

# AUTOMATED GENERATION AND UPDATING OF DIGITAL CITY MODELS USING HIGH-RESOLUTION LINE SCANNING SYSTEMS

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## ABSTRACT:

During the past few years lots of research has been carried out in the field of building extraction from airborne laser scanner data and airborne large-scale imagery. This data can be used to create highly detailed Digital Surface Models (DSMs) and eventually Digital City Models (DCMs). It seems that there exists also a potential in data acquired by high-resolution satellites and airborne multi-line scanners in order to derive these models.

Already existing extraction-algorithms for Lidar data cannot be adopted to those spaceborne and airborne imageries since the geometric resolution is too coarse. The proposed method can be divided into the following steps. The derived normalized DSM is used together with image data to localize potential building areas. Afterwards the building edges and corners are extracted, which is carried out with an adaptive region growing process and an iterative step-by-step Hough transformation. Finally, change detection techniques and a method for updating existing data-bases in an automated way are discussed.

## KURZFASSUNG:

Während der letzten Jahre wurde viel Forschung im Bereich der Gebäudeextraktion von Laserscanner- und Luftbildern betrieben. Diese Daten werden verwendet um detaillierte Oberflächenmodelle (DSMs) und eventuell auch Digitale Stadtmodelle zu erzeugen. Es besteht die Vermutung dass auch bei hochauflösenden Satellitenbildern und flugzeuggestützten Zeilenscanneraufnahmen ein gewisses Potential zur Erzeugung dieser Modelle existiert.

Bereits bekannte Extraktionsalgorithmen aus dem Bereich der Laserscannertechnologie können leider nicht adaptiert werden, da die geometrische Auflösung der Satelliten- und flugzeuggestützten Zeilenscanner-Daten zu grob ist. Die vorgeschlagene Methode kann in folgende Schritte unterteilt werden. Das abgeleitete normalisierte DSM wird gemeinsam mit den Bilddaten zur Lokalisierung potentieller Gebäuderegionen verwendet. Anschließend werden Gebäudekanten und -ecken extrahiert, was durch ein adaptives ‚region-growing‘ und einer iterativen ‚Schritt-für-Schritt‘ Hough Transformation geschieht.

Abschließend werden Methoden zur Veränderungsdetektion und Instandhaltung von Datenbanken vorgestellt.

## 1. INTRODUCTION

Digital City Models (DCMs) have become one of the most important and attractive products of photogrammetry and remote sensing. The spectrum of application areas dealing with such models is huge: environmental planning and monitoring, telecommunication, location based services, navigation, virtual reality, cadastre etc.

During the last decade photogrammetry and remote Sensing experienced a big technological advance. On the one hand, because the geometric resolution of satellite imagery has increased tremendously (footprints of one metre or less are current state); on the other hand photogrammetry has become more and more 'digital' and new techniques are needed to accelerate the workflow. Due to this progress the science of satellite remote sensing starts dealing with application areas, that until now were classical photogrammetric tasks, such as large scale mapping or city model generation.

A challenging goal is to automate and accelerate the production of DCMs, to increase their quality and to keep them up-to-date. When done manually this procedure is one of the most time consuming and expensive tasks.

The use of airborne laser scanners and the related processing techniques were a big step towards faster city model extraction. Though extensive research has been carried out, (e.g. Brenner, 2000; Haala et al., 1998; Vosselman and Dijkman, 2001) they are still affected with certain weak points. Optical systems based on multi-line sensor technology (ADS40, HRSC) are able to seriously compete with laser scanner systems in some application areas. The generation of Digital Surface Models (DSMs) from multi-line scanner data has been investigated thoroughly (Scholten and Gwinner, 2003) and has reached a certain level of practicability. Unfortunately these models are so-called raster models; hence the depicted features, e.g. buildings, are not classified and without topological information.

Besides airborne acquisition techniques high-resolution spaceborne scanners offer a very important data source, since they can capture images from nearly any region of the earth's surface without having any juridical problems.

This paper focuses on aspects concerning city model generation from both airborne and spaceborne line-scanning systems, while it does not deal with the derivation of DSMs from those images. By analysing (already existing) DSMs and therefrom

derived digital orthoimages the creation of 'GIS'-proof DCMs will be discussed.

## 2. BUILDING EXTRACTION – STATE OF THE ART

Airborne laser scanning has become one of the most important acquisition techniques for surface reconstruction. By collecting a huge amount of points (3D locations) with a very high resolution and accuracy they provide an optimal input for building extraction algorithms. Several approaches have been presented, among them one by Rottensteiner's (2004), which can be divided into three major steps. The first one is to hierarchically apply a robust interpolation using a skew error distribution function in order to separate terrain points from points that lie not on the ground. The outcome is a DTM (Digital Terrain Model). The second step is to distinguish between building points and off-terrain points (e.g. vegetation). This is achieved by applying an analysis of height differences between the DSM and the previously computed DTM. Finally, the third step comprises the creation of polyhedral building models.

A different method for automated building reconstruction is described in Peternell and Steiner (2003). Assuming that a dense point cloud is given, they try to determine all planar regions of a building. Firstly, local regression planes for all points are computed. The planar faces of the building possess local planes of regression (local planar fits) that are close to each other. The finding of the faces is achieved by transforming the local planes of regression into a parameter system where a segmentation is carried out. A drawback is the fact, that additional input information (digital map) is needed for defining the area of an object.

Both approaches need a dense and highly accurate point cloud in order to be able to derive and analyse the roof faces of buildings. They aim at a rather large scale reconstruction. Unfortunately these algorithms cannot be adapted to point clouds created by spaceborne or line-scanning systems since the geometric resolution as well as the accuracy and completeness is usually insufficient.

## 3. CHANGE DETECTION / UPDATING - STATE OF THE ART

Most of the algorithms for updating check the existing buildings in the data base for changes. They are not able to find new objects at locations with no entry in the old data base.

The ATOMI project (Eidenbenz et al., 2000) was used to update vector data of building roof outlines and increase their accuracy by applying image analysis techniques on aerial images. For finding new buildings Niederoest (2000) tried to localize extracted DSM blobs or apply a multispectral classification. In order to extract DSM blobs that really correspond to buildings we have to assume that there exists no big and high vegetation and that the DSM resolution and quality is good enough to be able to separate buildings from each other or from trees. The idea of applying a multispectral classification in order to determine new buildings is of course only relevant if multispectral data is available, which is unfortunately not the case for high-resolution satellite imagery most of the time.

Knudsen's (2003) strategy for updating digital map databases makes also use of pixel-based classification. The algorithm uses vector and spectral data as input to an unsupervised spectral classification method that controls a subsequent Mahalanobis classification step. Due to good geometric

resolution and the potential of using RGB images, changes may be traced and even new buildings detected, although again due to the pixel-based approach obtaining topologic information of the new situation becomes cumbersome.

## 4. WORKFLOW

The proposed workflow is divided into two major parts. The first one is data preparation and comprises all steps from data acquisition to the derived DSM. There are many off-the-shelf software packages available for solving this task. The second part deals with the actual creation of the DCM including building recognition and extraction. Figure 1 gives an overview of the proposed workflow.

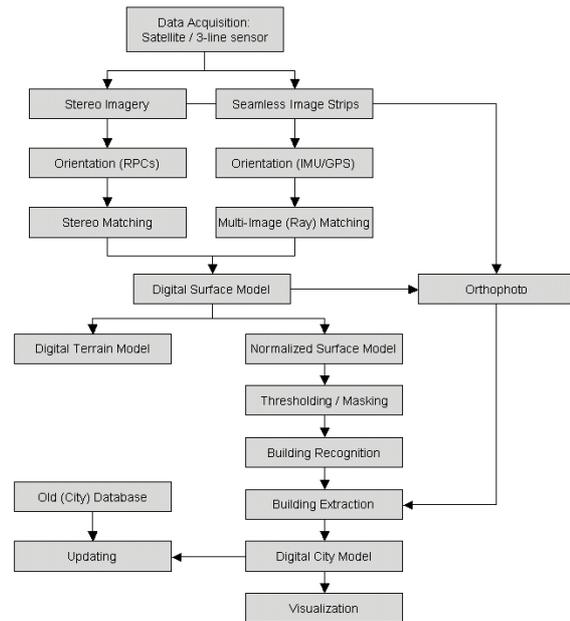


Figure 1. Proposed workflow

### 4.1 Data Preparation

High resolution satellites deliver overlapping image scenes in form of stereo pairs, whereas multi-line scanners generate one image strip for each sensor line, where each strip is associated with a different viewing angle. The orientation of multi-line sensor data can be automated to a very high degree.

Vozikis et al. (2003) have shown that images from the new high-resolution satellite sensors (IKONOS and Quickbird) cannot be oriented by applying the common procedures used in aerial photogrammetry, because, firstly, most distributors do not provide any calibration information (interior orientation parameters) and secondly, due to the extremely narrow field of view (bad intersection quality of the rays), the well-known collinearity equation would fail. Diverse orientation models have been proposed, but the fastest way is employing the so-called RPCs (Rational Polynomial Coefficients), which are usually provided together with the images. These coefficients describe a relation between object and image space and should give the end-user the possibility to start immediately with image exploitation. Unfortunately the RPCs are affected by a constant shift and hence are not very accurate, so they have to be refined by using two or three GCPs (Ground Control Points) (Hanley et al., 2001).

For the airborne line scanner image strips, the orientation procedure is a little bit different. Together with the image data

additional information from a GPS (Global Positioning System) and IMU (Inertial Measurement Unit) device are recorded at a very high temporal resolution, providing information about the exact position and orientation of the sensor at the time of acquisition. This so-called direct georeferencing is crucial, as due to the dynamic acquisition principle and due to unsteadiness of the airplane movement each scanline has its individual exterior orientation and a conventional orientation procedure would not be able to deliver the required accuracy. The typical process of this direct georeferencing is described in Fricker (2001). Next, after automatic tie-point measurement triangulation can be applied. It is recommended to use some GCPs at least at the block corners, but as shown in the excellent results from Scholten and Gwinner (2003) it is not obligatory, since the collected orientation data from the GPS and IMU unit seem to be sufficient.

Once the images are accurately oriented (multi-image) matching algorithms can be applied for deriving a DSM. Finally, the images and the DSM can be used to create an orthophoto of the scene, which will also be used as input for the building extraction algorithm.

At the DLR (German Space Agency) the processing chain for handling airborne three-line scanner imagery has been automated to such a degree, that human interaction is only needed at the data acquisition step (Scholten and Gwinner, 2003). Once the data is downloaded onto the computers the whole process from image correction and rectification, to orientation and triangulation, and to the DSM and orthophoto production can be done fully automatically.

#### 4.2 Building Recognition

The most important input for the creation of a Digital City Model is the DSM. But as mentioned previously, the resolution and accuracy if derived from spaceborne or airborne line scanning imagery is rather low (compared to Lidar-DSMs). Hence the images or orthophotos if available, will be used to proceed to building extraction.

The first step is to create a so-called normalized Digital Surface Model (nDSM), which is the difference-model between the DSM and the DTM. Hence all objects in the nDSM stand on elevation height zero.

There are multiple approaches for getting the nDSM. An approved method is to filter the existing DSM-data by applying a skewed error distribution (Kraus, 2000). This procedure is fully automated and the user needs only to input the parameters of the skewed error-distribution in order to calculate the nDSM, in which vegetation and buildings are eliminated. Of course, when the area of interest is highly urban and nearly no terrain points are available in the DSM this technique might not deliver the desired result. In such a case it is necessary to manually digitise points on the ground and interpolate or approximate a DTM-surface through them.

The next and maybe most critical step is to find the regions of interest, i.e. the regions of potential candidates for buildings. Until today, either the buildings were digitised in stereo or the building corners were localized in the orthoimage or the user had to tell the system where a building is.

Rottensteiner (2004) proposed to create a 'building mask' using a certain elevation threshold. This mask would point out areas where objects higher than the threshold are located, and everything below that height is considered as 'non-building'. 'Non-building' can be low vegetation, cars or other objects

positioned on the terrain surface, but not being high enough to be treated as building candidates. Unfortunately, it is not seldom that vegetation, especially trees or even forests, have the same height as buildings do.

Figure 2 shows such a typical case. One can easily recognize that the dense trees to the left are at least as high as the buildings. In such a case simple thresholding would not make it possible to distinguish between objects of interest (buildings) and vegetation.



Figure 2. Image and DSM subset from the HRSC-Bern data set

The algorithm proposed for finding regions with potential buildings is the following:

- Set a certain elevation threshold of minimal building-height according to the current scene, then
- mark the potential candidate-regions of the nDSM in the image and
- apply a check for homogeneity in the image to refine the candidate selection.

This makes sense, since most of the times building-roofs are very homogeneous e.g. one colour, or one regular pattern of tiles, in comparison to treetops or other vegetation. To use the first derivative of the nDSM as a homogeneity parameter (a very popular method) is not recommended, because the derived nDSMs from high-resolution line scanning systems are much too coarse.

#### 4.3 Building Extraction

Once the regions of building candidates are found, one has to extract the shape of the building. The coarseness of the nDSMs does not allow the determination of the roof shape. Even more, it is not even possible to get the building corners from these nDSMs. Therefore additional information is taken from the orthophotos. Since they provide higher geometric quality, they will be used to obtain the location of corners and hence the shape of the buildings.

For the segmentation in intensity images four approaches are common, namely threshold techniques, boundary-based methods, region-based methods, and hybrid techniques which combine the latter two (Adams and Bischof, 1994).

The proposed algorithm for building extraction is an 'adaptive' region-based method. The growing process of a certain region depends on the assigned threshold. If the difference between the value of the starting point (seed) and the value of examined neighbouring, adjacent pixels is equal or smaller than the given threshold, the neighbouring pixels will be aggregated into the region. The whole procedure is described in the following steps:

1. Inside the potential building area called seed region (Figure 3a) start with the region growing process and

determine the parameters of the geometric object modelling the data of the seed region

2. Increase the threshold of region growing.
3. Apply region growing again and recalculate the geometric object parameters (Figure 3b).
4. If the calculated geometric object parameters differ largely from the geometric object parameters of the previous iteration step, or if they do not fulfil certain conditions, stop the iteration process, else go to step 1.

The geometric object parameters of the newly grown region can be compactness ( $U^2/(4A\pi)$ , where  $U$  is the perimeter and  $A$  the area); the ratio of bounding box-area and object area; semi-major and semi-minor axis or the ratio of them etc. If these parameters vary a lot between two iteration steps, one can assume that the newly grown region went over the building edge as shown in Figure 3c. The conditions mentioned in step 4 can be used as additional information to stop the iteration process (For example the maximal area of a building in our study area, or maximal number of corners). Additionally, after every region growing process an open-close (blow-shrink) function is applied onto the found regions (Figure 3d). This is necessary to fill holes that might exist within the building regions, or to smooth frayed out areas. The kernel size of the open-close procedure must be chosen manually and it is recommended to choose a sequence of opening and closing steps with individual kernel sizes (e.g. close 3x3 – open 5x5).

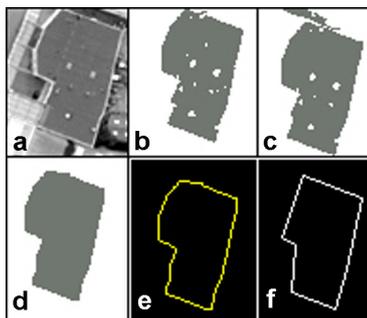


Figure 3. Example for building extraction

The found region of interest is now vectorized (Figure 3e). The result is a very long coordinate list, since every single corner is included. Many of these corner points do not really represent the building geometry, but were created due to inaccuracies of the region-growing process. The task is to minimize this point list without impairing the geometric properties of the building (Figure 3f).

One solution would be to calculate regression lines through points of the vectorized data (Figure 3e) that possibly belong to the same edge of the building.

Another approach is applying a Hough-Transformation on the vectorized data in order to find the building boundaries.

The second solution has been implemented and should be briefly described in the following (Gonzalez and Woods, 1992; Jain, 1989).

The Hough transform is defined for a function  $F(x, y)$  as shown in Equation 1.

$$H(\theta, \rho) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(x, y) \delta(\rho - x \cos(\theta) - y \sin(\theta)) dx dy \quad (1)$$

where  $\delta$  is the Dirac delta-function. With  $F(x, y)$ , each point  $(x, y)$  in the original image,  $F$ , is transformed into a sinusoid  $\rho = x \cos \theta - y \sin \theta$ , where  $\rho$  is the perpendicular distance from the origin of a line at an angle  $\theta$  (see Figure 4).

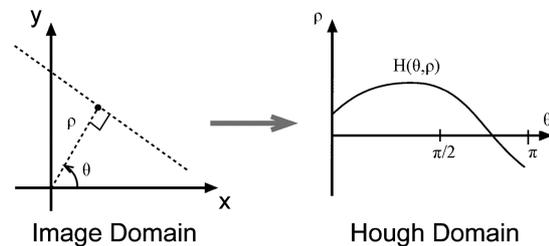


Figure 4. Hough Transformation

Points that lie on the same line in the image will produce sinusoids that all cross at a single point in the Hough transform. For the inverse transform, or back-projection, each point in the Hough domain is transformed into a straight line in the image. Usually, the Hough function is used with binary images, in which case  $H(\theta, \rho)$  gives the total number of sinusoids that cross at point  $(\theta, \rho)$ , and hence, the total number of points making up the line in the original image. By choosing a threshold  $T$  for  $H(\theta, \rho)$ , and using the inverse Hough function, the original image is filtered to keep only lines that contain at least  $T$  points.

The problem we face is that the points representing a building edge do not lie on one single line, but close to it. This means that the sinusoids in Hough domain will not intersect in exactly one single point, but a local maximum of the overlapping sinusoids will appear. This local maximum has to be determined and then we can perform the back transformation to obtain the according, representative line in image space. Unfortunately, the finding of local maxima in Hough space is not easy since the sinusoids are periodic function which leads to double-identifications at the close to the beginning ( $\theta = 0$ ) and end ( $\theta = 2\pi$ ) of the period.

The implemented solution to this problem carries out an iterative step-by-step Hough transformation (Figure 5).

- *First step:* apply the Hough-Transformation to all points lying on the boundary of the found building.
- *Start of iteration loop:* Determine the global maximum in the Hough domain. This maximum location delivers exactly one  $\theta$  and one  $\rho$  value. These two values represent one line in image space. (Figure 5, first row)
- Calculate the back-transform of the global maximum.
- Eliminate all points in the vectorized image that have a smaller perpendicular distance than the tolerance  $\tau$  from the back-transformed line. (Figure 5, second, third and fourth row)
- Apply the Hough Transformation again to the remaining image points and start next iteration.

This iterative process is terminated either if a requested number of lines has been found (= number of iteration steps), or when no more points lie on/near to a line. This would mean that the

value at the found global maximum in Hough Domain became smaller than the given threshold  $T$ .

In the example shown in Figure 5, the process was terminated after four iteration steps, which means that the building is described by four lines (Figure 5, last row).

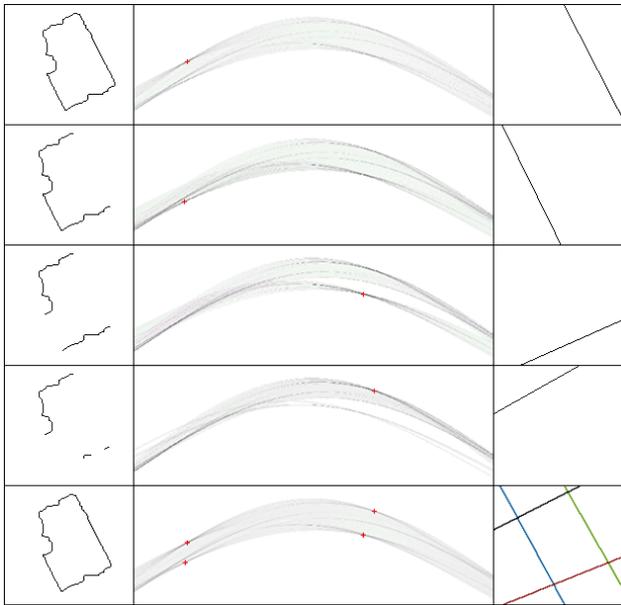


Figure 5. Iterations of Hough Transform (left column: vectorized building; centre column: Hough Domain; right column: lines of back-transformed maxima)

Summing it up, the user has to tell the system either how many edges have to be found for each building (e.g. if four is chosen, the buildings will have a quadrangle form), or the minimum number of points lying on an edge. In the latter case the building will be represented in more detail (Figure 6), but one has to keep in mind that the additional detail might come from vectorization errors. Furthermore, the user also has to tell the program how big the tolerance value  $\tau$  should be. This value depends on the quality of the vector model and hence the quality and resolution of the image.

The intersection of the obtained lines, as mentioned before, can lead to wrong points that do not lie on the building boundary. To avoid this problem the program searches only for intersections that lie close to the vector data.

- Each back-transformed edge is marked with a unique attribute (Figure 6c).
- All lines (and intersections) are dilated by the tolerance value  $\tau$  (Figure 6d).
- Starting at a point on the vectorized building (Figure 6b) and moving along the edges in counter-clockwise direction each pixel position is checked for the attribute of the closest dilated line.
- As soon as we have a change in line-attributes we search for the closest intersection of back-transformed edges and store the position as corner point (Figure 6e)!
- The procedure stops as soon as the start-position is reached.

Each extracted building will be assigned one height value (horizontal roof). So, all corner points of a building will have

the same elevation, which is taken from the DSM. The building is completed by assuming vertical walls that are intersected with the DTM.

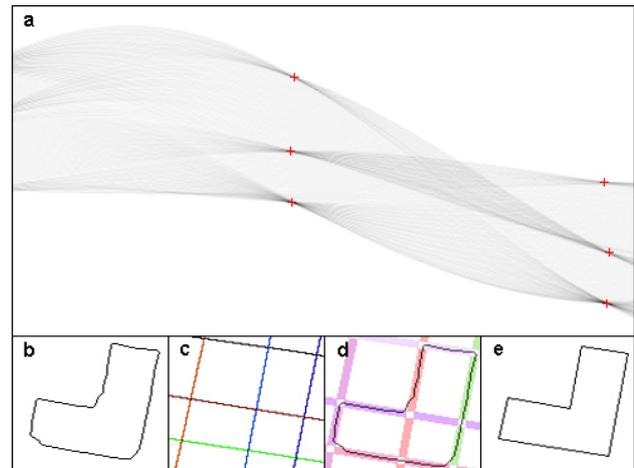


Figure 6. Finding the building corners (a: Hough Domain with 6 determined maxima; b: vector representation; c: back-transformed lines; d: dilated back-transformed lines with vector data superimposed; e: final building represented by 6 points)

## 5. CHANGE DETECTION AND UPDATING

The old situation is compared to the newly calculated geometric building properties and if a certain threshold in the difference is exceeded the 'old' database is updated.

The users may select one of the two proposed types of change detection dependent on their requirements:

- The comparison of two vector DCMs, namely the old one and the newly generated one. This updating procedure is capable of finding new buildings that do not exist in the old data set.
- The second approach is just to check the old vector DCM for changes. This process is much faster since the whole step of building recognition can be neglected, but it is not in position to detect new buildings.

When checking for changes one always has to bear in mind how good the quality of the extracted buildings is. This quality factor is highly correlated to the image resolution and DSM accuracy.

## 6. CASE STUDIES

The case studies comprise two spaceborne IKONOS stereo images and three airborne three-line sensor data.

The IKONOS (PrecisionPlus) along-track stereo imageries were taken over Athens (Greece) and Melbourne (Australia) with a ground sampling distance of one metre. The data-preparation (orientation, DSM extraction and Orthophoto production) was done with the ERDAS Imagine software version 8.6. Only subsets of these scenes were used for algorithm testing.

The ADS40 imagery of Nimes (France) and HRSC-AX data set of Bern (Switzerland) were acquired from the DLR (German Space Agency), where also the data-preparation was carried out (see Scholten and Gwinner, 2003). The Nimes images were captured at a flying height of 800 metres and have a ground resolution of 8 cm, whereas the Bern data was acquired at an

elevation of 4000 metres and provide a ground sample distance of 18 cm respectively. The data-preparation step was completed fully automatically at the DLR.

An additional airborne three-line scanner data set was available depicting Seattle (USA). It was taken from the Demo data set of the ERDAS Imagine 8.6 package and was used for algorithm testing.

In Figure 7 the results of a case study are visualized.

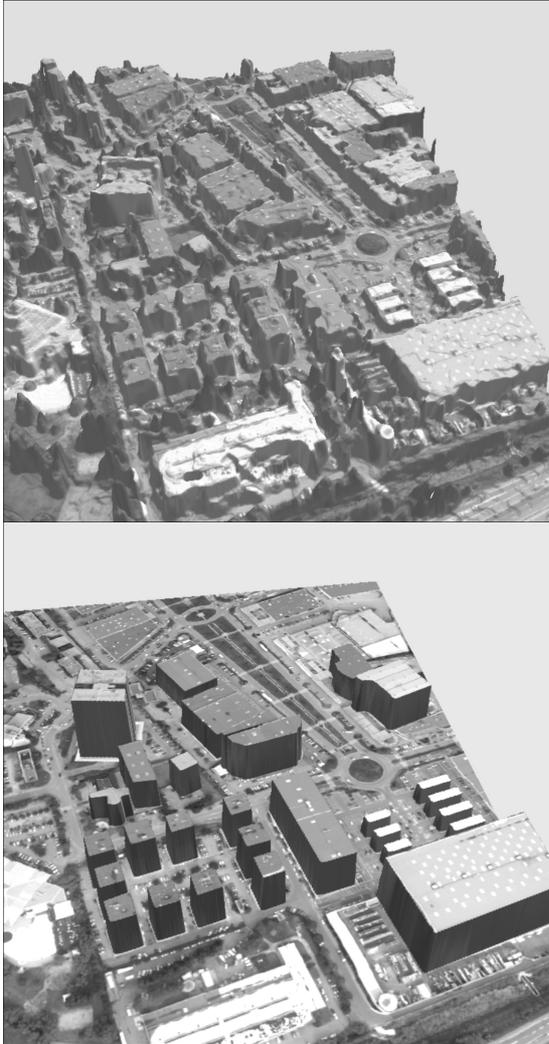


Figure 7. Example Nimes-subset. (above: DSM with draped orthophoto, below: extracted DCM with draped orthophoto)

## 7. CONCLUSION AND FUTURE WORK

A method was presented for creating, change detection and updating small-scale city models. The major processing steps are building recognition, edge determination and corners computation of the building candidates.

Further research is needed for building recognition in order to accelerate the existing algorithms.

Future work will not only focus on the implementation of the updating module, but also on the assessment of reliability and quality parameters of the results.

## 8. ACKNOWLEDGEMENT

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