approach consists of automatic detection of buildings and extraction of a description for the buildings. The detection and reconstruction of buildings is based on generic contextual knowledge. This knowledge is represented in geometric building models, parametric ones for simple buildings, which can be described by a few parameters, and prismatic models for complex buildings and blocks of buildings. We applied our approach for building extraction on the ISPRS test data sets and on other data sets with complex buildings in a down town areas.

The results for the ISPRS data sets show the capability of our approach when dealing with such simple buildings, if the DEM contains significant information about the buildings. Further work for parametric models will focus on the integration of other parametric models such as buildings with non symmetric sloped roofs or buildings with hip roofs. In order to improve the accuracy of parameters, template matching for the estimation of the point of gravity and the orientation will be investigated and robust statistics used for the estimation of the height parameters. Nevertheless, the resolution of the parameters related to the ground plan will always depend on the resolution of the DEM grid.

Prismatic models are used for the data set of a downtown areas. The achieved result is strongly influenced by the resolution of the grid. In order to deal with complex buildings consisting of parts with different heights more appropriately, discrimination of different parts using the height information within the region circumscribed by the extracted polygons with the aim of deriving a building graph is necessary (cf. Fua and Hanson 1987). Furthermore other constraints, e. g. symmetries, and semantic knowledge about rows of buildings, will be investigated.

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