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# 3—1 Generation and Update of 3D-City Models from Maps and Elevation Data

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## Abstract

In this paper we describe a procedure for generating building models from large scale vector maps and laser altimeter data. First the vector map is analyzed. The result is used to mask the elevation data of single buildings and to derive a coarse 3D-description by prismatic models. Afterwards roofs are reconstructed by fitting planar surfaces to obtain a polyhedral model.

## 1 Introduction

Three-dimensional city models find more and more interest in city and regional planning. They are used for visualization, e.g. to demonstrate the influence of a planned building to the surrounding townscape. Also there is a great demand for such models in mission planning and as basis for simulation e.g. in the fields of environmental engineering for microclimate investigations [1] or telecommunications for transmitter placement [5].

During the last years in industrial countries, many maps have been stored digitally and additionally are available in vector form. Large scale topographical maps (Fig. 1) or cadastral maps show ground plans with neither information on height of buildings nor shape of the roof. So far information on height was derived from manual surveys or from stereo pairs of aerial images.

Nowadays elevation data (Fig. 1) are available from airborne laser scanners. Knowing the precise position and orientation of the airborne platform from differential Global-Positioning System and Inertial Navigation System measurements, the geographic position of the surface points in three spatial dimensions can be calculated to decimeter accuracy. The sampled surface points distributed over a strip of 250-500m width allow the generation of a geocoded 2D array with elevation data in each cell (elevation image).

The manual construction and update of 3D building models is time consuming and expensive. That is why some authors propose approaches to automatically exploit elevation data.

In [3] surface areas belonging to buildings are detected in laser images by morphological filtering and examining local elevation histograms. The reflectivity obtained by processing the return signal energy is additionally used to seperate segments of artificial objects from vegetation. Polygonal 3D-descriptions of buildings were not derived.

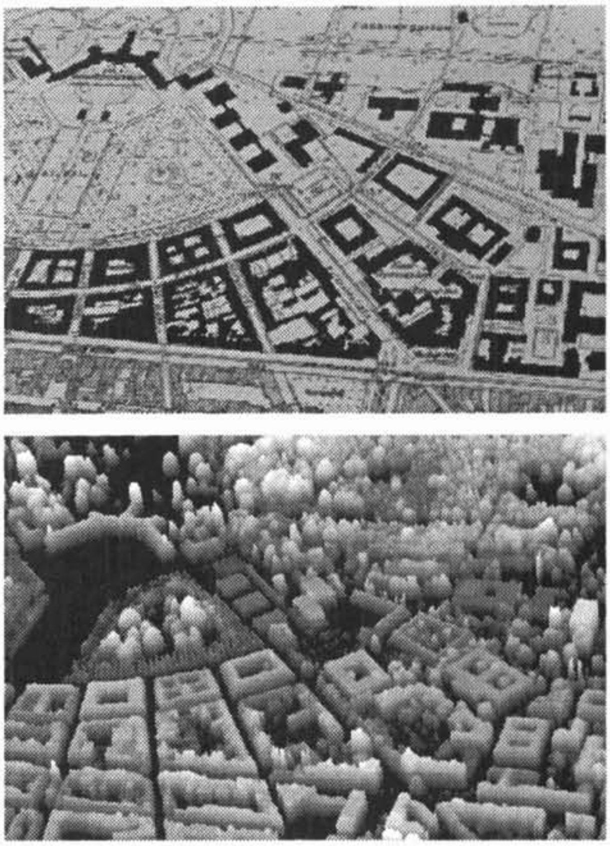

Figure 1: Perspective view of topographic map and laser altimeter data (Karlsruhe, Germany)

Geometric constraints in form of parametric and prismatic models are used in [10] to generate a polygonal description of a building with a flat roof or a symmetric sloped gable roof.

The reconstruction of more complex roof shapes can be found in [2]. A ground plan of a building is used to derive roof hypotheses. Any roof construction based on this approach provides incorrect results if the roof structure inside the ground polygon does not follow the cues that can be obtained from the ground polygon [2].

In our approach we also combine elevation data and map data to extract buildings - but the map data is not used to reconstruct the shape of the roof.

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## 2 Scene analysis

The automatic generation of urban scene descriptions consists of a multistage process, using different information sources as maps, elevation data, aerial images. The extraction of man-made objects from aerial images has been perfomed with different models in the system environment BPI (Blackboard-based Production System for Image Understanding) [6],[7],[8],[9]. Structural relations of the object models are described by productions. The hierarchical organization of object concepts and productions can be depicted by a production net which – comparable to semantic networks – displays the *part-of* hierarchies of object concepts [8].

The scene analysis based on aerial images can be supported by a digital map [6]. In this paper we focus on the analysis of elevation data combined with a map. First we analyze the digital map by means of a production net in order to obtain a simple urban model consisting of prismatic objects.

## 3 Prismatic objects

We use a large scale (1:5000) vector map which is organized in several layers each containing a different class of objects (e.g. streets, buildings, etc.). The topological properties *connectivity*, *closedness*, and *containment* of map-lines are tested by a production net of a generic model [8]. The aim of the analysis is to separate parts of buildings, to determine encapsulated areas and to group parts of buildings. The output of the analysis is a hierarchical description of the buildings or complexes of buildings.

The result of the first step is used to mask the elevation data. In this way we obtain different elevation data for buildings (Fig. 2) and non-buildings (surrounding). Calculating the mean height for each building object of the map, a coarse 3D-description is constructed by a prismatic model. This wire-frame model is transformed into a surface model using an automatic triangulation (Fig. 3).

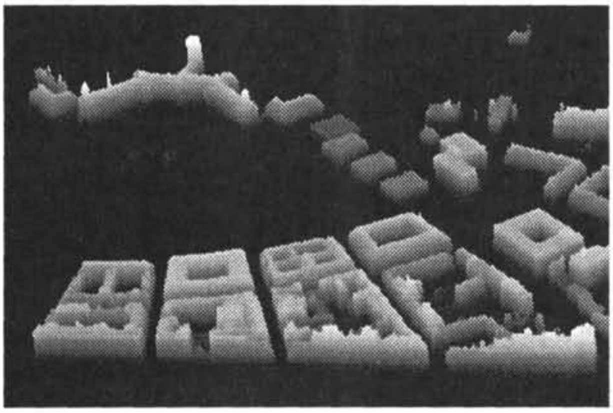


Figure 2: Masked elevation data (buildings)

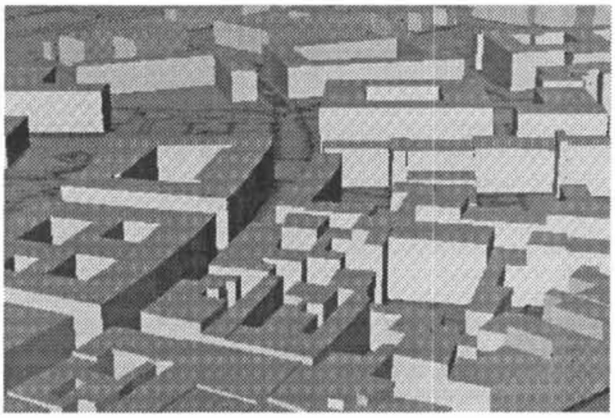


Figure 3: City model of prismatic objects (buildings)

## 4 Roof reconstruction

Depending on the task, a more detailed description of the buildings than that shown in Fig. 3 is required [5]. The roof has to be reconstructed from elevation data. Simple roof strurctures show characteristic histograms (Fig. 4). Flat roofed buildings show a significant peak in the histogram, belonging to an area corresponding with the base area. If a flat roofed building has a flat superstructure (e.g. penthouse, air conditioning or elevator equipment) the histogram shows an additional peak above the main peak. Simple gabled roofs show a rectangular histogram. Assuming the same base area, the width of the rectangle depends on the slope of the roof. A hip roof shows a trapezoidal histogram. The lenght of the ridge determines the height of the right side of the histogram. A cropped hip roof shows a mixture of rectangle and trapezoid form. Since the ideal histogram forms are not present in real data, the discrimination of sloped roofs by their histograms will be hardly possible.

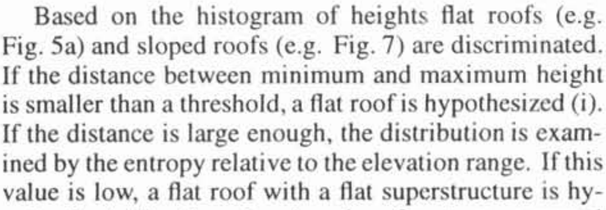


Figure 4: Characteristic height histograms of simple roofs

Based on the histogram of heights flat roofs (e.g. Fig. 5a) and sloped roofs (e.g. Fig. 7) are discriminated. If the distance between minimum and maximum height is smaller than a threshold, a flat roof is hypothesized (i). If the distance is large enough, the distribution is examined by the entropy relative to the elevation range. If this value is low, a flat roof with a flat superstructure is hypothesized (ii), otherwise sloped roof parts are assumed (iii).

### 4.1 Flat roofs

In the case of (i) the position of the peak's maximum

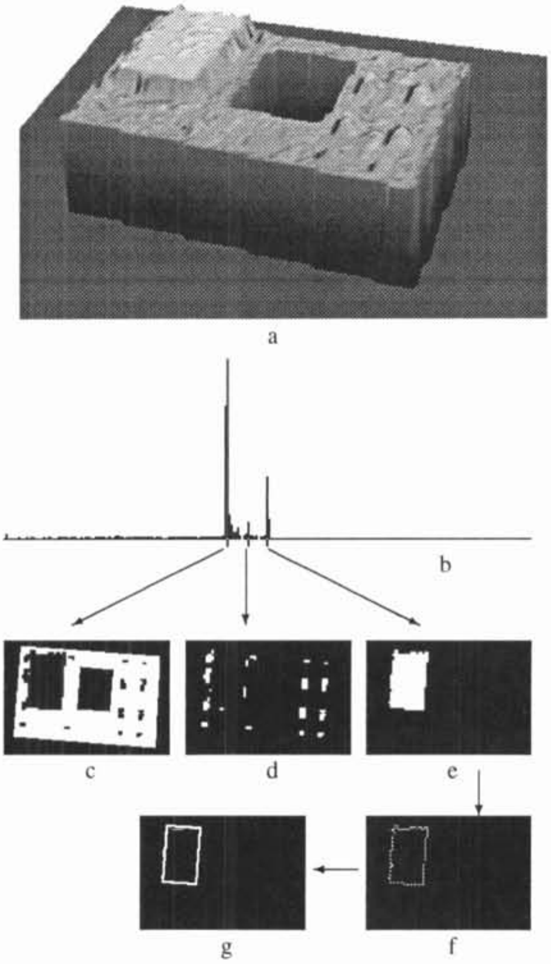


Figure 5: Reconstructing a flat superstructure (a-f see text)

is searched and is assigned as the height value to the prismatic object.

In the case of (ii) the minor peaks with a certain gap to the main peak are looked for (Fig. 5b). Between the peaks a minimum is searched and a threshold value is calculated. These thresholds are used to segment the elevation data (Fig. 5c-e). The segments are labeled and examined for size and compactness (circumference/area). Segments, which are too small or not compact, are not taken into consideration for further analysis (Fig. 5d). A compact segment of a size greater than a minimum area confirms the hypothesis (Fig. 5e) and the contour is accepted (Fig. 5f).

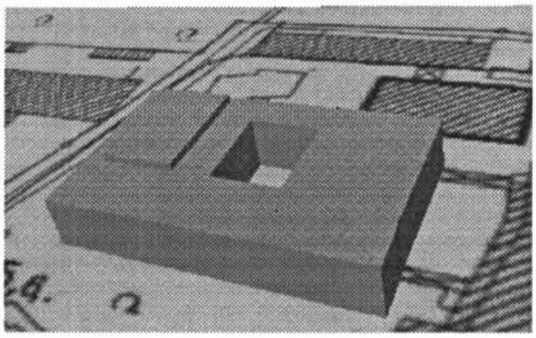


Figure 6: 3D view of the reconstructed roof

In the following vectorization step of the contour chain we first try to fit the contour by a rectangle (Fig 5g). If the assessment of the fit is lower than a given threshold the contour is rotated to a coordinate system parallel to the major orientation of the building. After projecting the contour points to the coordinate axes, peaks are searched in the histogram to describe the contour by a right-angeled polygon (e.g. L-structure). If this approximation is insufficient as well, the contour is approximated by a dynamic split algorithm [7]. This vectorization step may profit from the MDL-principle (c.f. [10]).

## 4.2 Sloped roofs

In order to test the hypothesis (iii) the gradient field is calculated of the elevation image (Fig. 7). From the orientation of the gradients possessing a minimum absolute value a histogram is determined (Fig. 8). In the histogram we search for peaks to determine major orientations and orientation intervals around them.

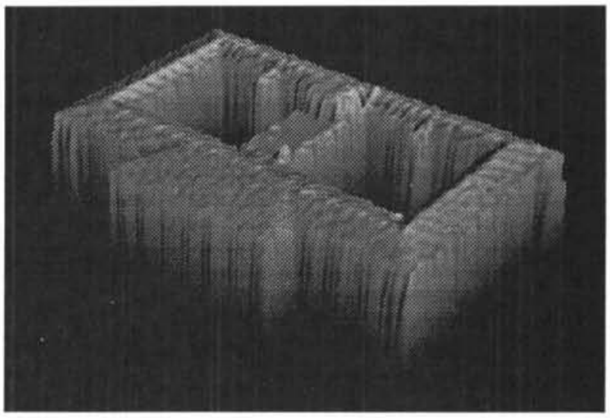


Figure 7: 3D view of elevation data of a single building

By thresholding the orientation image (Fig. 9a) at the boundaries of the orientation intervals segments of similar orientation are separated (Fig. 9b). The areas resulting from the segmentation are then morphologically dilated and eroded to fill small unknown enclosed areas, remove small regions, and separate components, which are connected only by few pixels.

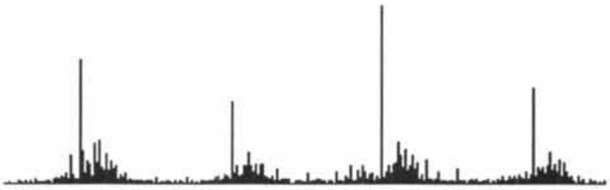
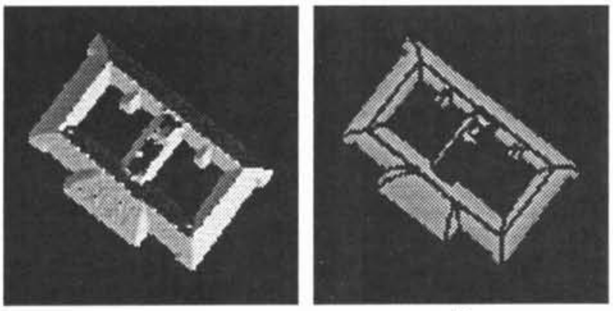


Figure 8: Histogram of gradient orientations

These segments of homogeneous oriented gradients may still contain areas of different slopes. To separate such connected areas, the histogram of the slope is determined. If the distribution shows several significant peaks essentially differing in slope, then the segment is split into the corresponding areas.



a b

Figure 9: a) Image of gradient orientation, b) segmented elevation image

If the histogram does not show a few major orientations, local relations have to be considered. Several segmentation algorithms which are based on region growing are described and compared in [4].

Out of the segments of homogenous orientation and slope, spatial planes are calculated by a least square fit. Recalculating the z-coordinate for the contour points by the plane equation, we ensure a plain 3D contour chain (Fig. 10).

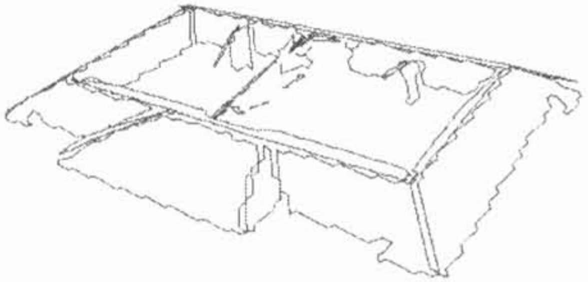


Figure 10: 3D contours of roof segments

A polygonal description is obtained by deleting points of the 3D contour chain. Special attention is required at the neighbouring edges of pairs of segments to receive a common line. Since edges of neighbouring segments do not intersect in exactly one point, a common vertex has to be calculated.

## 5 Update

For updating the database of the 3D-city model we propose a procedure in two phases. In a verification phase the buildings which are already stored in the database are compared with the new elevation data by histogram characteristics. They are confirmed, modified or deleted.

In a classification phase new buildings are searched in the elevation data of non-buildings (complementary part of Fig. 1 to Fig. 2). The discrimination of artificial objects from natural objects can be done taking into account the difference in reflectance, elevation texture, local variance of surface gradients, vertical structure (elevation), and shape of the object surfaces [3].

One possibility to find man-made objects is to search for regular structures. For this purpose the elevation data is thresholded appr. 2m above the ground. The resulting binary segments are examined for compactness. In the contour of compact segments we search for basic right-angled structures. A model for composing basic right-angled structures is described in [9].

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