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# Derivation of urban objects and their attributes for large-scale urban areas based on very high resolution UltraCam true orthophotos and nDSM – a case study Berlin, Germany

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## ABSTRACT

The development of automatic extraction methods for urban building and vegetation objects and the realization on a large urban data set have been accomplished within the project 'Derivation of Building- and Vegetation Heights and Structures in Berlin'. This project was executed on behalf of the Senate Department for Urban Development and Environment of the City of Berlin. As input an UltraCamX dataset consisting of the true ortho mosaic with four spectral channels and the normalized digital surface model (nDSM) with 30cm resolution were used. The size of the area adds up to about 450 km<sup>2</sup>. For the delineation of roof tiles additional slope and aspect layers were created.

The workflow was developed in eCognition for automatic extraction of elevated urban objects and their height structures. Additionally we used focal statistics in ArcGIS to extend the workflow for the extraction of single tree crowns, since detailed information about the correct position and number of urban trees is relevant and completes the urban geo database. In this way a unique, complete and extensive workflow for an automatic urban objects extraction arises. Within the project methods for robust extraction of buildings with roof tiles as well as vegetation were applied. Greened roofs are automatically extracted and assigned to the class buildings. Furthermore building tiles which are located under trees are extracted by the intersection with the cadastral building data. For the transferability of the complete rule set a multi-layered workflow consisting of automated data import and export, iterating segmentation methods and fuzzy classification as well as object reshaping was developed and applied. The methods are transferable and effectively operate on large data sets.

As results complete layers with building and vegetation shapes including single tree tops and crown outlines with comprehensive attributes like height and area are derived. The accuracies are in the range of 85 % (trees) to 95 % (buildings). The shapes primarily serve as input for a complex urban-specific climate model, which also takes the morphology of hinterlands into account. In addition this data can be used as a basis for a variety of urban planning tasks e.g. for modeling of noise pollution, the estimation of urban structure types, for town- or green space planning. They are a suitable basis for supplementing and upgrading of the official cadastral database, even though certain restrictions concerning the accuracies exist. Furthermore the object shapes are suitable for visualization tasks.

**Keywords:** urban remote sensing, building and roof extraction, single tree detection, tree crown delineation, object based classification, very high spatial resolution data, large data handling

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## 1 INTRODUCTION AND PROJECT AIM

The area of expertise of the Department for Sensor Concepts and Applications, part of the Institute for Optical Sensor Systems at the German Aerospace Center (DLR e.V.) in Berlin-Adlershof, lies on the one hand in the deployment of new and innovative sensor systems and in processing of the data with the highest quality and accuracy and on the other hand in the research and development of possible applications of the given data for different tasks <sup>1</sup>.

Remote Sensing is a valuable instrument for complex urban applications and urban planning tasks, particularly in regard to accelerating growth of urban areas in the last decades and the subsequent change of urban and social structures as well as urban climate. In particular Very High Spatial Resolution (VHSR) data of digital airborne cameras is being used in an increasingly wide range of urban applications, like classification of urban land cover <sup>2</sup> (mostly based on satellite data), extraction of single urban objects like buildings <sup>3, 4</sup>, single tree tops and tree crowns <sup>5</sup>, estimation of single roof geometries <sup>6</sup> or extraction of roads <sup>7</sup>. Automatically extracted detailed urban objects for city areas in connection with height and semantic attributes contribute to a continuously rising amount of urban information. Numerous applications and urban analyses are possible achieving unprecedented accuracy and reliability in the results, e.g. estimation of urban structure types <sup>8, 9</sup> and urban density <sup>2</sup> or analysis of soil sealing degree. The decisive advantage of VHSR data from airborne imagery is the simultaneously availability of spectral true orthophoto mosaics (TOM) and digital surface models (DSM), which together form an indispensable basis for reliable urban research. In conjunction with automated methods of data processing and image analysis, urban remote sensing becomes more significant for politicians and decision makers as well as planning, environmental and economic authorities.

The main **aim** of the project ‘Derivation of Building- and Vegetation Heights and Structures in Berlin’ on behalf of the Senate Department for Urban Development and Environment of the City of Berlin <sup>10</sup> is to precisely extract detailed **height structures** of the whole city area of Berlin, including building and vegetation objects. For this purpose not only buildings and their roof geometries but also vegetation and its height structures are extracted and assigned with height attributes. Since the extraction of **building** objects is supported by the official automated cadastral map (ALK) building objects not registered in the ALK have to be detected and a preliminary update of cadastral building data is performed. Beside the roof geometries also greened roof surfaces are extracted. These emerge as an important information for ecological and climatic planning tasks since greened and vegetated roofs have a positive effect on urban heat islands <sup>11</sup>.

The knowledge of numbers of trees, the exact position and attributes like the maximum tree height is very important for urban planning. Planning authorities in Berlin typically investigate this data with a terrestrial measurement or a visual interpretation and digitalization based on ortho aerial images or stereo aerial images. The terrestrial measurement is very expensive and slow and big cities like Berlin cannot be investigated completely. Because of the used data base the manual digitalization is mostly inexact. As a result in Berlin the existing data bank of urban trees is incomplete and not up to date <sup>12</sup>.

**Single trees** can also be extracted based on remote sensing data like aerial or satellite images and airborne laser data. This has a very long tradition in forestry and a lot of different methods have already been developed for forest areas <sup>13</sup>. The developed methods are focusing mainly on satellite images and airborne laser data as well as coniferous trees. The extraction of deciduous trees which are the main tree species in Berlin is still a great challenge <sup>14</sup>. The extraction of single trees in urban areas is not common in remote sensing. The most studies focus on the detection of urban tree cover <sup>15, 16</sup> or on partial solutions like the extraction of special tree species <sup>17</sup>.

## 2 DATA SOURCES

### 2.1 Research area

The selected study area (450km<sup>2</sup>) covers the majority of Berlin city center. It includes typical urban land cover and structure types. It is characterized by a variety of different classes such as sections with residential use (tenements, allotments), traffic areas (railway, city highways, airport), industry and wasteland, waterways, green and open spaces (parks) and small forested areas. All object categories show a high heterogeneity. The morphology is dominated by glacial remnants with local relief up to tens of meters. The examples presented here are all taken from Berlin-Mitte.

### 2.2 Image data and derived products

The UCX is a large format digital aerial frame camera with panchromatic and additional multispectral capabilities. Using the Semi Global Matching (SGM) developed at the DLR <sup>18</sup>, a detailed digital surface model (DSM) in full image

resolution is generated. The number of matchings for each DSM pixel is written into a separate count mask. Using this large true orthoimage mosaics (TOM) in 4 multispectral channels (infrared, red, green and blue) of extensive areas are derived (details in <sup>19</sup>). Both, DSM and TOM perfectly fit to each other and display very sharp object contours and breaking edges (see Figure 1). For this project 10 cm TOM and DOM (x/y) from 2010 was resampled to 30 cm to reduce the amount of data for the classification process. A radiometric depth of 16 bit / channel was used for the classification. Additionally a normalized DSM (nDSM) is calculated to determine the absolute object heights.

A normalized Digital Surface Model (nDSM) is the difference between the surface model (DSM) and terrain model (DTM). The nDSM shows only the buildings and vegetation that stand out from the site (terrain), all other surfaces have a constant height zero. In this way simple classification rule sets can be used to distinguish between ground and non-ground. To derive the nDSM from the DSM an almost automatic procedure was used, which was developed at DLR by <sup>20</sup>. The DSM is searched for edges and abrupt change of altitude. Along these ground points are identified. When sufficient ground points are known, they are interpolated to a closed surface and all non-ground objects can automatically be removed. The resulting DTM allows, by subtracting the DTM from the DSM, the calculation of the nDSM.

From the nDSM further input layers like slope and aspect are derived, which serve as further input layers for the classification process. Examples for nDOM, TOM and derivatives are given in Figure 2.

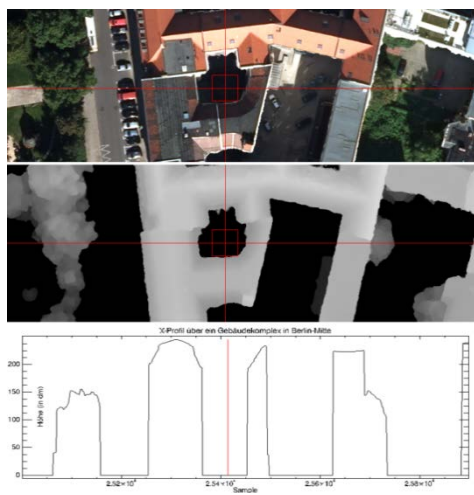


Figure 1 TOM, nDSM and height profile

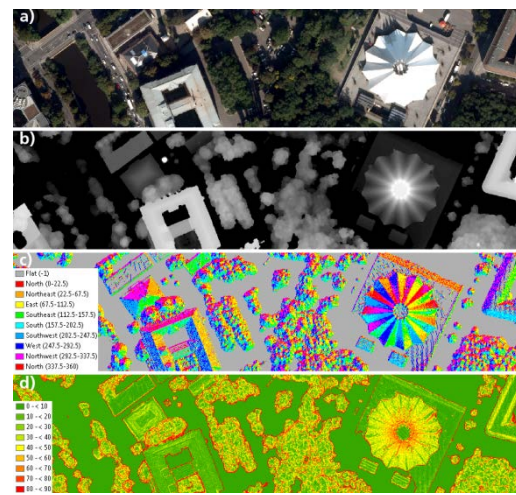


Figure 2 TOM, nDSM and aspect and slope

In addition to the multispectral true orthoimage, the DSM and the nDSM two official data sets of the Berlin Senate, the Automated Cadastral Map (ALK) and the statistical block map are used for the classification procedure.

### 2.3 Official Automated Cadastral Map and Statistical Block Map of Berlin

The vector basis data was provided by the Berlin Senate due to ensure a junction and completion to existing geodatabase in the digital *Environmental Atlas of Berlin*. The automated cadastral map (ALK) is an official part of the land register, it contains topography, building layers and tree register. It stores not only the geometric information but also additional information like the unique key number for every building object, number of storeys and the usage type of building. The ALK serves in this project as a basis for the estimation of building geometries. In the research area the ALK contains around 270.000 building and topography objects as closed polygons and around 263.000 registered trees as points (Jun/2012). Another official vector data base used in the project is the statistical block map (ISU5) in the scale of 1:5000 (Dec/2010). This map contains so called statistical blocks, which cover surfaces limited by the streets as well as administrative borders for districts and subdistricts. Each block contains a unique number, so that for each building inside a block an exact position is known. Also the land use, the urban structural type and the area type of block are saved as attributes.

While establishing the ALK in Berlin the trees on streets or public places were part of the ALK. Since that time the geo-database has been maintained differently in the Berlin districts. As a result of this development the tree database is not up to date in all districts, e.g. new planted trees are not registered into the database or cut trees are still a part of the database. Also the position of trees is sometimes incorrect. As a reaction on this situation the Berlin Senate is developing a new tree cadaster. Figure 3 represents the given vector data.

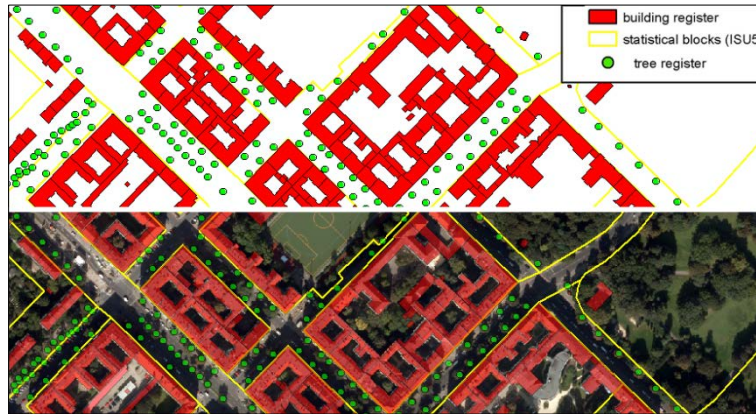


Figure 3 Vector data: official cadastral map: buildings, trees and statistical blocks

### 3 METHODOLOGY

#### 3.1 Analysis workflow

In this study a complete workflow for the extraction of urban objects is presented (see Figure 4). The used UCX data constitute in the meantime a relatively cheap and widely available data source worldwide. Not only a standard data set is used but also commercially available standard processing software – in this case Trimble eCognition 8.0 and ESRI ArcGIS 10.0 – for segmentation and object-based classification to provide a solution accessible to many users.

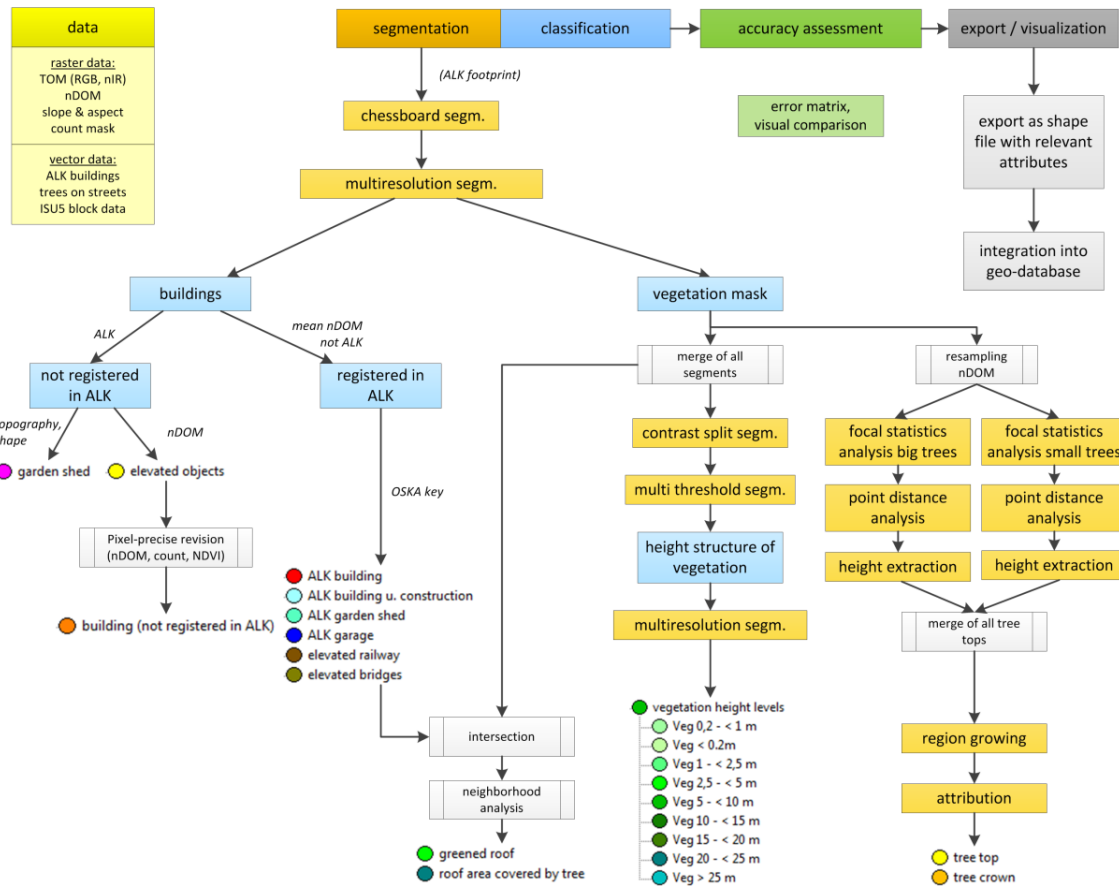


Figure 4 Complete workflow for the extraction of urban objects

The research area constitutes a big amount of data which is computationally very intensive. For this reason the data set was split into 12 tiles representing official Berlin districts. The generated district tiles are edited in a batch process using the eCognition server solution. For both building and tree crown detection fundamental vegetation and building masks were prepared with object based classification in Trimble eCognition and afterwards refined in two parallel process sequences (see 3.2 and 3.3). All results are saved in the geo-database for each district separately. The detailed descriptions of used methods as well as the quality of the results and their accuracy are presented subsequently.

### 3.2 Extraction of man-made elevated objects

For the extraction and refinement of building objects and roof tiles the object-based classification was used. In the previous investigations <sup>3, 21</sup> it was proven that this method can not only effectively work with VHSR data but also propose very good solutions for large data handling which is important with regard to transferability of developed rule sets to wide and morphologic diverse urban areas. Also the shape of objects and especially the context information can be used for the improvement of segmentation and classification results <sup>22</sup>.

There are several approaches for the detection and extraction of buildings based on VHSR data. A main goal of this study is the extraction of particular roof regions and not only building outlines as well as greened roof surfaces. A detailed description of all used algorithms can be found in the final report of the project in the digital *Environmental Atlas of Berlin* under <sup>23</sup>. In this paper only a brief summary is given.

In the first step the classification of vegetation mask was performed with the help of normalized differenced vegetation index (NDVI); it was subsequently extended into the shadowed vegetation and serves as a basis for the subsequent generation of vegetation height structures and for the extraction of single tree tops (see 3.3). The integration of shadowed vegetation is a precondition for a correct and complete building extraction. In this way an avoidance of false building objects in shadowed vegetation areas is possible.



Only the objects outside of the vegetation but inside of the ALK polygons with a minimum height of 3 m are classified as buildings. In this way building objects can be transferred directly from the ALK into the classification. Additionally with the help of the available object key (OSKA) within the ALK different relevant object types can be distinguished. Nevertheless the directly adoption of the building objects from the ALK still doesn't represent the complete *building* class, since some new buildings are not registered in the cadastral map. In order to complete the *building* class, an additional classification is performed. All remaining elevated objects, which are not classified as vegetation are extracted and subsequently optimized under consideration of shape features, context and pixel-precise revision. Elevated *bridges* and *railway tracks* are removed from the class *buildings* using intersection with the OSKA key. Finally not registered buildings and big roofed constructions but also some temporary objects, like circus tents or construction site containers are extracted and assigned to the class *buildings not registered in ALK*. In this way a preliminary identification of not registered objects for an update of the geo-database is done. Of course these objects still cannot directly be implemented into official cadastral map since they are not corresponding to the strict requirements of cadastral object catalogue, nevertheless they can serve as an indication for the necessary update.

Since the generated nDSM shows some shortcomings according to low heights, some small and low buildings (*building under construction*, *garages* or *garden sheds*) still remain unclassified. They are adopted into the *building* class using the object key from OSKA. In this way the building layer is completed containing registered and not registered buildings as well as their different types and can be following used as a basis for the extraction of roof tiles, which are important for detailed climatic modeling and other urban planning applications. The extraction of roof geometries is performed according to the method presented in <sup>3</sup>.

Of particular interest for the project are also greened roof surfaces. They are extracted with the help of sole intersection of the existing vegetation mask with the building ALK-layer. However this is still not the final solution, since neighboring overriding trees also cover and overlap roof surfaces (Figure 5). For this reason the greened roofs and trees have to be distinguished. To do so the deviations of height and NDVI values to the neighboring tree and building objects are compared. If the height and NDVI differences to the trees are low, this false greened roof segments are integrated into the class *roof area covered by tree*. In this way they can be flexibly integrated during the export into the *building* or *vegetation* class. At this step the advantage of neighborhood analysis helps to avoid misclassifications. The correct classification of *greened roofs* plays subsequently a major role for the detection of single trees, since greened roofs can cause a false positive detection of tree tops. Greened roofs are consequently also a crucial factor for the complete building mask.

At the end the exact position, the height statistics, as well as area and class name are attributed to the extracted building objects. These attributes are the adopted to the geo-database and can be used for different planning applications. In the Figure 6 below the complete *building* layer including registered and not registered buildings is presented. It can be recognized that relative high amount of not registered buildings or big roofings is correctly extracted.



Figure 5 Preliminary classification of *greened roofs* by the intersection of vegetation mask with ALK buildings, also some overriding trees are falsely classified and subsequently corrected

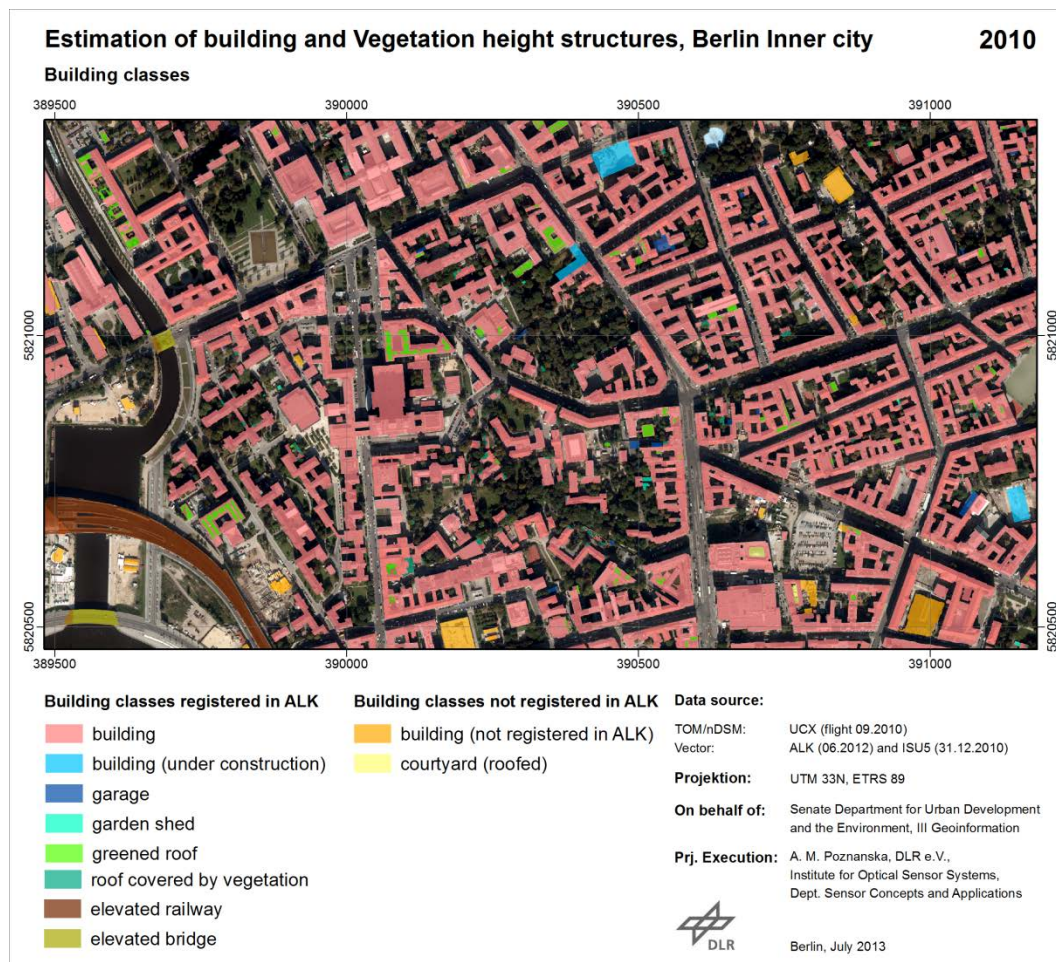


Figure 6 Complete building layer including registered and not registered buildings in the ALK (exemplary subset of Berlin Center)

### 3.3 Optimization of vegetation mask and estimation of vegetation height structures

The available vegetation mask is additionally optimized by conditional growing in shadowed areas. To do so the shadowed elevated areas with lower but not negative NDVI were detected and conditionally assigned to the *vegetation* class under the constraint of similar nDSM-values and high standard deviation values, which is typical for heterogeneous tree surfaces. The integration of shadowed vegetation is crucial for the correct delineation of natural tree crown extents. The resulting vegetation mask is complete containing shadowed tree areas and serves as basis for the generation of height structures.

Because of the high spectral heterogeneity of the given data set – especially concerning vegetation objects – the use of the nDSM during the segmentation process emerges as a precondition. Since the height structures should be delineated not the common multiresolution segmentation but contrast split segmentation<sup>24</sup> based solely on the nDSM layer was preliminary applied to the vegetation mask to separate dark (low) and bright (elevated) objects. In the next step the multi threshold segmentation<sup>24</sup> also based on nDSM was used for the subdivision in 8 height levels. This segmentation method generates height contour lines (see Figure 7a). Additionally the multiresolution segmentation<sup>25</sup> is applied to subdivide the given height levels into meaningful height structures (see Figure 7b and c). In this way the resulting height segments are representing homogenous and significant vegetation height structures. They are exported with relevant height statistics in the attribute table.



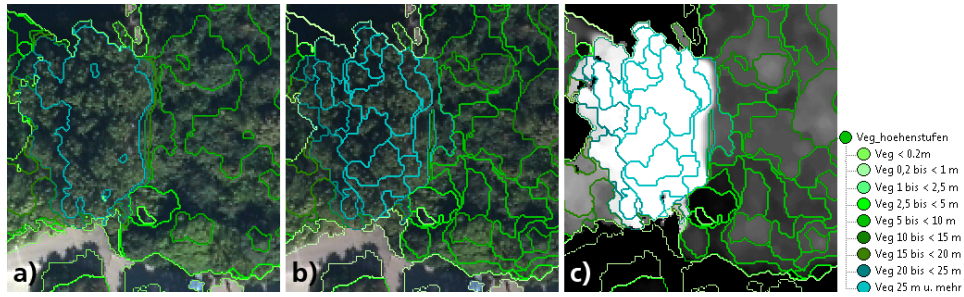


Figure 7 Generation of height structure segments for the vegetation (a: multi threshold segmentation with 8 height levels, b & c: subsequent multiresolution segmentation subdividing the height levels into meaningful height structures)

### 3.4 Extraction of single tree tops and tree crowns

Based on TOM and nDSM the extraction of deciduous and coniferous trees is possible with a high accuracy<sup>14, 26</sup>. Most methods of single tree detection were developed for forest areas. With some modification some of these methods can also be used for single tree identification in urban areas. The automatic single tree extraction means in this case the identification of tree tops (points) and tree crown extents (polygons).

At the beginning of the extraction process a morphological definition of trees is necessary. In this paper a tree is defined by a minimum height of 2.5 m, a minimum crown area of 2 m<sup>2</sup> and a high value of NDVI. Limited through constraints of the used data base other attributes like the tree trunk cannot be used for the definition.

To improve the results and to reduce the calculating time only the areas inside the vegetation mask were used for the realization of single tree detection. Additionally a constraint for the height of 2.5 m was applied in order to extract elevated vegetation. Build on the vegetation mask a GIS supported so-called focal statistics analysis was appropriated for the extraction of tree tops.

The focal statistics analysis is an implementation of a neighborhood operation with a maximum function within a default detection raster for tree tops in a nDSM. The detection raster is based on an annular shape which applies only values between the inner and the outer circle. The output value is in this case a function of the adjacent input cells that means the sum of all values in the neighborhood of the local maximum will be added and outputted<sup>27</sup>. This fact allows the detection of different kinds and heights of trees through the modification of the annular shape's size and the change of the proportion between the inner and outer circle.

The structure of trees in urban areas like Berlin is characterized by a high diversity of trees, tree heights and tree crown areas. To consider the variable tree populations in urban areas two parallel focal statistic loops were established. The first focal statistics analysis path utilize a small and tight annular shape and extracts only tree height up to 10 meters to detected small trees. The second analysis path uses a big and wide annular shape and extracts tree heights from 10 meters to detected big trees. To correct possible multiple tree tops a point distance analysis was implemented to eliminate the superfluous tree tops. Also extracted tree tops with a distance of less than 2 m to buildings are deleted within the process due to possible erroneous data in the nDSM. At the end the tops of the small and big trees are merged and used as one class. For the extracted tree tops the height of the tree is calculated based on the nDSM for further analysis.

The tree crowns are extracted after the identification of tree tops. Especially for deciduous trees the region growing<sup>28</sup> segmentation method is the most suitable one for crown detection. The detected tree tops are used as starting cells for the segmentation step. The region growing process considers both the geometric and the radiometric information. The growing segments cannot grow in regions with a low vegetation index value or very high slope value. The consideration of statistical tree proportions also improves the accuracy of the segment extraction.

At the end the exact position, the maximum tree height, average crown diameter and tree height and the crown area are calculated and attributed to the extracted tree crowns. These attributes can be used for different planning question and also for the modeling of trees in virtual environments.

## 4 RESULTS AND ACCURACY

### 4.1 Building objects

The extracted building objects include a total of 10 classes. The quality of the registered buildings can be assessed as very good, since these objects were directly adopted from the ALK. The accuracy corresponds to the accuracy of this vector layer. The extraction of non registered buildings was successful. A total of round 3.300 objects in the project area was achieved. The accuracy of the results corresponds to the accuracy reached in the previous study by <sup>5</sup>, where building objects were detected without ALK. Detailed information to applied accuracy assessment methods can be found in <sup>29</sup>. The completeness adds up to 93,3% and the correctness to 95,9%. The extracted objects are exported with several relevant attributes, in particular the height statistics and include the information about the location in the statistical blocks and administrative areas. The results are integrated into the geo-database and serve as a basis for climatic modeling but also for many other urban applications. In Figure 8 exemplary results for the estimation of building and vegetation height structures are presented.

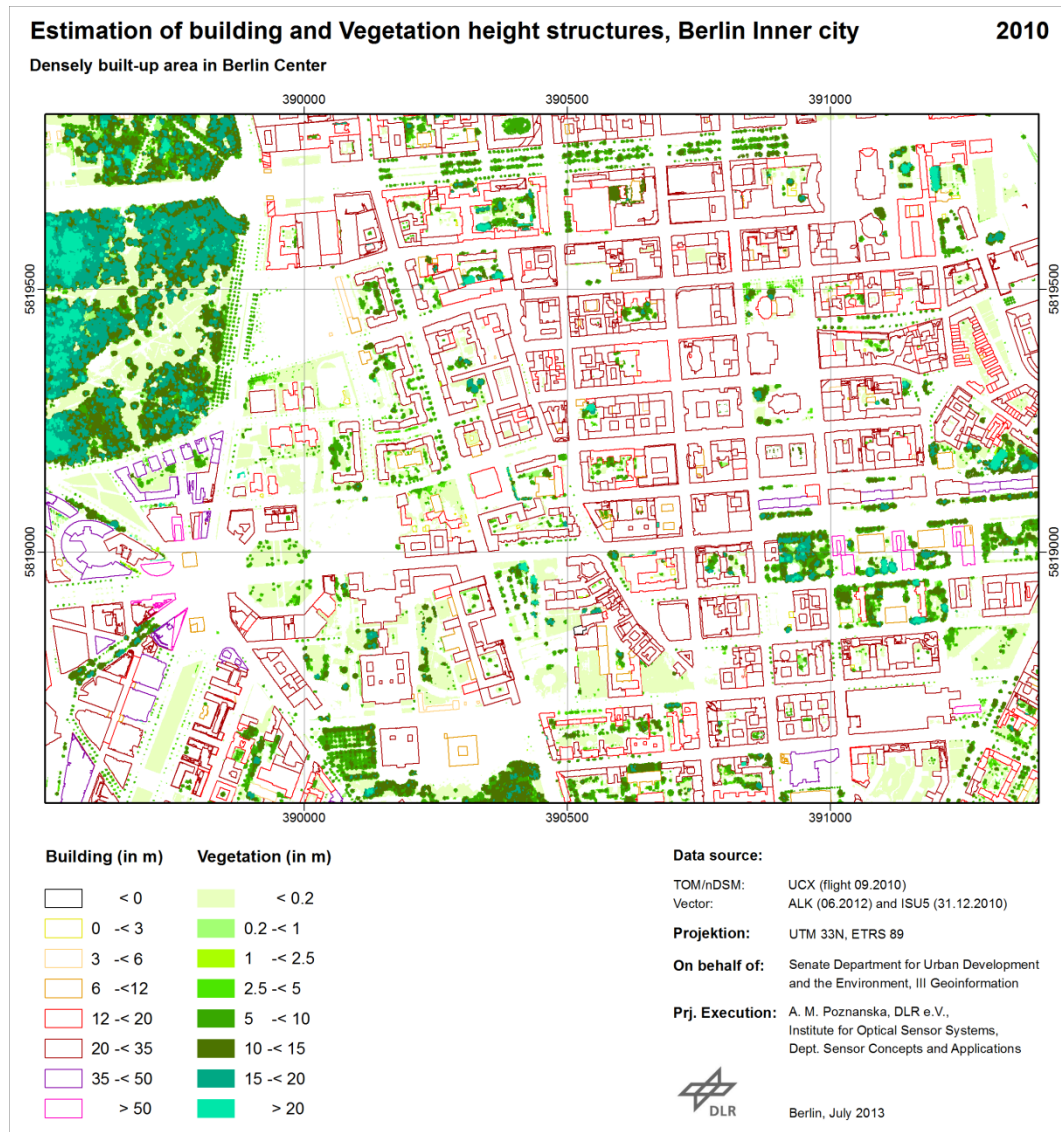


Figure 8 Results of the estimation of building and vegetation height structures (exemplary subset of Berlin Center)

## 4.2 Single tree tops and crown outline

To evaluate the accuracy of the single tree extraction results more than 350 control trees were collected with an in situ measurement in the downtown area of Berlin. The control trees are divided into three tree classes: old trees along streets, young trees along streets and trees in park areas. The completeness and the correctness were calculated after<sup>13</sup>.

The completeness (com.) of the results is calculated as follows:

$$\text{completeness (\%)} = \frac{\text{correctly extracted trees}}{\text{correctly extracted trees} + \text{not extracted trees}} * 100$$

The correctness (cor.) of the results is calculated as follows:

$$\text{correctness (\%)} = \frac{\text{correctly extracted trees}}{\text{correctly extracted trees} + \text{wrong extracted trees}} * 100$$

The overall accuracy of the *tree tops* is high (see Table 1). Approximately 85 % of the control trees were extracted with the focal statistics analysis. The correctness of the extracted trees amounts 86 %. The highest accuracy was achieved in the class *young trees* along streets due to the clear delineation in the nDSM. The completeness within this class was more than 91 % and all trees were extracted correctly. Because of the structure of the tree populations in park areas the worst accuracy was achieved in the class *park trees*. Almost 82 % of the control trees were detected but around 30 % of these trees were extracted wrong. *Old trees* along streets were also extracted with a high accuracy (see Figure 9). As the positions of tree tops normally do not correspond to the tree trunks the achieved position accuracy of street trees does not fulfill the necessary accuracy of less than 10 cm for a street tree cadaster.

Based on a TOM and a nDSM unpaired trees can be extracted with a very high completeness and correctness. Also trees in a tree population with a diverse age and size structure can be extracted with a high accuracy. Only trees within a monostructured tree population with trees with the same age and with the same size cannot be extracted very well but significantly better than a visual image interpretation. The limits of the presented approach are the constraints of the used data source. Because of the central perspective of the aerial images trees with a branching trunk are usually extracted as multiple tree tops and not as one object. Also big bushes and small trees cannot be distinguished if they surpass a defined height of more than 3 meters, they are extracted as trees.

Table 1 Accuracy of tree tops

	old trees along streets	young trees along streets	park trees	overall accuracy
completeness	84,62 %	91,51 %	81,93 %	85,04 %
correctness	88,52 %	100 %	69,89 %	86,06 %

In Figure 8 an exemplary subset with the extraction results of single tree tops and crowns for the old trees along streets is presented.



Figure 9 Results of old trees along streets (tops and crowns)

## 5 CONCLUSION AND OUTLOOK

Automatic extraction of semantic objects with relevant attributes was performed operationally and automatically resulting in very high classification accuracies. Perfectly co-registered TOM and nDSM form the indispensable data basis for the automated object extraction in densely and heterogeneously built-up areas as well as in densely vegetated parks. eCognition has proven to be a reliable and efficient software for automated object extraction for large data sets. It provides a variety of given features and options for individual extensions for both a robust workflow as well as for individual solutions for detailed classification rule bases. In interaction with the cadastral data and other given vector data the classification process was stabilized and missing or false objects in the vector data were identified. The objects were attributed with very detailed height and structural information, both on the buildings and on the individual tree level. In this way accurate climatic modeling with unprecedented accuracy, in particular precise estimation of potential biomass in urban areas are possible. A server solution allowed a parallel processing of the Berlin district tiles. Adaption and optimization of the rule sets for the upcoming second phase (1800 km<sup>2</sup>) in the urban hinterland of Berlin with a different ground resolution of 50 cm is currently in process. The results of the first phase of the Senate project, which were exported as attributed ESRI shape files are online in the digital *Environmental Atlas of Berlin* <sup>10</sup>, as well as a detailed report under <sup>23</sup>.

Concerning the actuality of the cadastral ALK data the presented methods show a potential to differentiate existing utilization maps and to update selected information layers and missing details. Missing and “left over” objects can be identified for both the building and the tree level. A fully automated update of the building layer is not possible, as the roof edges identified in the airborne data are not consistent with the buildings base body outlines in the ALK. Nevertheless the extracted not registered buildings are good position indicators for the necessary update. For the tree layer, which has a large deficit in actuality and completeness, an update could significantly improve the data base, especially for trees in parks, as a lower spatial accuracy is necessary in the green spaces register (ger. *Grünflächenkataster*); for the trees along streets, where the required accuracies are in the range of dm, the accuracies of the tree crowns are not sufficient for a direct update of the data, they can only be taken as evidence for either planted or cut down trees.

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