Ascertainment of Building and Vegetation Heights in the Area of the City of Berlin

---

Documentation of Results

Contracting authority:
Senate Department for Urban Development and the Environment
Geo-Information Section, Office III F,
Urban and Environmental Information System

Project implementation and publication
Dipl.-Ing. (FH) Anna Maria Poznańska
German Aerospace Centre (DLR)
Department for Sensor Concepts and Applications,
Institute of Optical Sensor Systems

DLR Deutsches Zentrum für Luft- und Raumfahrt

Senatsverwaltung für Stadtentwicklung und Umwelt | be Berlin

Contracting authority and preparation of the basic vector data:

Senate Department for Urban Development and the Environment
Geo-Information Section, Office III F Urban and Environmental Information System
Contact: Jörn Welsch III F 12
Fehrbelliner Platz 1
10707 Berlin, Germany
Phone: +49 (30) 90139-5256
Fax: +49 (30) 90139-5251
E-mail: Joern.Welsch@SenStadtUm.berlin.de

Preparation and processing of the raster data:

German Aerospace Centre (DLR)
Department for Sensor Concepts and Applications
Institute of Optical Sensor Systems
Contact: Frank Lehmann (Section Chief)
Phone: +49 (30) 67055 – 425
Fax: +49 (30) 67055 – 602
E-mail: Frank.Lehmann@dlr.de

Project implementation:

Anna Maria Poznańska, Engineer
German Aerospace Centre (DLR)
Department for Sensor Concepts and Applications
Institute of Optical Sensor Systems
Rutherfordstr. 2
12489 Berlin, Germany
Phone: +49 (30) 67055 – 349
Fax: +49 (30) 67055 – 602
E-mail: Anna-Maria.Poznanska@dlr.de

Table of Contents

Directory of Abbreviations

ALK	Automated Map of Properties
AT	Aero-triangulation
CCD	Charge-coupled device (for use with area scan cameras)
CSS	Contrast split segmentation
DLR	German Aerospace Centre
DTM	Digital Terrain Model
DSM/NDSM	Digital Surface Model/Normalized DSM
ETRS89	European Terrestrial Reference System, 1989
FIS Broker	Interdisciplinary Information System Broker/Geoportal of the State of Berlin
GDB	Geo-database
GIS	Geo-information system
GPS	Global Positioning System
GRS80	Geodetic Reference System 1980
HRSC	High Resolution Stereo Camera
IR/NIR	Infrared/near infrared (refers to range of electromagnetic radiation)
INS	Inertial Navigation System (usually in connection with GPS/INS)
ISU/ISU5	Urban and Environmental Information System
LOR	Real-world oriented spaces in Berlin (planning bases)
MRS	Multi-resolution segmentation
MTS	Multi-threshold segmentation
NDVI	Normalized Differenced Vegetation Index
OBIA	Object-Based Image Analysis, also Geographic Object-Based Image Analysis (GEOBIA)
OS	Property code (in the ALK)
OSKA	Property code catalogue of Berlin (also OSKA-Bln)
RGB	Red-green-blue (as channel combination in a true-colour image)
SAPOS	Satellite positioning service of the German National Survey
SenStadtUm	Senate Administration for Urban Development and the Environment
SGM	Semi-global matching
TOM	True ortho-mosaic
UCD	UltraCam D
UCX	UltraCam X
UTM	Universal Transverse Mercator
VHSR	Very high spatial resolution (also VHSR data)

1. Introduction, Project Goal and Project Environment

In recent years, the use of very high resolution digital remote sensing data for a wide range of analyses in urban areas has increased. This is on the one hand due to the increased use of digital sensors, which are opening up new technological possibilities. On the other, it is driven strongly by the advantages of these data, especially for automated information extraction.

For more than ten years, the Institute of Optical Sensor Systems of the German Aerospace Centre (DLR) at Adlershof in Berlin has been developing its core competence in the creation of very high spatial resolution digital surface models (DSM) and true ortho-mosaics (TOM), and in the processing and application of high resolution digital remote sensing data (LEHMANN et al., 2011). The focus of the research work in the Department for Sensor Concepts and Applications has first of all been on the development of innovative remote sensors, and second on the processing of data products for practice oriented application. In recent years, investigations have been carried out into the possibilities of the use of very high spatial resolution data (VHSR) for application in urban areas. Moreover, suitable methods for extraction and analysis have been tested. TOM and DSM data provide an indispensable database for detailed efficient object extraction in urban areas. As TROSSET et al. (2009) observed, a geometrical resolution in the range of 30 cm provides an optimum base for automated extraction of building information, taking into account both calculation time and ascertainment precision. It could be shown that DSM plays an important role in stabilizing the analysis of structures, since it is insensitive to differences of shade and illumination. Also of key importance is the fact that DSM is normalized at ground level, so as to retain the absolute height of objects. Based on these realizations, it was shown that this database is very well suited for urban applications (BAYER et al., in press). With the aid of object based image analysis, it was possible to extract objects with semantic information, and integrate them into a geo-information system (GIS). Such applications as the calculation of impervious ground coverage, the analysis of urban structures, and climatic modelling, have been realizable with unprecedented precision on the basis of the data process by the DLR.

In the context of the project carried out for the Senate Department for Urban Development and the Environment, Geo-Information Section, Urban and Environmental Information System (hereinafter SenStadtUm), the concept for the automated extraction of structural and vegetation objects and their height attributes is to be developed and applied to large areas of the city on the basis of UltraCamX data. An extension to the rest of the city's area and to the adjacent surrounding areas is being prepared (as of July 2013).

The goal of the project is the derivation of roofs and roof geometries, and the extraction of vegetation height stages. A further goal is the integration of automatically extracted objects to a geo-database, and the preparation of these data as the basis for the calculation for further reaching urban analyses. A major goal is a complex climatic modelling project, in which the results of object extraction from both the Berlin inner city and from the surrounding areas are to be incorporated.

Participating organizations

The project was carried out entirely at the DLR facility is Adlershof in Berlin, under contact with the Senate Department for Urban Development and the Environment. The participating organizations are described below:

German Aerospace Centre (DLR)/
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)

The German Aerospace Centre (DLR) is the research centre of the Federal Republic of Germany, concentrating on research and development in the areas of aeronautics, space travel, energy, transport and security. The DLR operates major research facilities for its own projects, and is tied into national and international cooperative efforts; it also provides services to the private sector. Its headquarters are in Cologne, and it operates a total of 16 sites throughout Germany, with some 7400 staff. The broad range of issues addressed by the DLR is shown by the fact that it includes 30 different institutes (cf. DLR, 2013a).

DLR Institute of Optical Sensor Systems,
Department for Sensor Concepts and Applications
Institut für optische Sensorsysteme –
Abteilung Sensorkonzepte und Anwendungen

The Institute of Optical Sensor Systems (OS) defines the development of geometrical and/or spectral high resolution sensor systems in the visible and infrared ranges of electromagnetic radiation. The facility focuses its activities on imaging optical systems used in aircraft and satellites (cf. DLR, 2013b).

The Department for Sensor Concepts and Applications focuses on the definition and development of innovative camera sensors, their verification and validation, and the processing of their data products for practice oriented application. Core competences of the

Department extend from the common database research, through planning and implementation of airborne photographic operations, all the way to data processing and evaluation of aerial and satellite imagery (cf. DLR, 2013c).

Processing of available digital aerial image data is carried out in the Photogrammetry Working Group, where the generation of the data products DSM/NDSM and TOM were also realized. The automated object extraction and integration of the results into a geo-database was carried out by the Geo-Information and Applications Working Group. The solutions for object extraction presented here have been developed and refined in the context of a Ph.D. dissertation by A. M. POZNAŃSKA (née TROSSET), at the Free University of Berlin.

Senate Department for Urban Development and the Environment (SenStadtUm),
Office III Geo-Information, Section F Urban and Environmental Information System (ISU)
Senatsverwaltung für Stadtentwicklung und Umwelt, Abteilung III – Geoinformation, Referat III F Informationssystem Stadt und Umwelt

The Senate Department for Urban Development and the Environment (SenStadtUm) consists of ten different sections and the Special Office for Climate and Energy (as of July 2013), with activities in the areas of urban planning, construction, transport, the environment, and waste management. Section III Geo-Information is responsible for the gathering, administration and preparation of geo-basic and technical data. The focus of Office III F Urban and Environmental Information System (ISU) is on the processing, preparation, evaluation and visualization of environmental data for Berlin, which are freely available to business, policy-makers, the public and the administration, and accessible via the FIS Broker (transdisciplinary information system; cf. ISU, 2013; SENSTADTUM, 2013a). The basic and technical data can be combined and evaluated with respect to various issues.

The available stocks of data and work results from numerous branches of the Berlin administration and of many scientific institutes are presented in the Berlin Environmental Atlas in the form of maps, tables and graphics. The work results published since 2000 are available only online. The Environmental Atlas encompasses eight topical areas: Soil, Water, Air, Climate, Biotopes, Land-Use, Traffic/Noise and Energy. By preparing spatially referenced basic data, and pursues the goal of "*informing the public about the state of the environment*". For most of the topical areas, the information is gathered in the sections of the Department of Urban Development and the Environment, and updated in cooperation with universities, institutes and partners in the private sector (cf. SenStadtUm, 2013b).

2. Database

The full-coverage processing of the area of the city of Berlin and the adjacent surrounding areas is being carried out in two separate work steps.

This breakdown is first of all mandated by the data available at the time of project initiation; however, it also reflects to a large degree the different morphological features of the two project areas. The very high resolution UltraCam X (UCX) data covers approx. 445 sq km, roughly, the densely built-up, heterogeneous area of the Berlin inner city, while the lower resolution UltraCam D (UCD) data cover the area on the edge of the city and the adjacent surrounding areas with their largely loosely built-up and more homogenous vegetation structures, with an extent of approx. 1800 sq km. The expanse of the two project areas is shown in Figure 1. They reflect the division of the project into two phases:

- First project phase: The Berlin inner-city area
- Second project phase: The rest of the area of Berlin and adjacent surrounding areas.

This report contains only the description of the data on the work in the first project phase.

For this processing phase, very high resolution raster data obtained in 2010 for the major part of the Berlin inner-city area was available. This data and its pre-processing are described in detail in Chapter 2.1.

The available raster and vector data were available in various projections, and were transformed into a uniform projection. The reference system used for processing was the worldwide standard Universal Transverse Mercator (UTM) coordinate system in Zone 33, together with the geodetic reference system ETRS89 (European Terrestrial Reference System 1989).

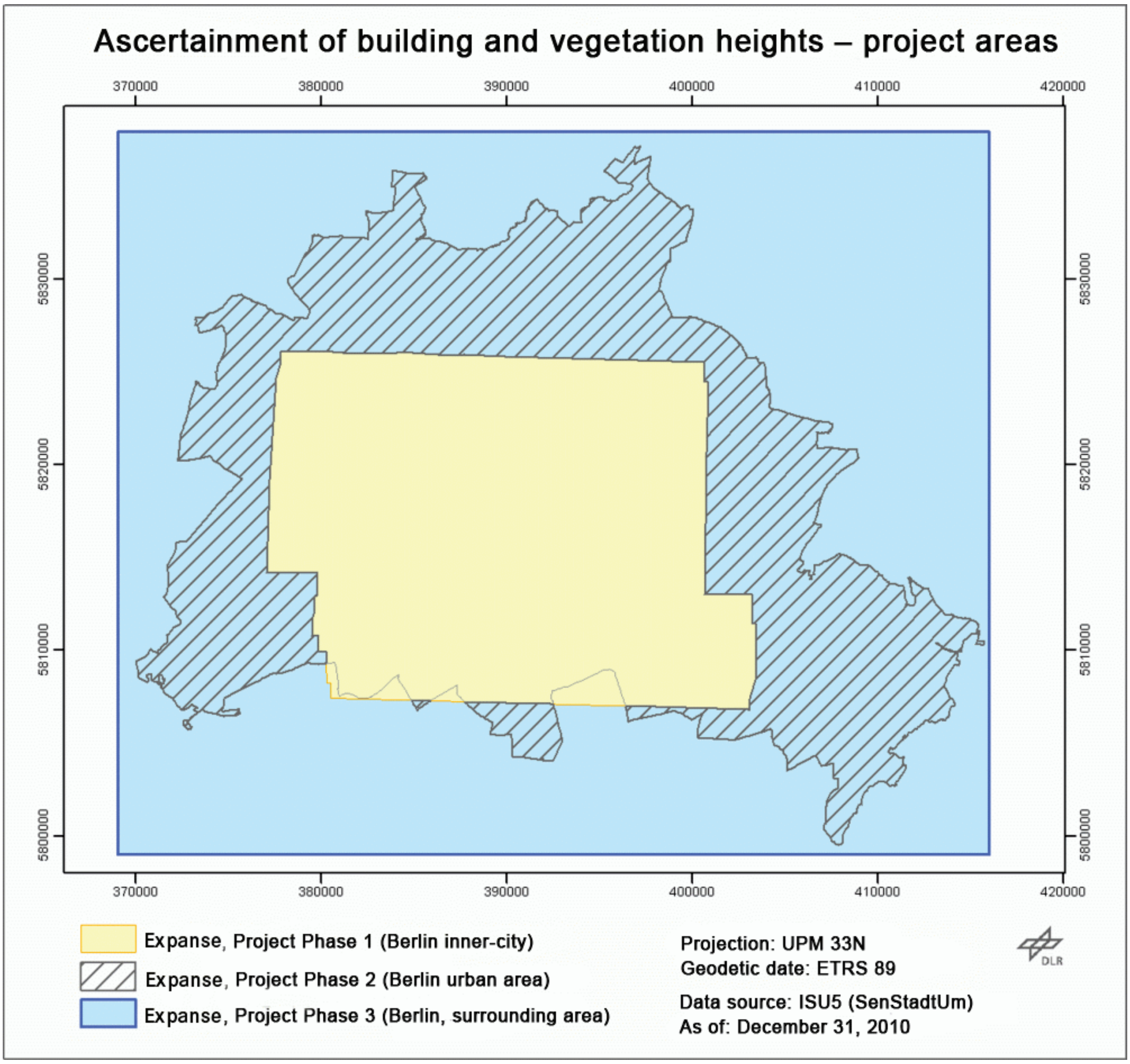


Fig. 1: Extent of the project area: Area of the city of Berlin and surrounding areas

2.1. Digital aerial image data – UltraCamX

For the automated object extraction, digital aerial image data from the UltraCamX (UCX) matrix camera were available. The camera system, its parameters the aerial photography operation and the processing of the resulting data are described below in detail.

2.1.1. The UltraCamX camera system

The UltraCam X (UCX) aerial image camera is a matrix (or frame) camera, a further development of its predecessor, the UltraCam D designed by the Austrian technology company Vexcel Imaging GmbH (today Microsoft). Since 2006, the UCX has established itself as one of the most widely used airborne camera systems on the market. The following description is based largely on the publication by GRUBER et al. (2008).

Matrix cameras for photogrammetric use capture their image from an aircraft by means of matrix sensors arranged in a sensor unit with a central perspective. The UCX consists of a sensor unit with eight independent cameras, equipped with a total of 13 CCD sensors. Four of the cameras take the high resolution large-format panchromatic picture, while the other four take images in the spectral channels blue, green, red and near-infrared at lower resolutions (Figure 2). All data have a radiometric depth of more than 12 bits.

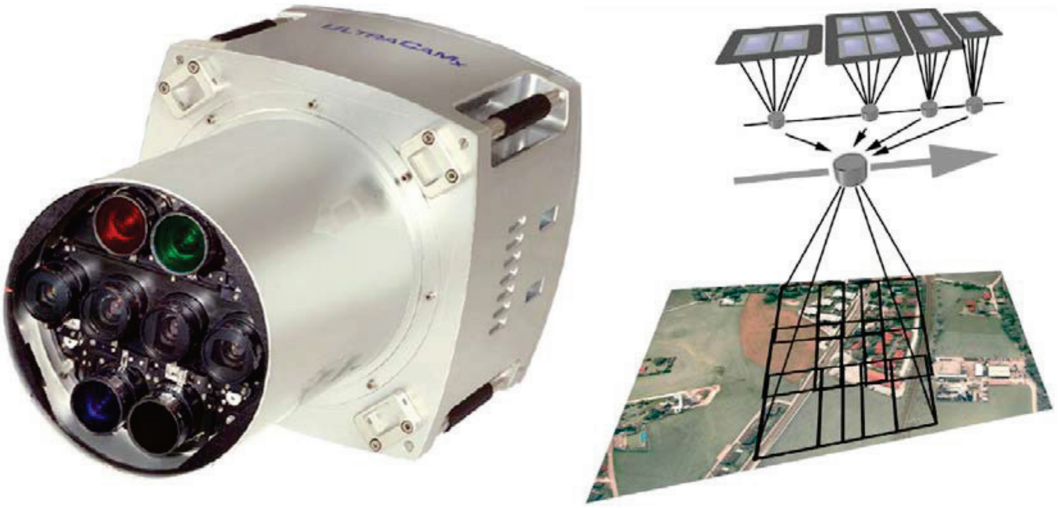


Figure 2: UltraCamX camera head (left, source: GRUBER et al., 2008, p. 666) and its photographic principle (right, source: LEBERL & GRUBER, 2003, p. 74)

The four panchromatic cameras are arranged in the camera system in a row in the direction of flight with parallel optic axes. They are triggered at staggered intervals, creating nine slightly overlapping single images in each photographic cycle. These are then merged to a final fine-resolution panchromatic image of 14,430 x 9420 pixels in size. At the same time, the four multispectral cameras take pictures of 992 x 3328 pixels. In a pan-sharpening process, the multispectral data are translated to the geometric resolution of the panchromatic data, 14,430 x 9420 pixels.

Matrix cameras provide stereo capacity by means of an overlapping area of at least 60% in the direction of flight and 30% in the transverse direction. This overlapping ensures that each point on the image is recorded from at least three different angles. This permits the merger of all available single images into an overall mosaic, and the stereoscopic creation of a DSM. The size of the overlapping area of the single images directly affects the quality of this DSM. For this reason, it is recommended that an optimum longitudinal overlap of 80% and a transverse overlap of 70% be carried out in the aerial photographic operation (Hirschmüller & Bucher, 2010).

2.1.2. Aerial photographic operation

The aerial photographic operation over the inner-city area of Berlin was carried out in early autumn, 2010. Thereafter, the most important flight parameters from the flight log of the technical report were compiled:

Flight carried out by:	BSF Swissphoto GmbH
Date of photography:	Sep. 23, 2010
Start and end of photography:	8:05 - 11:24 a.m.
Camera:	UltraCamX (Vexcel GmbH, today Microsoft)
Ground resolution:	10 cm
Longitudinal/transversal overlap:	80/60%
No. of flight strips:	17
Total number of images:	1793
Processing of frames:	Software UltraMap, by Microsoft
Altitude above ground/sea level:	Approx. 2090 m/approx. 2130 m
Geodetic date	ETRS89
Reference ellipsoid	GRS80
GPS reference station	SAPOS Station, Berlin-Wilmersdorf
GPS processing precision	Position and height theoretically 5-6 cm; realistically 10 cm

The position of the resulting images (DSM and TOM in RGB true colour) from the September 23, 2010 aerial photography operation over the Berlin inner-city area is shown in Figure 3.

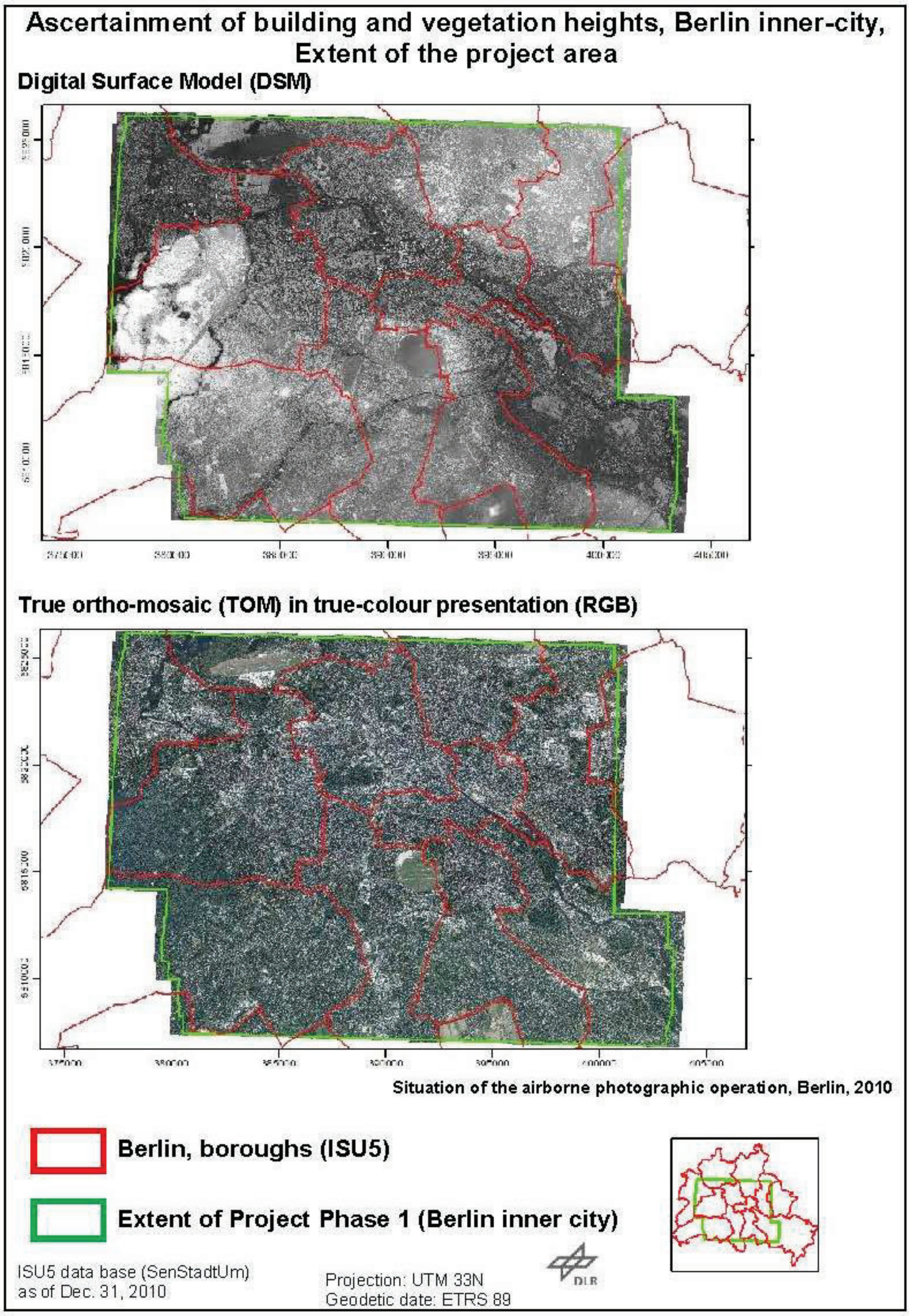


Figure 3: Berlin inner-city area: Location and extent of the area of the airborne photographic operation of September 23, 2010

2.1.3. Data processing (DSM/TOM creation)

The single images were processed to true ortho-mosaics (TOM), and the DSM was created, by the DLR, Department for Sensor Concepts and Applications, at the Institute of Optical Sensor Systems at Adlershof in Berlin, as is described in more detail below.

The present DSM and the TOM generated from it were processed on the bases of stereo photography. With a matrix camera, the properties of the external orientation changes from one image to the next (Kraus, 2004: pp. 201ff). The processing of the orientation data was carried out by the company BASF SwissPhoto GmbH. For this purpose, the image orientation must be known, i.e., all parameters necessary to create a reference between the area being photographed and the aerial image taken must be present. For this purpose, the internal and external orientation data are important (Heipke, 2003: pp. 60ff). After the evaluation of the Inertial Navigation System (INS) and the differential Global Positioning System (GPS) data, these have a very good location precision. The flight path of the aircraft carrying the sensors is continually monitored via GPS, as is the position of the camera and its movements during the flight, with the aid of the INS. SAPOS data were used for the differential processing of the navigation resolution.

If all orientation parameters are present, the single broad overlapping images are placed in relation to one another by means of so-called connection points, forming an image strip, and are then translated into the required coordinate system. This process of so-called aerial triangulation (AT) permits passing over large areas in which no terrestrially measured fixed points or pass points are available. This permits a site precision of several centimetres per kilometre to be attained (Kraus, 2004: pp. 273ff).

Thereafter, the existing combined image is subjected to an image attribution procedure, called semi-global matching (SGM), which was developed at the DLR (Hirschmüller, 2005), and results in a highly precise DSM. It is a pixel-based algorithm which carries out the image attribution by means of a global cost function (cf. Hirschmüller, 2005: p. 811), which guarantees very good edge sharpness, and the depiction of very fine details in the DSM. The image attribution is carried out in the panchromatic channel, in each case starting from one image, together with the two previous ones and the two next ones, in the direction of flight, as well as the adjacent ones in the two neighbouring flight lines. One image element is thus paired with six corresponding overlapping image elements. Thereafter, homologous rays are extended through that projection centre of each aerial image, causing them to intersect at a common object point. As a result, the object point is determined by the coordinates x, y and z. In order to create the DSM, the calculated height information (z-value) of each pixel is stored in a geo-referenced raster as the grey value. Since the SGM is used as a pixel-by-pixel image attribution procedure, the DSM resolution corresponds to the average ground resolution of the image, so the edges and fine structures are also depicted in the DSM. These simultaneous databases permit the creation of true ortho-mosaics (TOM) (Hirschmüller, 2008).

The point of departure for the airborne photography operation is a combined aerial image with a central perspective depiction. This projection causes a geometric distortion of objects toward the outside, so that no uniform scale exists in the image, and no realistic distances can be obtained. Since the image data can be used in a GIS, a differential rectification with the aid of a DSM must be carried out. This procedure results in a true ortho-photo, which HEIPKE (2003: p. 62) has defined as follows: "*True orthos are ortho-photos in which differential corrections uses a strict DSM and not, as is traditionally the case, a DTM, and in which the blind spaces occurring are filled by information from neighbouring images*." True ortho-image generation is designed for pixel-precise, geometrically exact locations. Each pixel corresponds to a projection on the DSM from above with geometrical precision. There is no longer any tilt which might, e.g., reveal building façades.

True ortho-image generation and subsequent mosaic generation is carried out image-by-image, i.e., single images are rectified in a process in which the inner image areas with the minimum angle of sight is used. Visually shaded areas in the central areas of each image are interpolated. As a result, a mosaic is obtained consisting of internally consistent, sharp single images in which the position of the raised objects is depicted correctly and with precise edges. Only in the interpolated visually shaded areas is it possible for distortions of height to occur.

In Figure 4, the advantages of a TOM become obvious. While in a digital ortho-photo (DOP), the raised structures are shown tilted, and areas of the street are covered (see e.g. the DB Tower), the TOM provides the correct object situation and sharp edges, so that the measurement of distances, edges and surfaces is provided. The difference occurs because the DOP is only rectified by using a DTM which only contains terrain heights. The existence of the DSM and the TOM is therefore the basic precondition for an exact analysis in densely built-up urban areas, and increases the reliability of the statements.

The latest development in the area of image attribution has succeeded in improving the quality of DSMs to the point where a largely correct depiction of extreme heights and improved image attribution in visually shaded areas is possible (HIRSCHMÜLLER, 2011).

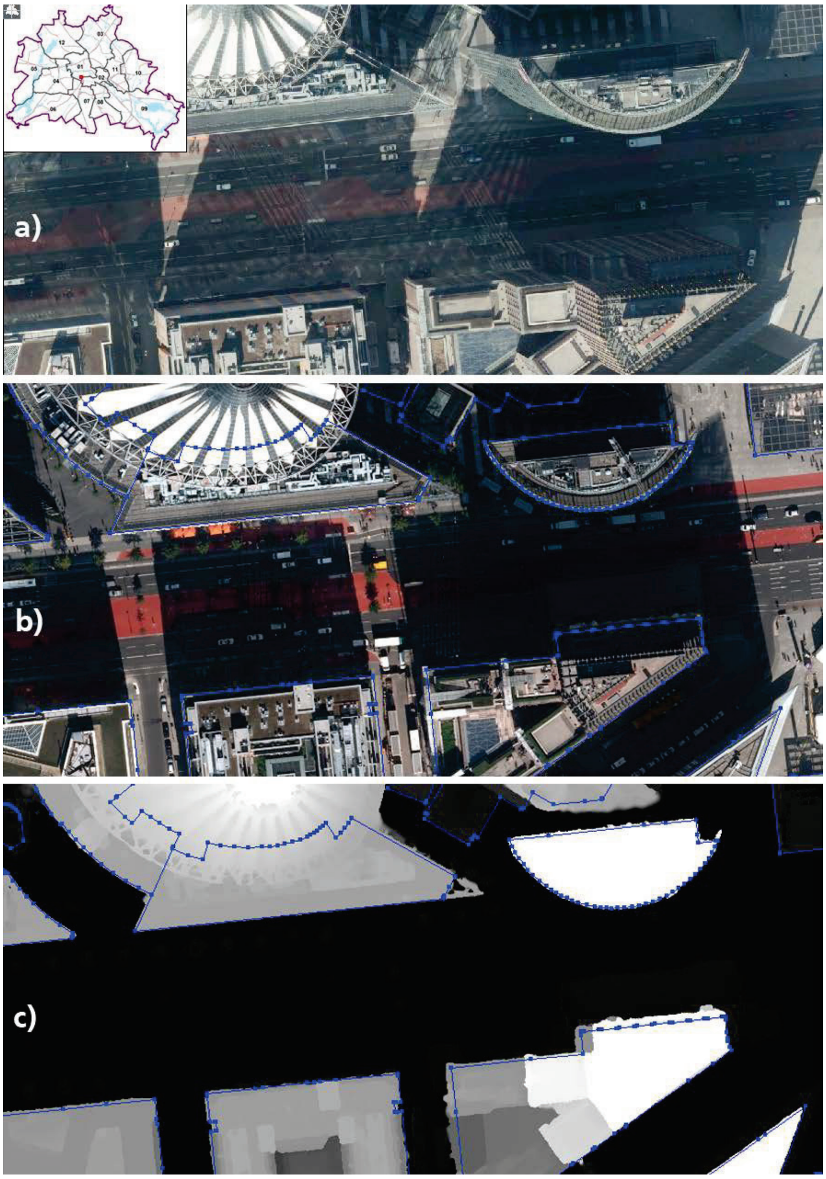


Figure 4: Comparison of DOP and TOM; a) DOP 20RGB, 2011 (Source: SenStadtUm, 2013a), b) TOM RGB overlaid with ALK building contours, c) NDSM overlaid with ALK building contours.

2.1.4. Data projects and additional layers

The processing of the UCX (2010) data at the DLR's Department for Sensor Concepts and Applications yielded a very high resolution and location-precise dataset consisting of a DSM and a TOM. These data and an additional layer derived from them are used by the project as input data for the automated ascertainment of structural and vegetation objects, including their height attributes. All data were transformed into a uniform projection (UTM 33N, ETRS89). In the following, the features of all data products used will be described and illustrated.

The DOM largely represents height levels of the earth's surface coded in grey stages, including all objects, such as buildings, roads, vegetation growth, etc., located on it. This means that the terrain height is added to the object types. The terrain heights in the project area range from 30 m above sea level in the Spree Valley to 120 m above sea level at Devil’s Hill in the borough of Wilmersdorf-Charlottenburg. Since the height difference is relatively great in the entire area, and also locally, no constant terrain height can be assumed in order to ascertain object types from the DSM. For that purpose, a standardized digital surface model (NDSM), with the terrain standardized to zero, will have to be assumed.

The NDSM is hence created by the subtraction of the digital terrain model (DTM) from the DSM:

NDSM = DSM - DTM

The NDSM derived from the DSM is therefore, in addition to the TOM, the indispensable basis for automated object extraction in urban areas. For the photography with the high resolution stereo camera (HRSC) series, the DLR developed a semiautomatic procedure for generating DTMs and calculating NDSMs (Mayer, 2000). This method was adapted to the current database and applied. In this process, the fact that the raised objects contrast with their surroundings in the DSM through greater height values and abrupt leaps at their edges was utilized. By means of a matrix which scans the entire image, raised pixels in the DSM are found and at the same time defined by a height threshold value as being definitively either ground pixels or non-ground pixels. For this search, several search matrices of differing sizes can be combined in order to handle the varying object sizes. A full coverage DTM can thus be interpolated from the identified ground pixels, provided enough of them are available. The resulting DTM is then subtracted from the DSM, which then yields the final object type model, an NDSM, in which the ground is standardized at zero, and from which precise absolute object types can be obtained.

Figure 5 schematically shows the calculation of an NDSM, using the example of a segment of Berlin – the area from Devil’s Hill in the Grunewald Forest in the west of the city to the Friedrichshain neighbourhood in the east. Comparing the image examples of the DSM and the NDSM, it is evident that objects located at a terrain height in the DSM show considerably higher height values – very bright areas – than they do in reality, and as shown in the NDSM. In the NDSM, it can be seen that the object types are standardized to the terrain, and that therefore the absolute types can be obtained; see e.g. Devil’s Hill in the red circle, or the raised terrain in the Prenzlauer Berg neighbourhood, above right.

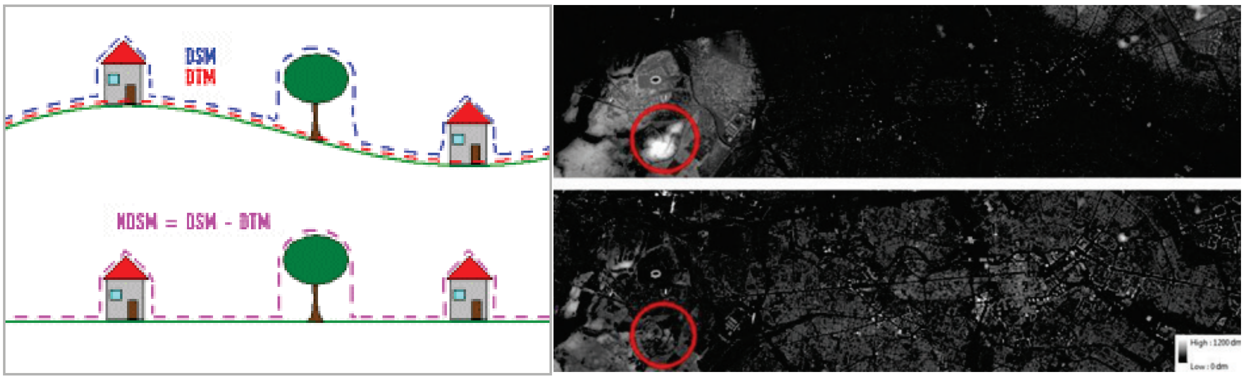


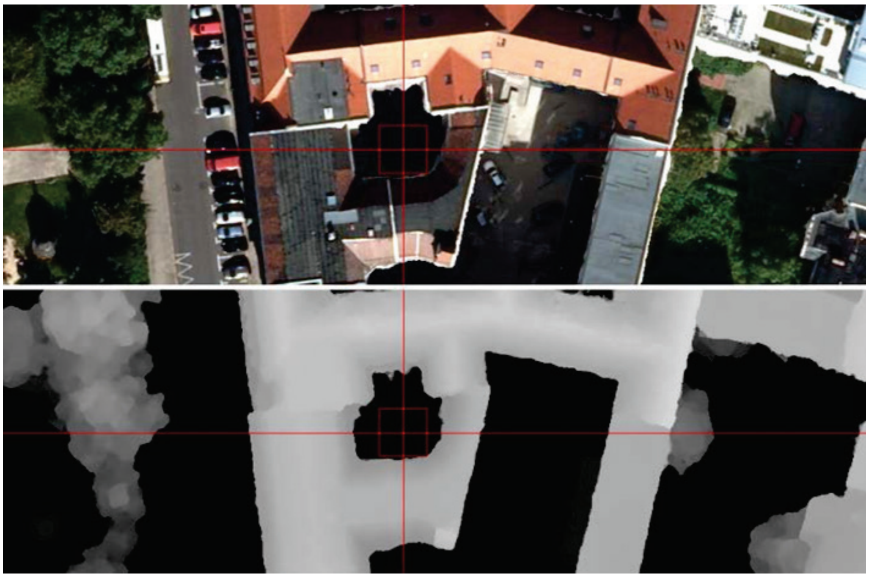
Fig 5: NDSM – Schematic representation of the calculation (left); Image example: DSM (right top) and the calculated NDSM (right bottom), (Source: In-house, from Mayer, 2004)

The calculated NDSM has the geometric resolution (x/y) of 15 cm, and a height resolution (z) of 10 cm. In order to reduce the enormous quantity of data in the project area, it is, like other raster layers, reduced to a resolution of 30 cm in x/y. The height resolution then remains unchanged.

The NDSM is characterized by great precision of the edges. Figure 6 clearly shows that the building edges and the roof and vegetation structures have been reproduced very well. This is thanks to the image attribution procedure, the SGM (cf. Chapter 2.1.3). On this basis, very precise object classifications and the precise ascertainment of object types are possible. Since the NDSM is incorporated into the segmentation process, its quality has a positive and stabilizing effect on the form of the segments, particularly when breaking the object down into their height stages (cf. Chapter 4.5.4).

In spite of the great degree of precision and quality of the NDSM, it does have some weaknesses which can affect the object extraction results to a slight degree.

As described above, a mask for ground and non-ground pixels is generated during the course of the NDSM calculation. For that purpose, a height threshold value is defined, so that no very low terrain heights are declared as raised objects (Figure 7).



X profile above a building complex in central Berlin

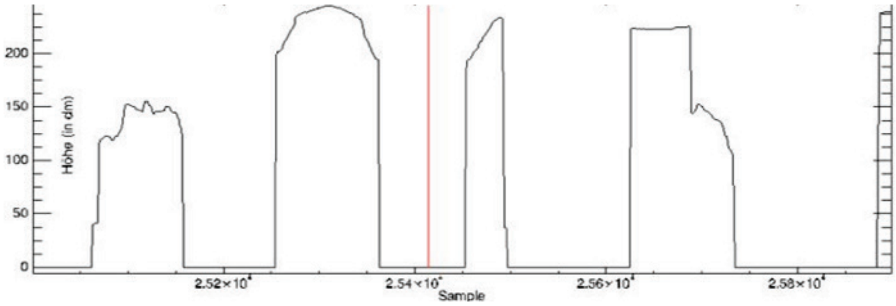


*Fig 6: A horizontal height profile of the NDSM (height in dm)
various roof shapes and vegetation structures can be recognized*

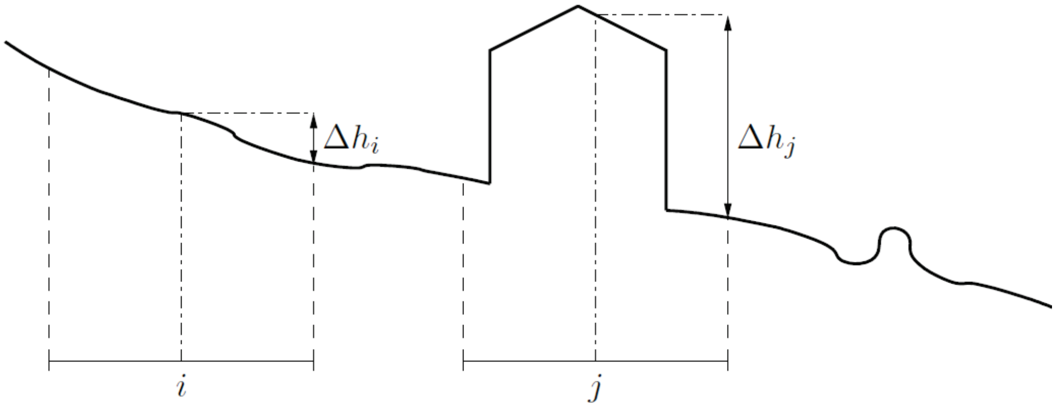


Figure 7: Schematic presentation of the procedure for the detection of raised points for the basic height interpolation an of a height profile (Source: MAYER, 2004: p. 49)

If the spatial value set is too high, small and low objects may be mistakenly attributed to ground pixels. The described procedure on the one hand permits terrain disturbances to be removed, but on the other hand also causes such small and flat objects as low shrubs, garden cottages or garages (Figure 8) to disappear. At the same time however, such small disturbing objects as parked cars are eliminated, and heights are reduced to the essential.

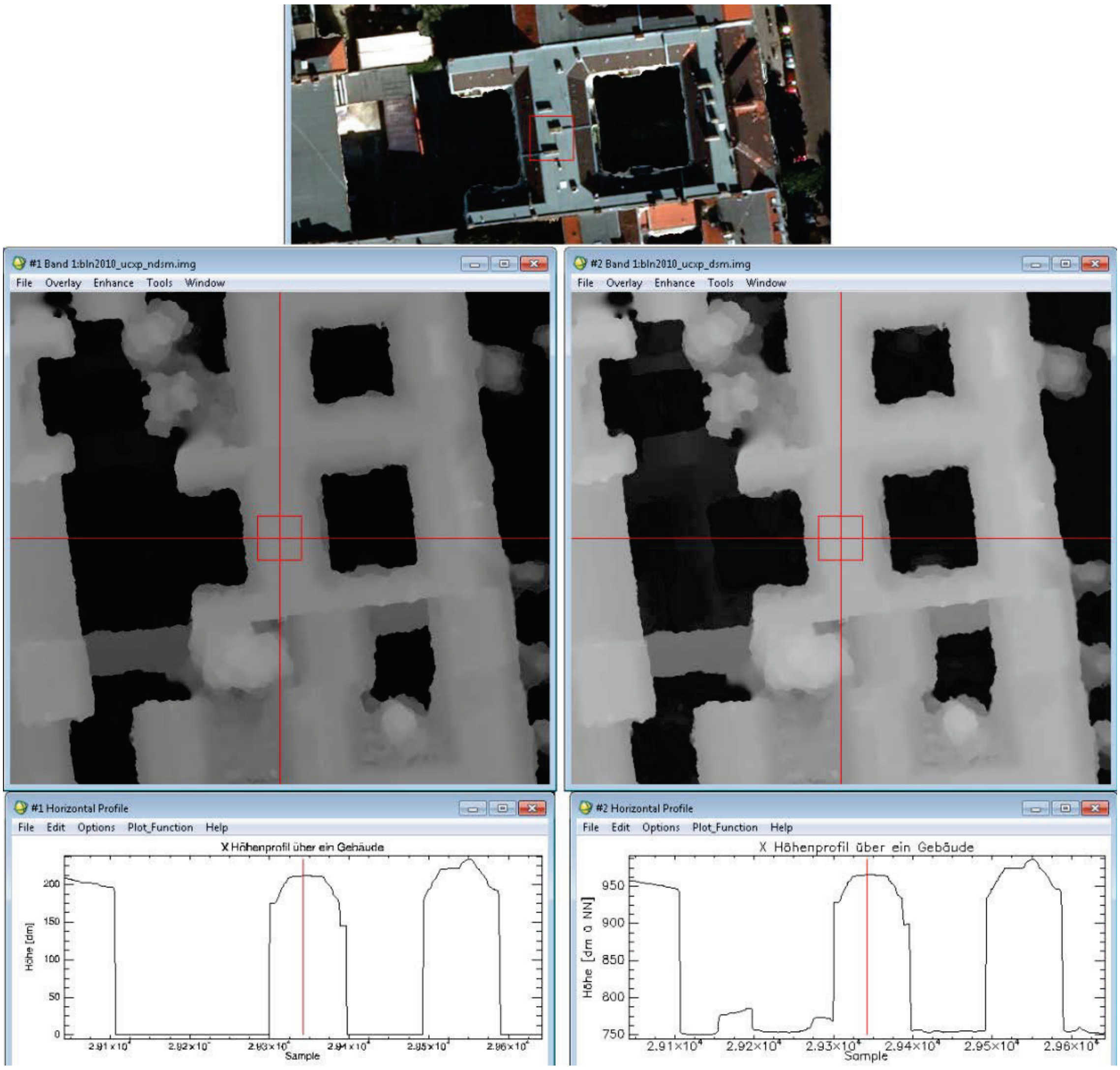


Figure 8: Comparison between NDSM and DSM height profiles (right); the threshold value formation causes small and low objects to disappear in the NDSM (here, garages in the internal courtyard).

Other weaknesses of the NDSM include the interpolated areas. Due to the early hour of the airborne photography operation (cf. Flight Parameters, Chapter 2.1.2), the image data obtained contained many shaded areas. As described in Chapter 2.1.3, this has an effect on the quality of the DSM generated, since if there are too few corresponding points, as is the case with shading, homogenous areas and visual shadows, the heights are interpolated, which can cause distorted object types. In Figure 9, it can be seen that the building edge is not shown sharply, but rather blends into the adjacent tree. This error occurs increasingly with very high structures, since such areas are the ones where the most visual shadows are created.

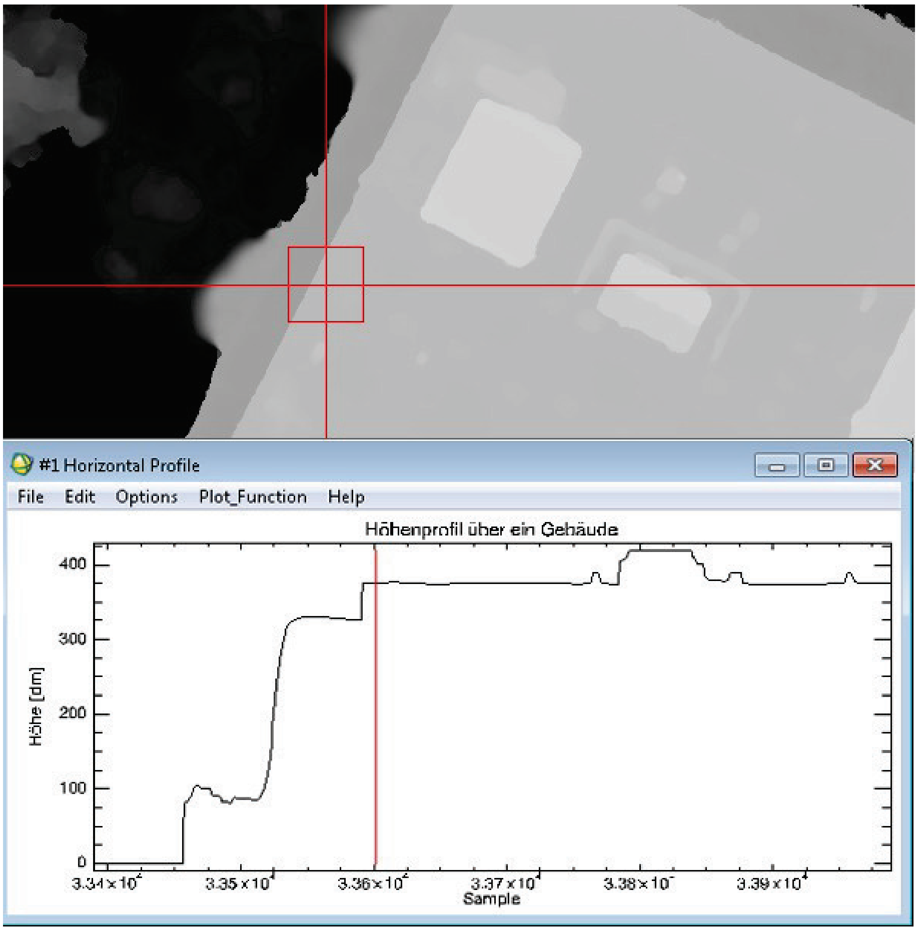


Figure 9: NDSM interpolation error: Fuzzy building edges in visual shadow

TOM

The available TOM data set consists of four channels: red, green, blue (RGB true colours), and near-infrared (NIR), in a geometric resolution in x/y 15 cm. Like with the NDSM, the spectral data was reduced to a resolution of 30 cm. This is primarily done in order to reduce the data quantity, but also for the sake of the spectral and geometric heterogeneity of the object being ascertained (TROSSET et al., 2009).

As stated above, the spectral data at a relatively high degree of shading, due to the late-season of the early hour of the flight operation (cf. Flight Parameters, Chapter 2.1.2). Thanks to the high radiometric resolution of more than 12 bits and the simultaneously generated DSM, it was nonetheless possible to correctly identify many objects in the shaded areas (Figure 10). Especially thanks to the NIR channel, where the vegetation has high spectral values, these objects can be reliably ascertained (Figure 11).

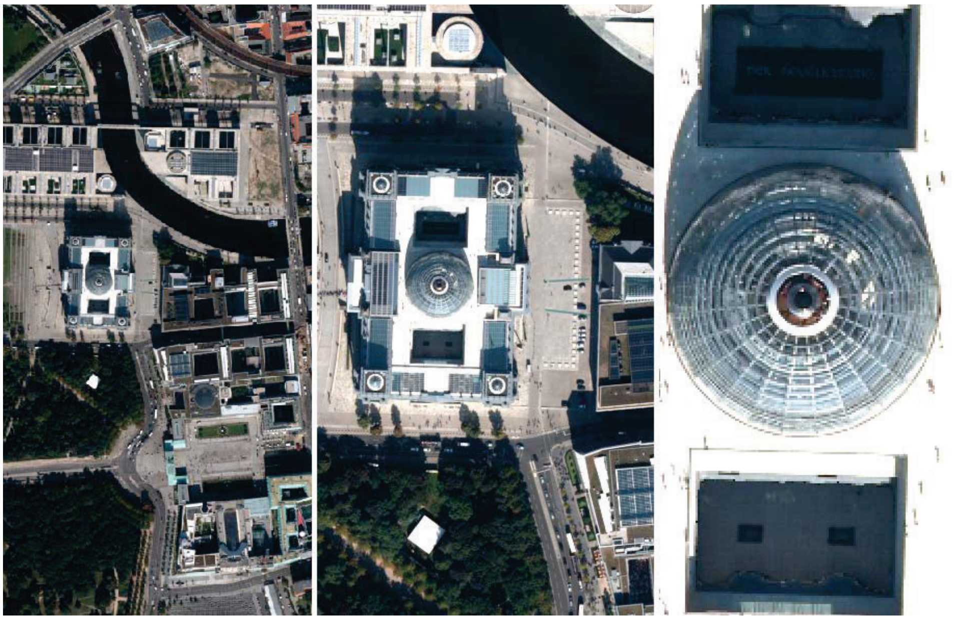


Figure 10: TOM data in true-colour presentation, in three different stages of detail

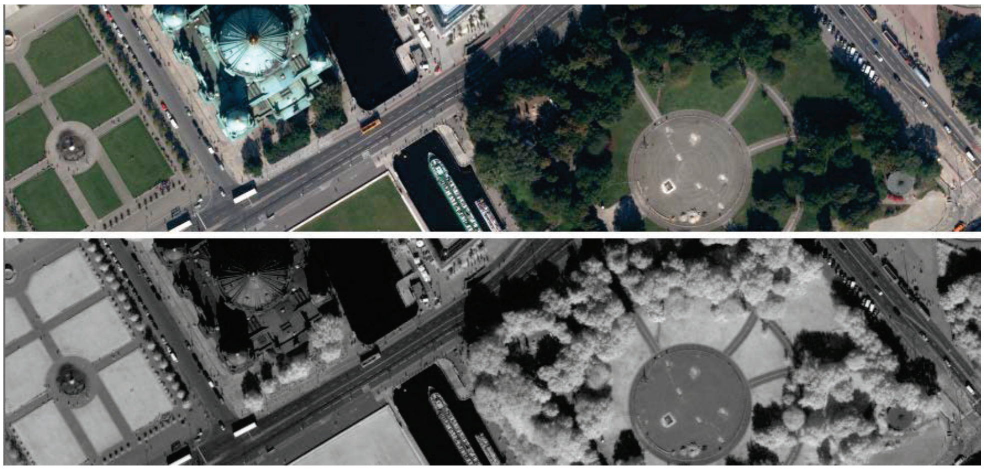


Figure 11: TOM data: Near-infrared channel (below); vegetation shows high spectral values (light areas)

Count Mask

During the SGM processes (cf. Chapter 2.1.3), the *Count* mask is also generated. The number of the corresponding points for each single image element is stored in this file during the image attribution procedure. For the non-visible areas, for example, a value of zero is set. This permits the recognition of *no-data* areas which are interpolated in the DSM. In Figure 12, it can be seen that in the visual shadow areas, e.g. behind high buildings (cf. a), very few corresponding points are available – the black areas in the *Count* mask (cf. c). There, no correct height information can be generated (cf. b); the height is interpolated from the neighbouring pixels. This information can be used during the classification process to correct the height stages (cf. d).

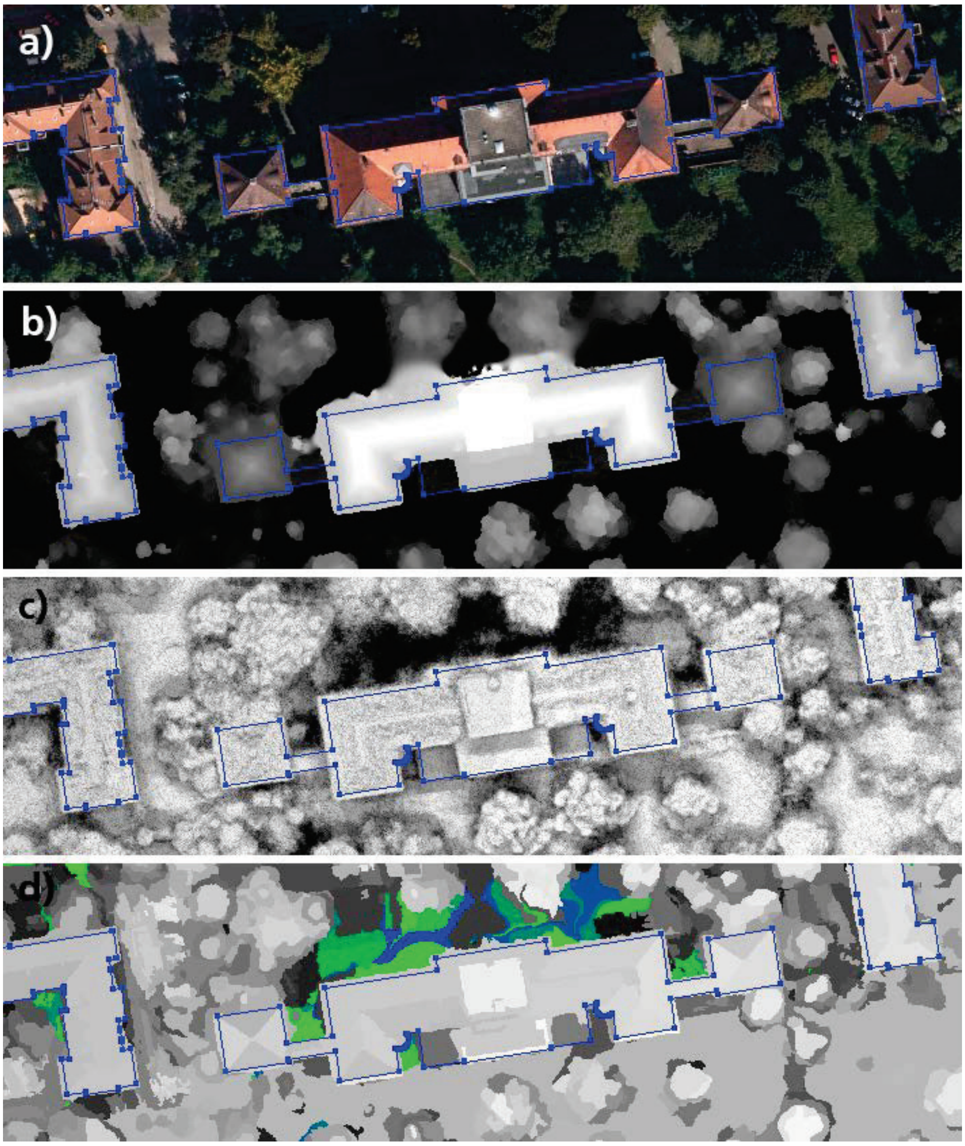


Figure 12: Visual shadows behind a high house: a) TOM RGB; b) NDSM with interpolation errors; c) Count mask; d) Average count value per segment; low values are colour-coded from zero (dark blue) 24 (bright green); all layers have been superimposed from the ALK (blue lines)

Slope and aspect layers

The slope and aspect layers were calculated in ESRI ArcGIS based on the available NDSM.

The aspect determines the slope direction of a pixel compared to the neighbouring pixels in a pixel matrix. The value of each pixel in the output raster is provided by the point of the compass toward which the surface area is oriented at that position. The aspect is measured clockwise in degrees, from 0° (due north) through 360° (again, due north). Flat surfaces have no slope direction. They are assigned a value of -1 (cf. ESRI Resources, 2013a).

The slope expresses a change in height of a pixel compared to its neighbouring pixel in the pixel matrix. And thus describes the angle between that height and a horizontal plane, in degrees (cf. ESRI Resources, 2013b).

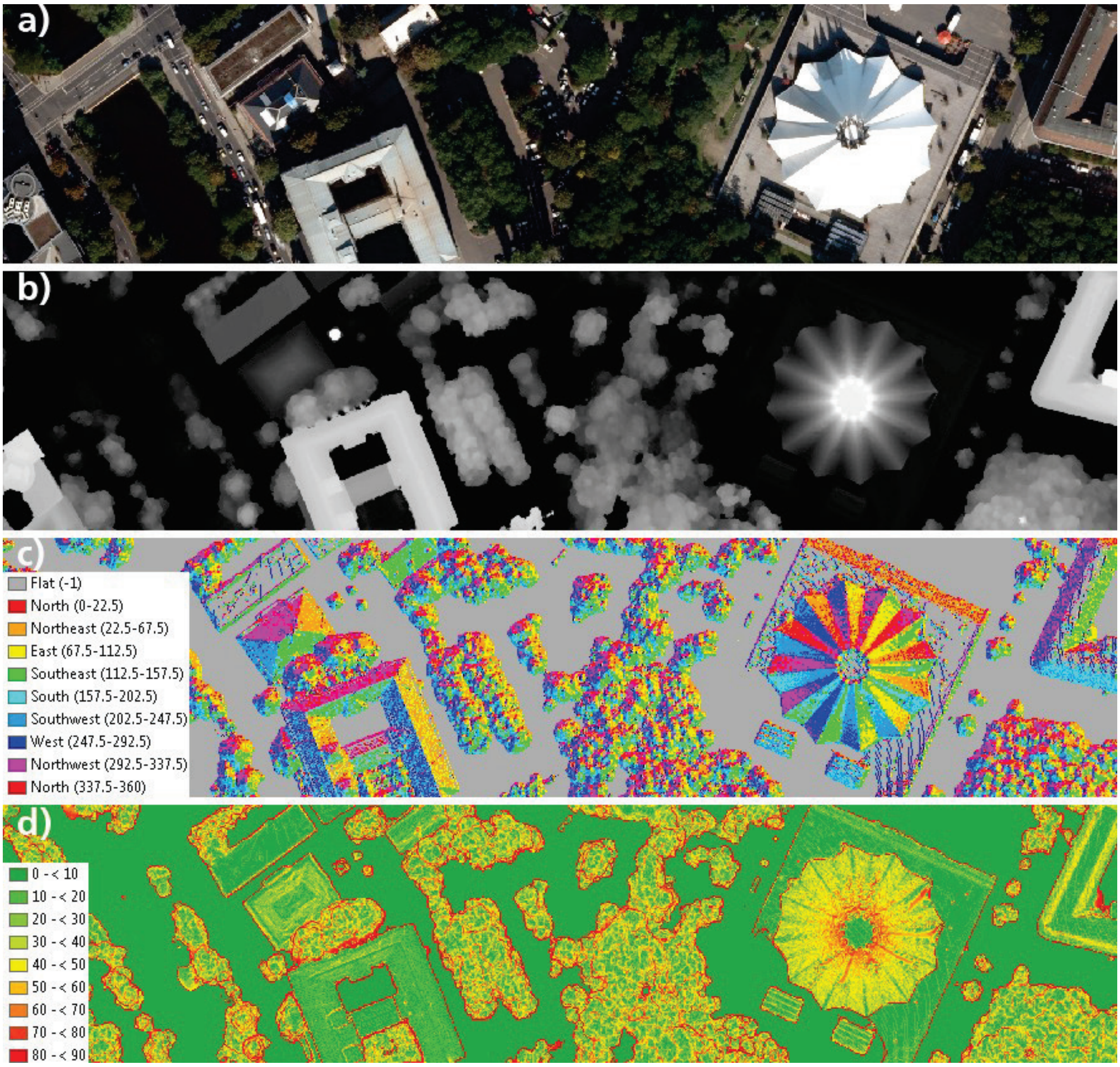


Figure 13: The aspect (c) and slope (d) layers

Both layers are additionally smoothed with a median filter, to eliminate any outliers. The aspect layer is used to separate roofs into geometrical and height structures, while the slope layer is used for refining the structure classification, particularly for identifying greened roofs.

2.2. Basic vector data

The vector data have for all of Berlin been made available by SenStadtUm, and encompass the following layers:

- The Automated Map of Properties (ALK), (as of June 2012)
    - the *Building* layer, consisting of buildings planned or under construction
    - the *Street tree* layer, as of October 2009 (street trees are no longer recorded centrally in the ALK database)
    - the *Topographic* layer, with basic and supplementary topographic information

- The Urban and Environmental Information System, 1:5000 (ISU5), (as of December 31, 2010):
    - the *State and Borough* Layer
    - the *ProgSpace* Layer
    - the *Block* Layer (with blocks and blocks segments).

The vector data were provided in the state coordinate system Soldner-ALK Berlin EPSG 3068, and transformed into the UTM ETRS89 coordinate system.

According to SENSTADTUM (2013c), the entire database of the Berlin ALK contains 2.2 million objects. In the Berlin inner-city project area, there are 270,000 buildings and 263,000 street tree objects in the *Building* and *Topographic* levels. The ALK has been provided with technical data, so that the objects contain important attributes, such as distinct item codes (OS), building or street tree codes, and information on building use. Moreover, the buildings include information on the number of existing storeys. The *ALK* layer is used for the classification of buildings (cf. Chapter 4.5).

The *Street tree* layer moreover contains attributes on numbers, species and positions of trees (x/y coordinates), as well as information on the street names and the house addresses where the trees are located. In the *Street tree* layer, only the trees on public roadway land, but not those on private property (gardens, rear courtyards), or in public parks, are listed. This layer is used only for correlation with the technical data, but not for the classification of tree objects.

The existing ISU5 block map provides the reference geometry for the ascertainment of the objects to be determined, and their heights. The Berlin inner-city project area contains some 14,000 blocks and blocks segments. The extracted objects are correlated with the block keys by means of their distinct idem codes, so that each single object is identified, not only by its precise location, and also by its attribution to an object type, and to a block and borough number. The ISU5 is moreover used to subdivide the entire dataset into smaller tiles which are more manageable in terms of computer time. As described, this map provides the reference geometry for the building and vegetation objects ascertained during geo-database generation. Figure 14 shows the existing ISU5 and ALK data overlaid with TOM.

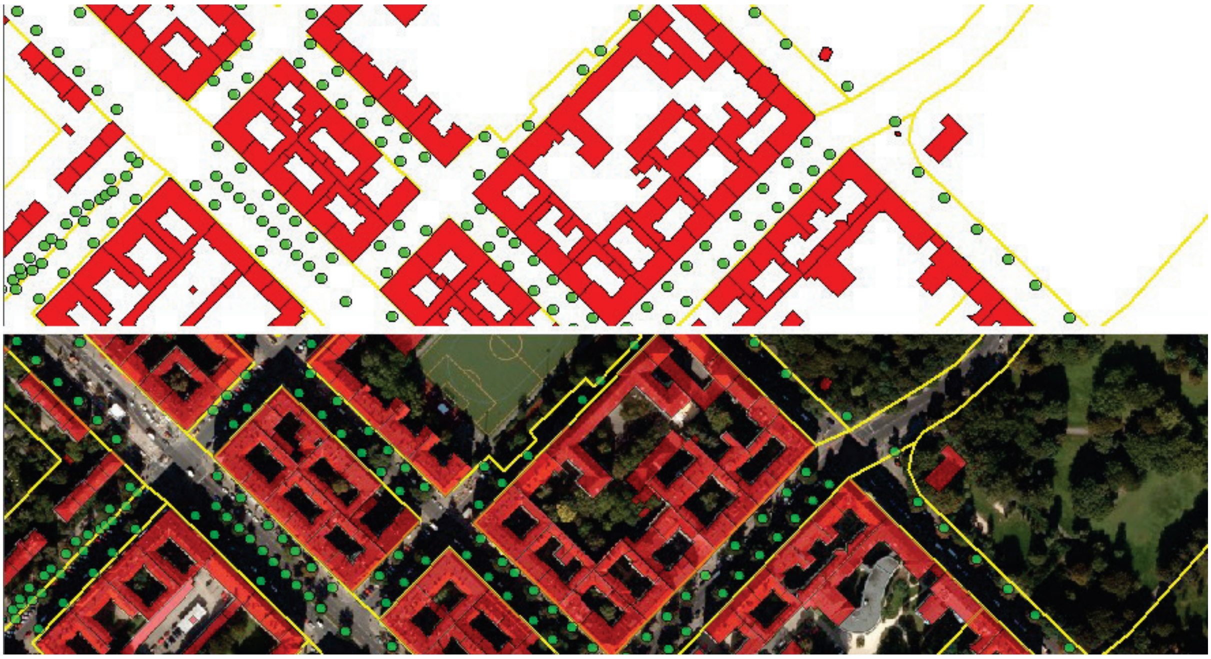


Figure 14: Excerpt from the ISU5 and ALK data: ISU5 block map (yellow lines), ALK buildings (red polygons), and ALK street trees (green dots)

3. Methodology

With the increasing availability of very high spatial resolution (VHSR) data on the geo-market, suitable methods for the automated access to information in this area are increasingly in demand. Particularly in densely built-up urban areas, characterized by a high degree of heterogeneity of the semantic classes and structures, this task is proving to be very complex. On the one hand, only very high resolution digital aerial photographic data enables the extraction of relevant information and its analysis in a satisfactory manner; on the other, precisely this high resolution, together with the spectral and spatial heterogeneity of urban areas, causes problems. Due to the large amounts of data, suitable methods for large-scale data processing need to be applied (creation of tiles in the compilation of the results). However, due to the varying features of the objects, robust class definitions and applicable extraction rules need to be developed.

3.1. Segmentation and object-based classification

Since the pixels to be classified are much smaller than the objects which they represent, pixel-based classification procedures have proven to be unsuitable. There are many investigations and indications in the literature which show that object based classification procedures for urban applications on the basis of the HSR data are more suitable (Blaschke, 2000, Blaschke & Strobl, 2001, Myint et al., 2011 and Sebari & He, 2013). In object based analysis, single objects are analysed in their contexts. Not only spectral features, but also object shapes, textures and especially neighbourhood relationships – all of them information which cannot be derived from single pixels – are taken into account. In this manner, the object based procedure attempts to model human perception, in that it is not the single image elements, but rather segments consisting of a number of pixels, which form the basis for classification (BLASCHKE, 2000).

In the object based procedure, two different approaches to automated image analysis, or object extraction, are distinguished: the knowledge-based/model-driven (top-down) approach, and the data-driven (bottom-up) approach (KINCHLA & WOLFE, 1979). The knowledge-based approaches assume a model defined on the basis of expert knowledge (usually a database). Only the objects suitable to the model are segmented. The data-driven procedure, the one used in this project, segments the entire image scene on the basis of certain statistical procedures and defined parameters. The resulting segments are pixel clusters which do not yet have any semantical significance. Only in the process of classification are the objects assigned to those classes the class descriptions of which they best fulfil.

With respect to segmentation, there is, according to SCHIEWE (2002), a similar distinction between bottom-up and top-down procedures. Bottom-up segmentation follows the "region-growing" principle, according to which the smallest initial cell segments grow together to form ever larger ones. One such procedure is multi-resolution segmentation, which is most frequently used for remote sensing data. Top-down segmentation, by contrast, follows the "region-splitting" principle, according to which one starts with the entire scene, and breaks it down into ever smaller segments.

In this project, the data driven object-extraction principle was used, and the top-down approach to segmentation was applied, starting with (here) the ALK, and subdividing it into ever smaller segments (cf. Chapter 4.4 – Segmentation Processes).

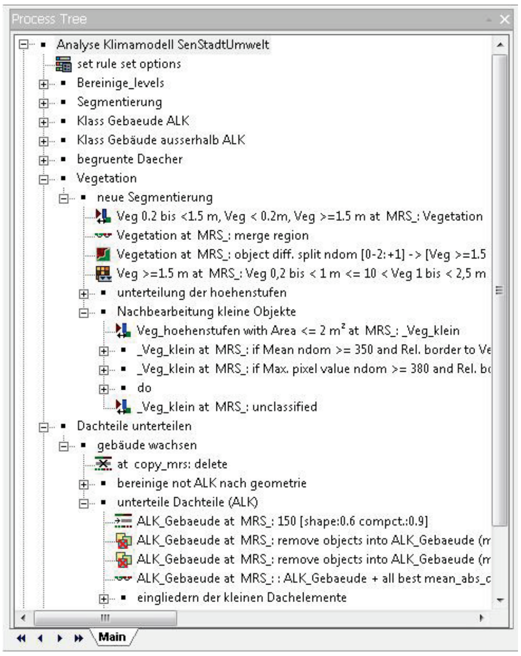
3.2. Software used

For the present project, a software package for object based image analysis (OBIA) called Trimble eCognition Suite, version 8.64.0 was used (cf. TRIMBLE, 2013). To optimize the exported attribute tables, and create the required geo-database, the geo-information system (GIS) Software ArcGIS by ESRI, version 10.0 was used (cf. ESRI, 2013).

The software package Trimble eCognition Suite consists of three linked programs, eCognition

Developer, eCognition Server and eCognition Architect. The actual development and optimization of the segmentation and classification rule base takes place in eCognition Developer. eCognition Server constitutes a processing environment in which the developed rule base is applied to the entire dataset through stack processing. The advantages of a server solution are very evident with these large quantities of data. The rule base is developed on a small representative image area, and only subsequently applied in the server software to all available tiles or segments. This is done in a batch process which only needs to be started once. A distribution of batch processes to several computers is also possible, but requires additional licenses. In eCognition Architect, only a user interface is created. In a simplified viewer, the end user can calibrate and apply the rule base generated in the developer. This solution is not used in the context of the present project.

The object based classification in eCognition is a multistage procedure. Each work steps is stored hierarchically in a so-called process tree (Figure 15), and can be transferred to other areas.



```
Analyse Klimamodell SenStadtUmwelt
  set rule set options
  Bereinige_levels
  Segmentierung
  Klass Gebaeude ALK
  Klass Gebäude ausserhalb ALK
  begruente Daecher
  Vegetation
    neue Segmentierung
      Veg 0.2 bis <1.5 m, Veg < 0.2m, Veg >=1.5 m at  MRS_: Vegetation
      Vegetation at  MRS_: merge region
      Vegetation at  MRS_: object diff. split ndom [0-2:+1] -> [Veg >=1.5
      Veg >=1.5 m at  MRS_: Veg 0,2 bis < 1 m <= 10 < Veg 1 bis < 2,5 m
      unterteilung der hoehenstufen
      Nachbearbeitung kleine Objekte
        Veg_hoehenstufen with Area <= 2 m² at  MRS_: _Veg_klein
        _Veg_klein at  MRS_: if Mean ndom >= 350 and Rel. border to Ve
        _Veg_klein at  MRS_: if Max. pixel value ndom >= 380 and Rel. b
        do
        _Veg_klein at  MRS_: unclassified
  Dachteile unterteilen
    gebäude wachsen
      at  copy_mrs: delete
      bereinige not ALK nach geometrie
      unterteile Dachteile (ALK)
        ALK_Gebaeude at  MRS_: 150 [shape:0.6 compct.:0.9]
        ALK_Gebaeude at  MRS_: remove objects into ALK_Gebaeude (m
        ALK_Gebaeude at  MRS_: remove objects into ALK_Gebaeude (m
        ALK_Gebaeude at  MRS_: : ALK_Gebaeude + all best mean_abs_c
        eingliedern der kleinen Dachelemente
```

Figure 15: Use of eCognition developer software:
Excerpt of a developed rule base stored in a process tree

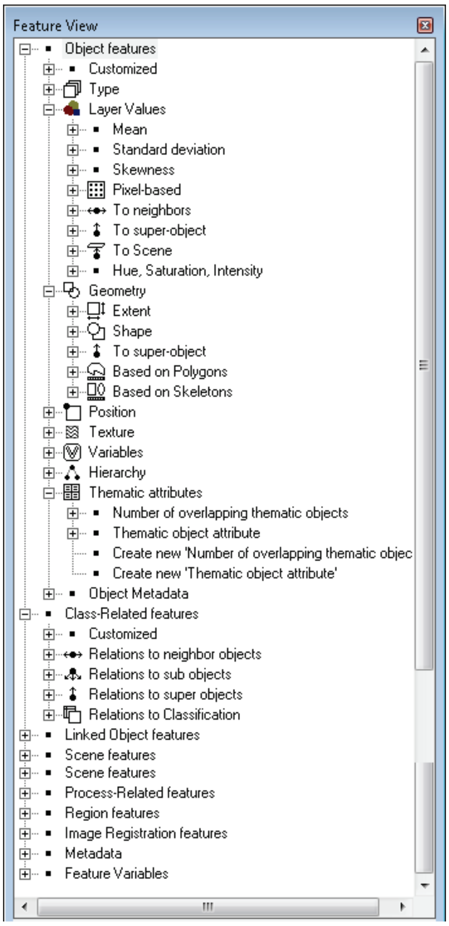
A further use of the developed process tree in other projects is provided, since the developed rule base can be edited, and the parameters adapted to single work steps. This is decisive and very useful with regard to different kinds of databases in the second project phase. In the following, the made work steps in Trimble eCognition Developer are summarized:

- Automated import of data to the project, or to the tiles in certain projects, in case of large data quantities (selection of layer to be used)
- Initiating segmentation (a number of segmentation procedures are available for this purpose); if necessary, segmentation can be applied to a number of segmentation levels with various scales
- Definition of the classes in class descriptions; these may be so-called associated or fuzzy functions, or “nearest-neighbour” classifiers based on training areas
- Classification of the entire dataset/the tiles, or the defined segments and masks
- Precision analyses, assessment of the existing results, and possible optimization of the rule base
- Export of results as thematic raster layers, or as vector data, including relevant attributes, e.g. statistics of the layer used, mean NDSM (average object height).

The segmentation and classification work steps are mostly carried out iteratively. Often, it makes sense to undertake further object-optimized segmentation steps after classification, or to create additional classes in the process of the analysis, which can be used as masks for further steps. In this sense, the course described above can be seen as schematic.

The classification in eCognition can be carried out using class descriptions with associated functions. This procedure permits the modelling of knowledge bases with the aid of fuzzy logic, which is a further development of binary logic, and softens up its hard values 0 and 1 (false or correct). Fuzzy logic permits the use of intermediate values, and thus attempts to formulate the non-precise human definition of objects mathematically (ZADEH, 1965: pp. 339ff). eCognition uses this by defining class descriptions with the aid of fuzzy functions. An object may be associated with several classes with different degrees of association (probabilities). Ultimately, it will be assigned to the class with the highest probability value. The use of hard threshold values for certain properties in class descriptions, and a combination of both, is also possible.

A major advantage of Trimble eCognition software is the possibility it provides for the simultaneous use of various data types in the project. At the same time, raster and vector data, can be used both in the segmentation and classification steps. The raster data can have various different geometrical and radiometric resolutions, and various extents. Moreover, they can be weighted differently for the segmentation step, or even be turned off. The use of a variety of data is decisive for the project.



Feature View

- Object features
  - Customized
  - Type
  - Layer Values
    - Mean
    - Standard deviation
    - Skewness
    - Pixel-based
    - To neighbors
    - To super-object
    - To Scene
    - Hue, Saturation, Intensity
  - Geometry
    - Extent
    - Shape
    - To super-object
    - Based on Polygons
    - Based on Skeletons
  - Position
  - Texture
  - Variables
  - Hierarchy
  - Thematic attributes
    - Number of overlapping thematic objects
    - Thematic object attribute
    - Create new 'Number of overlapping thematic objec
    - Create new 'Thematic object attribute'
  - Object Metadata
- Class-Related features
  - Customized
  - Relations to neighbor objects
  - Relations to sub objects
  - Relations to super objects
  - Relations to Classification
- Linked Object features
- Scene features
- Scene features
- Process-Related features
- Region features
- Image Registration features
- Metadata
- Feature Variables

Figure 16: The available features for class descriptions in eCognition, which are also the attributes for exporting.

The accompanying generation of object attributes, such as height statistics, is a further strength of the software, and is of key significance for geo-applications. At the same time, a large number of different technical data can be exported together with the extracted objects (Figure 16). These include statistics of the layers used in the projects (layer values), and the attributes of the thematic layers used (somatic attributes), shape attributes (geometry) and texture dimensions, statistics of neighbouring objects (class-related features), and position attributes. All of these features can be used for the class descriptions. Figure 16 gives an overview of the features available.

For the generation of the geo-database with the required attributes, a so-called model-builder, is used in ESRI ArcGIS for each extracted object. This tool serves to combined geo-processing steps in the process chains, which can then be implemented automatically in several datasets.

The entire process and the single work steps, from segmentation through classification, to the export of the results, will be explained in detail in Chapter 4.

4. Implementation of Object Extraction

4.1. Definition of classes

On the basis of the available digital aerial photographs and of the NDSM, and using the ALK building data, the object classes to be extracted are defined, after consultation with the contracting authority. Two major classes with stipulated: *Buildings* and *Vegetation*. In addition, subclasses were also defined – height stages for the vegetation, and semantical classes for the buildings, including *Garages, sheds, cottages,* and *Buildings planned or under construction.*

The ALK is continually updated – weekly. The airborne photography was carried out in the early autumn of 2010; the most current version of the ALK, with data as of June 2012, was available at the part of the start of the project. Since the ALK ascertainment state lags behind reality, and, moreover, not all structures are ALK relevant, the ALK building layer is different from the available aerial pictures of the stock of buildings. This on the one hand includes buildings not recorded in the ALK, such as roofed parking lots, temporary buildings or other roofed-over areas. In some cases, this also involves newly built buildings not ascertained as of June 2012. Since the goal of the project was to have as complete as possible a degree of ascertainment of all structures, regardless of their ALK status, it was important to discover them and classify them. For this purpose, three subclasses were defined: *Buildings (not in the ALK), Roofed inner courtyards,* and *Cottages or sheds (not in the ALK).*

Moreover, other raised objects such as *Bridge structures* and *Elevated railway areas of various types* were classified. In addition, *Greened roofs* were extracted at the wish of the contracting authority.

A total of nine vegetation height stages and over ten building classes were thus defined.

4.2. Subdivision of the data set

The existing dataset has a total area of approx. 445 sq km. This means that even for the spectral data (three channels), in a geometric resolution of 30 cm in x/y, a data quantity of approx. 55 GB is generated. If the IR channel, the NDSM and all additional layers are also considered, a data quantity of very great computing intensity is created, which, given the associated long calculation times, makes a subdivision of the data into smaller segments or calculation areas, necessary; these are known as “tiles”. Experience from previous studies has shown that the rectangular tile form is not particularly favourable for the ascertainment of urban objects, since these are then segmented by the tile boundaries. An ex-post recombination of anthropogenic objects with hard boundaries has proven to be difficult in that respect. Therefore, the concept for the subdivision of the scene has been developed, which takes into account the existing borough and borough segment areas existing in the ISU5 basic layout. This is based on the so-called *real-world oriented spaces* (LOR), which were created as a planning system in Berlin in 2006, and which, at the highest aggregate level, consists of 60 areas known as “prognosis spaces” or *ProgSpaces* (cf. SENSTADTUM, 2013d). These *ProgSpaces* serve as boundaries for the tiles to be processed in eCognition. Each has a distinct key, which contains the borough number. After the conclusion of processing, the single tiles are combined to form the 12 borough units of Berlin. The geo-database is also generated on the bases of the boroughs.

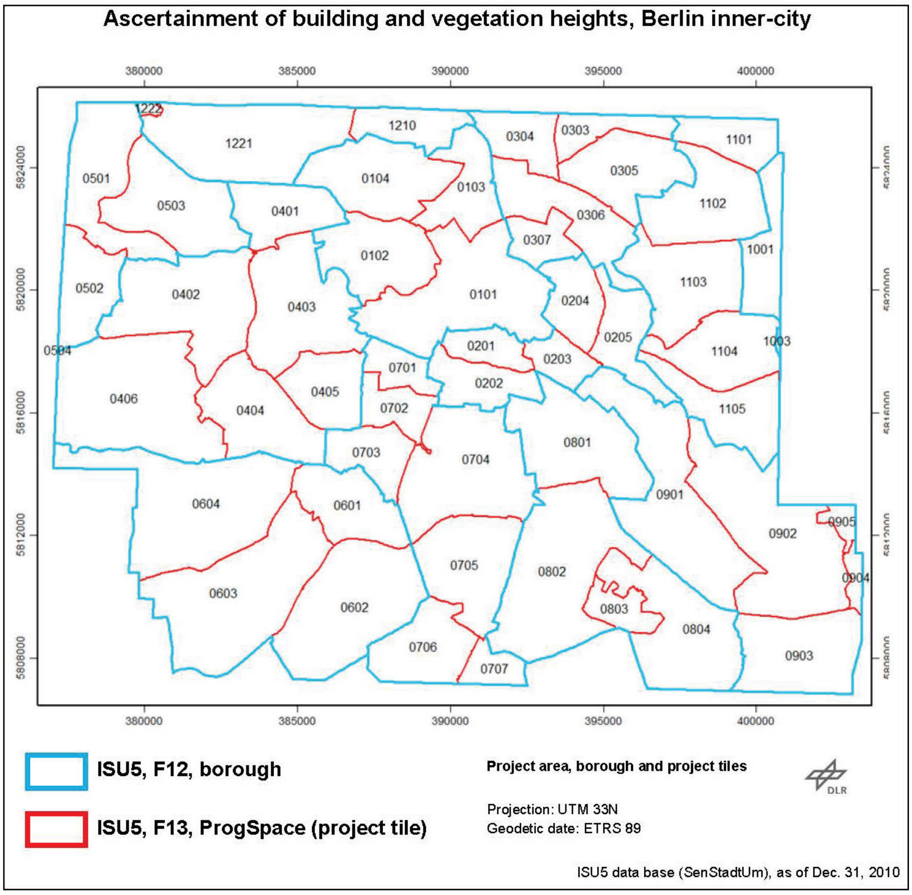


Fig. 17: Breakdown of the Berlin inner-city project area by borough (basis for the GDB), and in project tiles (basis for object extraction in eCognition

4.3. Procedure: Ascertainment of building and vegetation objects

In Figure 18, the entire object extraction procedure of the project is shown schematically. In the following sections, the algorithms used, and the class features will be described, and demonstrated by pictorial examples.

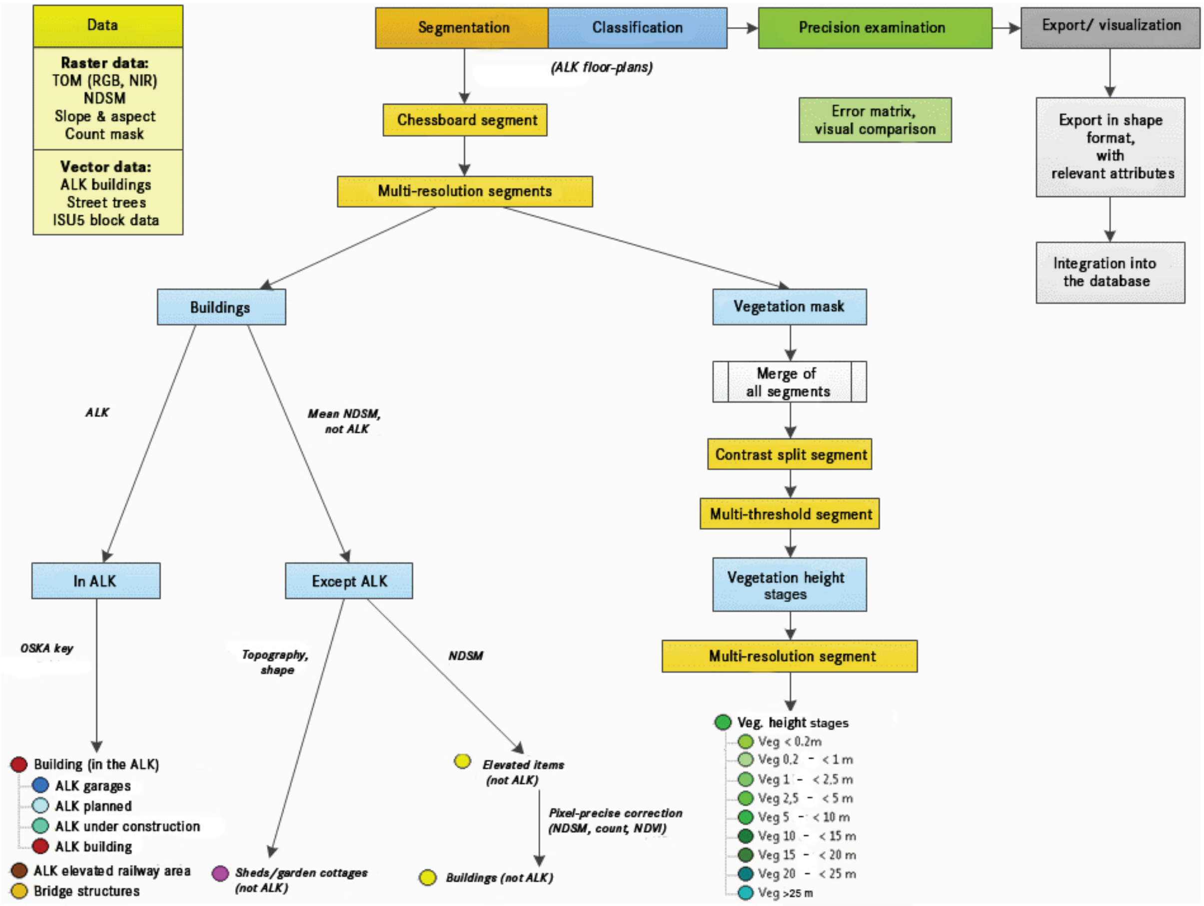


Fig. 18: Work procedure for the ascertainment of buildings and vegetation items in the Berlin urban area (DLR 2013)

4.4. Segmentation processes

The initializing segmentation of the entire image scene, or of the portion defined in the project, e.g. a tile, constitutes a basis for the classification of an object. Here, different pixels which fulfil certain homogeneity criteria, are merged into significant “homogenous” segments, also known as “objects”. The segmentation can also be seen as the generalization of the dataset upon which this is based, since the heterogeneous pixel information is merged into homogeneous objects. The quality of the segmentation is determinant for the following classification, since not only the spectral but also the shape features of the resulting segments can be used to create a class description. Hence: the more precisely the resulting segments reflect the real shapes of the objects, the easier and more precise the ensuing classification will be (Baatz & Schäpe, 2000).

Trimble eCognition provides a number of different segmentation algorithms which can be used in different ways, depending on their data foundation and the objects they are to classify. The segmentation can be carried out in a number of steps and various scales (sizes of the resulting objects). However, this is not necessary in all cases. Nonetheless, regardless of the segmentation method used, the vertical object hierarchy, given a number of segmentation levels, may not be violated. This ensures that the smaller objects are at the lower levels (Level I) and the larger ones above that (Level III) (Figure 19). Such a hierarchy ensures that one can query not only the features of neighbouring objects on the same level, but also those of all vertical levels.

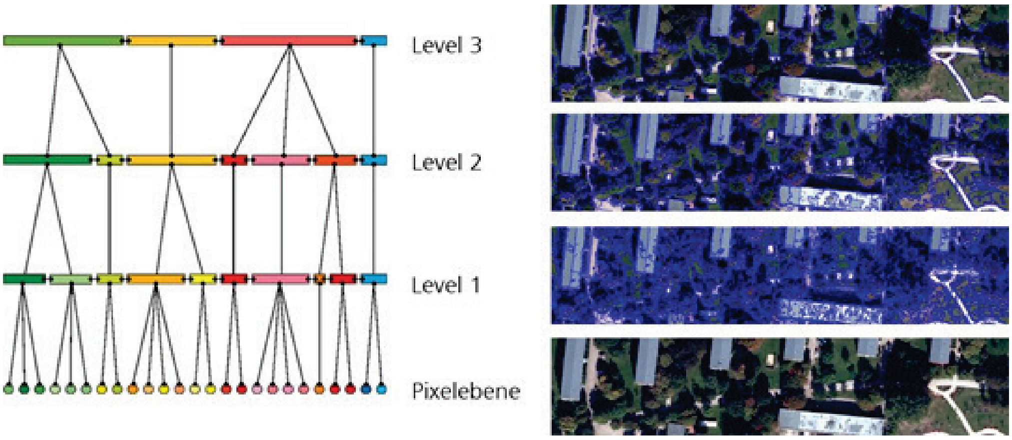


*Figure 19: Object hierarchy at several scale levels, in abstract depiction (left), and with pectoral examples (right) (Source: in-house, modified, from B*AATZ *et al., 2004)*

In any segmentation process, it is possible to take into account thematic layers (e.g. ALK polygons). Polygon boundaries are then drawn ex-post, and constitute object boundaries.

The vertical object hierarchy is used to segment the ALK building polygons at the top level. The object boundaries resulting are not violated in the following finer segmentation steps, i.e. the objects at the lower levels (building elements) are components of the upper objects (ALK buildings). This has the decisive advantage that the parts of buildings at the lower levels can query the thematic object features of the upper objects. As a result, each part of a building “knows” its own ALK idem code.

4.4.1. Chessboard segmentation

For the “post”-segmentation of the ALK, “chessboard segmentation” is used. This method merely subdivides the image scene into squares segments of equal size (Figure 20) and, due to its simplicity, is the most rapid segmentation algorithm in eCognition.

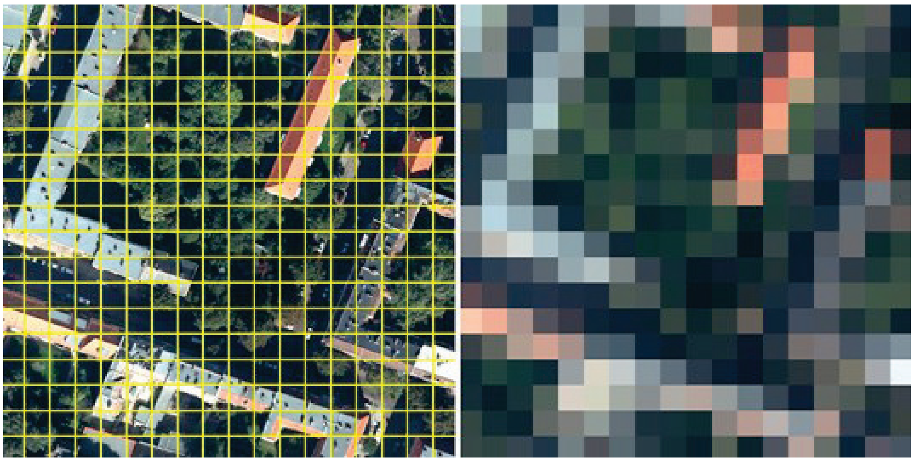


Figure 20: Chessboard segmentation with a chessboard size of 30 x 30 pixels

Since the ALK layer is switched on at this segmentation step, its polygon boundaries are also post-drawn. If they chessboard size becomes larger than the expanse of the scene selected, only the ALK object boundaries are segmented. As a result, there are then objects which fully represent the ALK (Figure 21). This segmentation level is thereafter known as the “ALK level”.

Figure 21: Results of chessboard segmentation using the ALK layers (yellow lines)

4.4.2. Multi-resolution segmentation

On the basis of the ALK level, a finer segmentation then follows. This is used to generate a vegetation mask, in order to be able to delineate vegetation from the anthropogenic objects. For this purpose, multi-resolution segmentation (MRS) is used. This segmentation method was developed by BAATZ & SCHÄPE (2000), and is one of the so-called region-merging procedures. In such procedures, neighbouring pixels which fulfil certain homogeneity criteria are merged into ever larger segments. This continues as long as a certain homogeneity threshold value is not exceeded. In this case, the ALK level directly above determines the maximum size of the resulting vegetation object. Distributed across the entire scene, all segments grow simultaneously, ensuring that they are of similar size, and hence comparable. The user can influence the size and form of the objects by assigning different weights to the incoming layers, and by establishing a value for the maximum allowable heterogeneity within the segments, the so-called scale parameter, and certain homogeneity criteria (Figure 22). For the homogeneity criteria – *colour & shape* and *smoothness & compactness* – the values are equalized at 1. If one partial value is set at 0.2, the other is automatically 0.8.

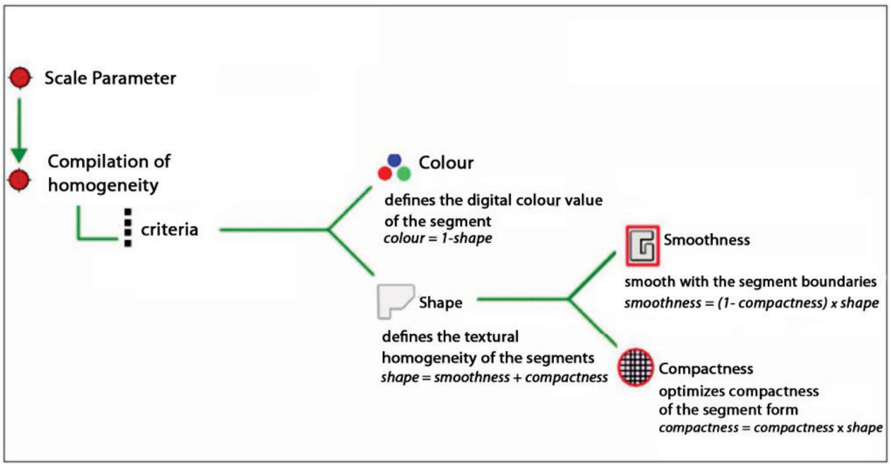


Figure 22: Compilation of the segmentation parameters for multi-resolution segmentation in eCognition (Source: Modified from DEFINIENS, 2007: p. 22)

The criterion *colour* takes into account the spectral values of all incoming layers. The establishment of this criterion then influences the structure of the object boundaries, since all colour shades are encompassed. It therefore results in strongly structured boundaries. The criterion *shape*, on the other hand, defines the homogeneity of shape. If this criterion is heavily weighted, coarser and/or simplified segments will be formed, in accordance with that heterogeneity of the data. If the segments are to have clear, non-fractal boundaries, a high value for *shape* should generally be selected (e.g. when segmenting the roofs of buildings), while a higher value could be selected for *colour* if spectral nuances are to be ascertained (e.g. when segmenting vegetation). The criterion *shape* is also defined by the two parameters *smoothness* and *compactness*, which either smooth the shapes of the segments, or increase their compactness.

Generally applicable setting parameters for the MRS are difficult to specify. Their determination varies depending on the data used, and particularly on the questions which the investigation is to answer. Usually, an iterative procedure is used in order to find optimal parameters for the objects desired.

In order to obtain optimum segmentation of the vegetation surfaces and anthropogenic objects, the following weighting of the layers was carried out:

Spectral channels:	highest weighting
NDSM:	half-weighting

- *Count*:	not used
- *Slope* and *aspect*	not used.

The NDSM layer was incorporated into the segmentation, since the height information is decisive for separating spectrally similar but differently high objects (e.g. adjacent shrubs and trees). The weighting was reduced to half, since the NDSM with 32-bit data format has a higher effect on the segment formation. By double reduction, it is set equal to the spectral channels.

The MRS parameter was set as follows:

- *Scale parameter:*	150
- *Shape / colour:*	0.6 / 0.4
- *Compactness / smoothness:*	0.5 / 0.5

The *scale parameter* selected generally generates small segments in order to deal with the various forms of vegetation. The resulting MRS segmentation (Figure 23) forms a solid foundation for the ensuing classification of the vegetation mask. It includes vegetation, shaded vegetation and, in the further course of the procedure, also greened roofs. In the course of object extraction, this segmentation result is optimized to the extracted objects with the aid of chessboard segmentation, MRS and other segmentation procedures.

Figure 23: Results of the initializing multi-resolution segmentation (MRS), based on new CX data

4.5. Classification and object extraction processes

4.5.1. ALK class: Buildings planned or under construction

The available raster and thematic data are two years apart. For this reason no correct height determination for the ALK class *Buildings planned or under construction* is possible. Since the aerial photographic data is two years old, differences between the two data sets, such as not yet initiated construction, buildings not yet finished, or the presence of very tall construction cranes, exist in many places, so that no correct height can be determined. Theoretically, remote sensing change detection might be possible, but not within the framework of the present project. Accordingly, the areas defined at the ALK as *Buildings planned or under construction* are classified even before the generation of the vegetation mask (Idem code Catalogue/OSKA, foil 087). This special classification excludes any further height-distorting effects of any neighbouring vegetation, and permits a supplementary correction of height attributes. The classification is thus carried out exclusively on the basis of the OSKA key, i.e. the class description refers to the "key" column in the attribute table of the ALK layer. In Figure 24, an example of a classification result of these objects is shown.

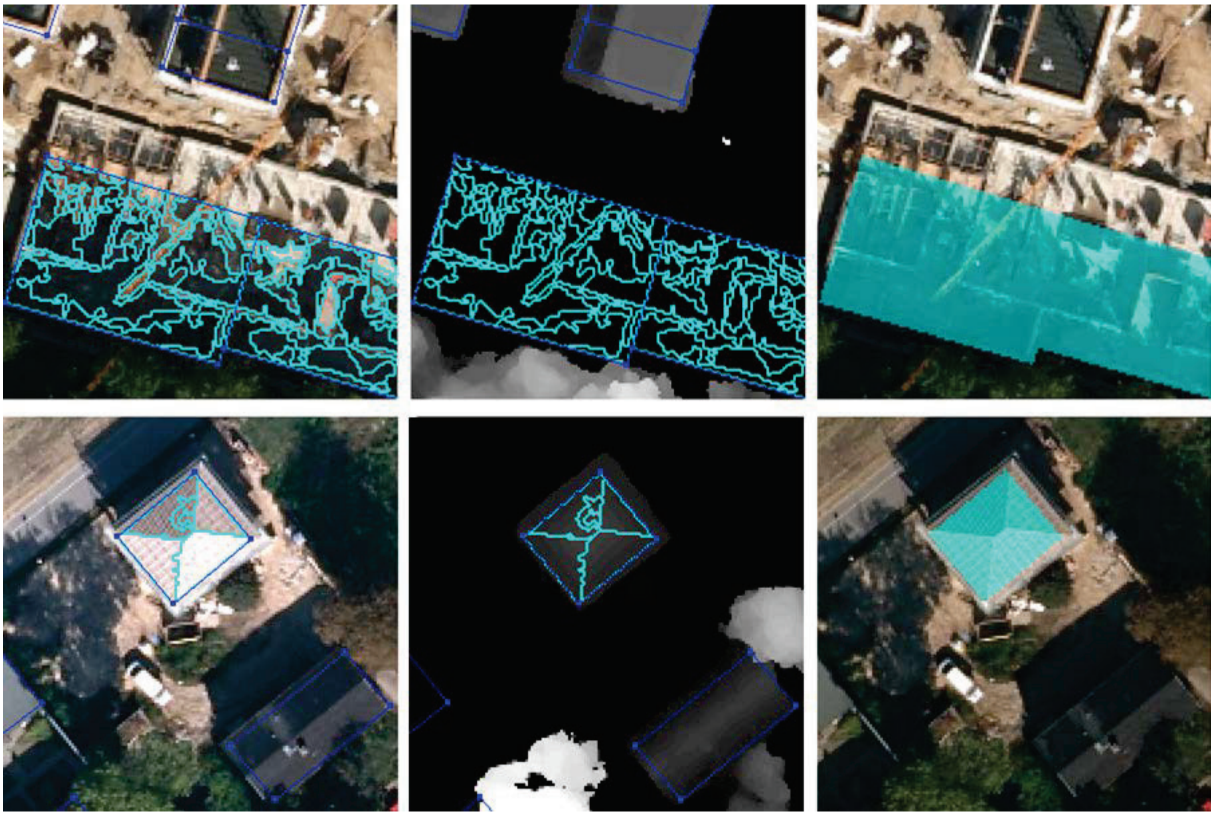
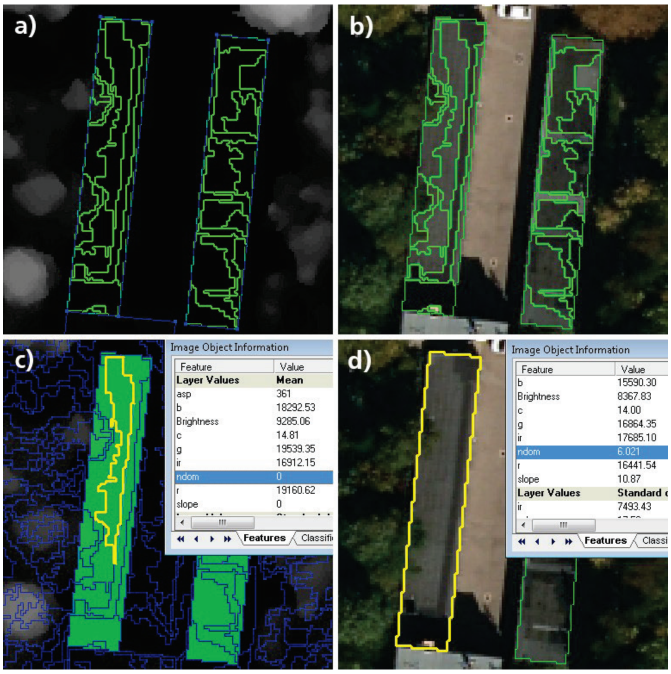


Figure 24: Two classification results of Buildings planned or under construction*, from the ALK processing situation, June 2012; left and centre: single classified sections, and right, merged object; Above, an example of construction operations in progress, and below, a completed building (2010).*

4.5.2. ALK class: Garages, sheds, cottages

As described in Chapter 2.1.4, the NDSM generated contains weaknesses in the areas of very low heights (<2.5 m). Due to the strictly established rules for the generation of DTMs, small and low objects, such as sheds, were not masked as raised objects in the DTM, so that they were set at zero after subtraction from the DSM. For this reason, low and small building type such as garages (ALK use types: Large garage – OS 011 2364; Double garage – OS 011 2365; Single garage – OS 011 2366), Sheds and cottages (ALK use types: Sheds – OSS 011 2723; Storage sheds – OS 011 1744; Garden or weekend cottages: – OSS 011 2862-2863) are also classified prior to the generation of the vegetation mask, using the corresponding use data from the ALK idem code catalogue. These objects are then each merged into a single object, and have a uniform average height value (mean NDSM).

Figure 25 elucidates the problem of the distance of small objects, such as garages, by way of example, in the process of NDSM generation. The garages which are part of the ALK (green segments) have a false height of zero in the NDSM. When the segments are merged into an object, the height of adjacent tree segments are additionally incorporated into the calculation of the object height, so that the latter is additionally falsified. In this case, an ex-post correction of object type is necessary. For all structural objects with an average height of less than 28 dm (which corresponds to one storey), the height attributes are calculated to the maximum number of storeys on the basis of information available in the ALK (maximum number of storeys x 2.8 m). This calculation step is carried out in ESRI ArcGIS.



Feature	Value
Layer Values	**Mean**
asp	361
b	18292.53
Brightness	9285.06
c	14.81
g	19539.35
ir	16912.15
ndom	0
r	19160.62
slope	0

Feature	Value
b	15590.30
Brightness	8367.83
c	14.00
g	16864.35
ir	17685.10
ndom	6.021
r	16441.54
slope	10.87
Layer Values	**Standard**
ir	7493.43

Figure 25: Classification of the ALK use class Garages*; Bottom:*
c) "Missing" height information for certain garage segments;
d) After merger: average height of 6 dm

4.5.3. Ascertainment of vegetation and its structure

Vegetation mask

After the classification of building objects of the ALK use classes *ALK Buildings planned or under construction* and *ALK Garages, sheds and cottages*, the vegetation mask is classified. The vegetation objects generated at the MRS level are delicately structured, which permits dealing with the multiplicity of the existing vegetation.

The method of vegetation extraction usually used in digital remote sensing is based on a vegetation index generated by the existing channels Red and Infrared. This Normalized Differenced Vegetation Index (NDVI) is calculated as follows:

$$NDVI = (nIR - R) / (nIR + R)$$

This index uses the fact that vital vegetation shows particularly high values in the near-infrared range, while registering much lower values in the red spectral range. This constellation is not encountered in any other object class, so that a simple separation of vegetation from other classes is ensured (ALBERTZ, 2001:p. 219). As a result of the difference formation, a range of values between -1 and 1 is generated, with negative values corresponding to such artificial materials as asphalt or concrete, while natural objects tend to have positive values.

In eCognition, NDVI is calculated as a user-defined layer, or "customized arithmetic feature". For the class description of the vegetation, a probability value of > 0.2 is defined. In Figure 26, it is evident that this value distinguishes vegetation from other objects: the artificial lawn remains unclassified, while the other lawn surfaces are, with greater or lesser probability, depending on their NDVI values, assigned to the class *Vegetation.*

The normalized formation of the relationship between the near-infrared and red channels in NDVI causes differences in lighting conditions and the effects of shading to be greatly reduced, so that even for shaded vegetation, vegetation-typical values are registered. This permits a virtually complete classification of vegetation (Figure 27).

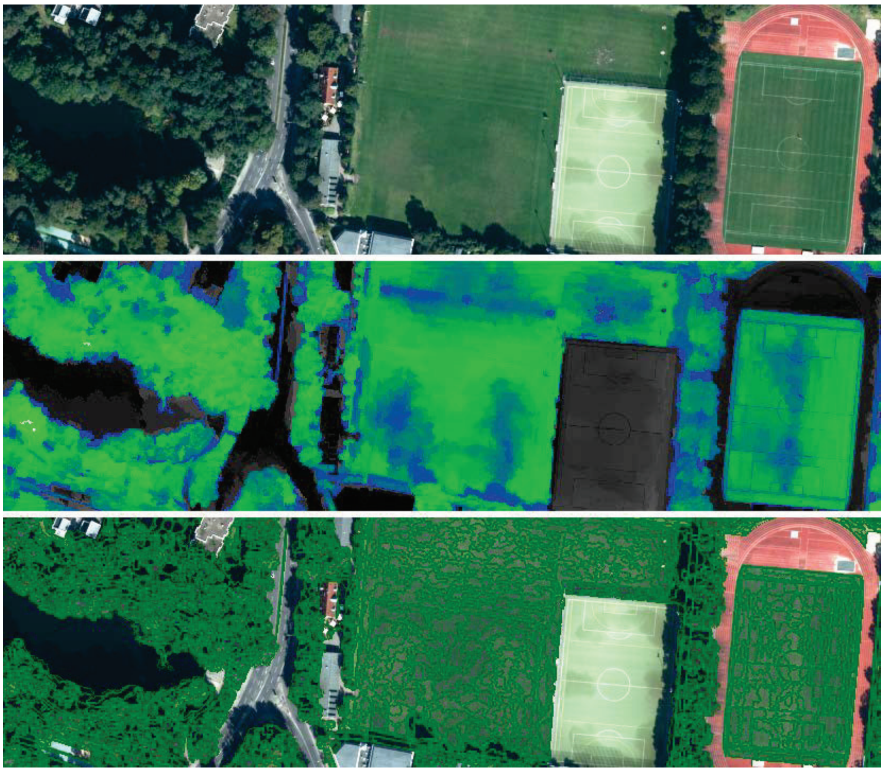


Figure 26: Vegetation mask; Centre: a colour-coded NDVI (from dark blue = 0.2 to light green = 1.0); Bottom: the classification result (green)

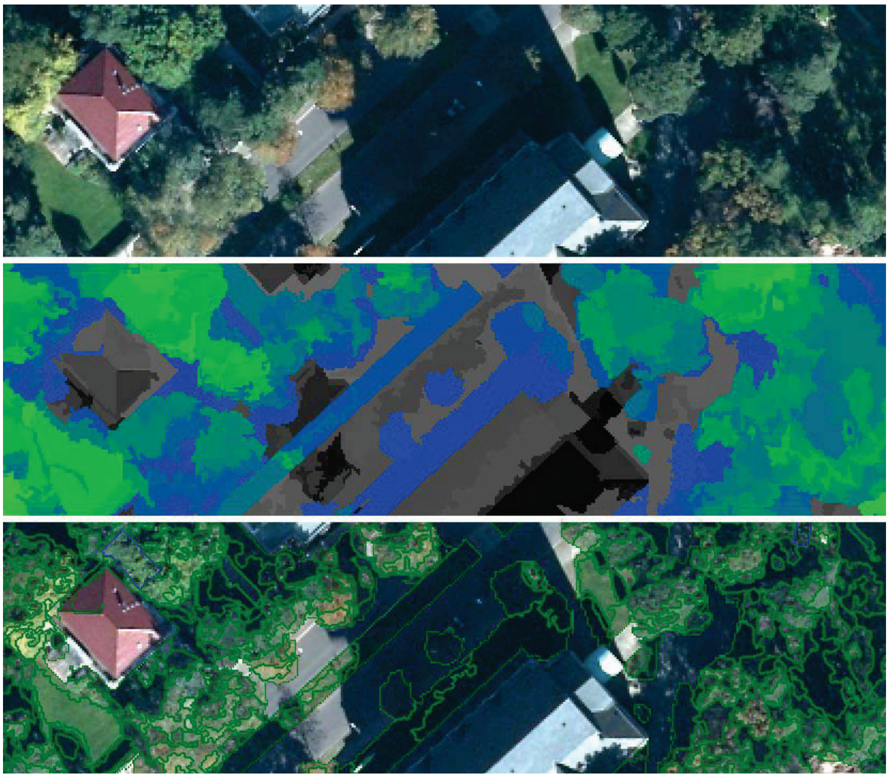


Figure 27: Vegetation classification: Evening shaded areas, NDVI values > 0.2 (centre, dark blue), resulting vegetation masks (bottom, green)

In the classification pre-setting, it was established that objects would be assigned to a class only if their average probability values for that class were greater than 50%. In Figure 28, it is clear that the smaller (less vital) tree objects show NDVI values too low to permit their classification as vegetation – it is only 0.1355, which yields a low probability value of only 4%.

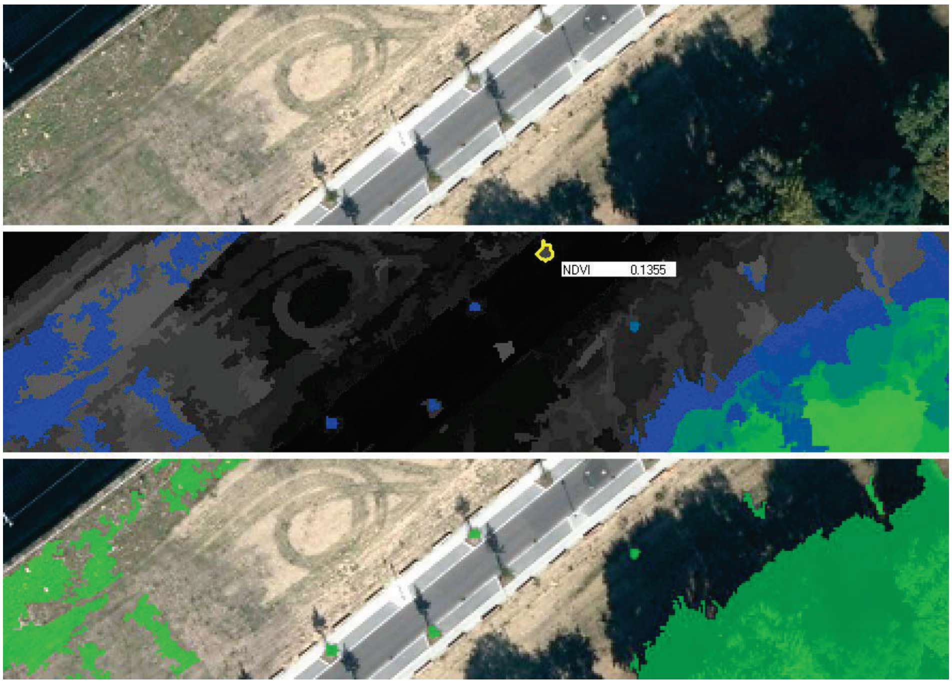


Figure 28: Result of vegetation classification (bottom): No class attribution, since the NDVI value is too low.

The classified vegetation is masked out, so that in the ensuing building classification process, only the remaining area needs to be taken into account. The vegetation mask should for that reason reflect the actual vegetation situation as precisely as possible. Since it contains few errors in the shaded areas, as well as in the case of less vital vegetation, further refining measures are planned.

Refining of the vegetation mask

The optimization of the existing vegetation mask is necessary in the shaded areas. This correction is carried out in the course of the classification of building objects which are not part of the ALK; this will be elucidated in Chapter 4.5.6, on p. 45.

4.5.4 Vegetation height stages

For the generation of the vegetation mask, MRS segmenting was used (cf. Chapters 4.4.2 & 4.5.3). This is done on the basis of the spectral channels, and is well suited for detailed ascertainment of vegetation objects. For the ascertainment of height structures however, it is too greatly oriented toward irregular shapes, and therefore reflects vegetation height stages too imprecisely (Figure 29). This is due on the one hand to the high geometrical resolution, but is also caused by the great spectral heterogeneity of the vegetation objects. For this reason, all existing vegetation mask objects are merged, so that the form of the vegetation masks remains unchanged. They are subjected to a new, appropriate segmentation process, this time with a focus on the existing vegetation irregularities and heights.

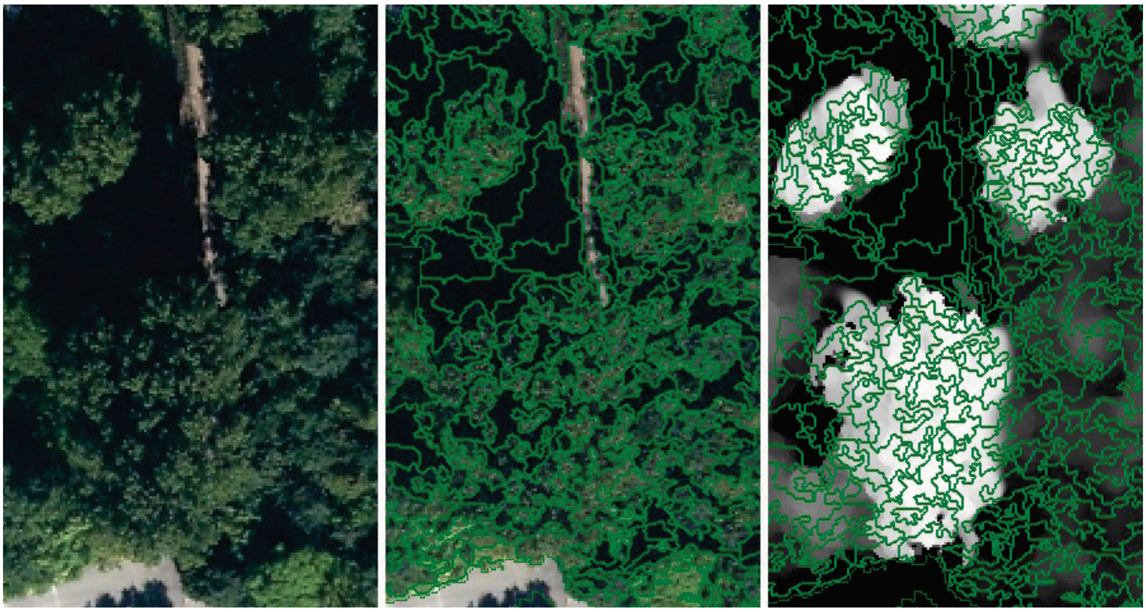


Figure 29: MRS segmentation of the vegetation – used to generate a vegetation mask, but too strongly oriented toward irregularities to ascertain the height structure.

Contrast Split Segmentation

For the ascertainment of the high structures, the *contrast split segmentation* (hereinafter: CSS) procedure was used. This algorithm separates the basic image into light and dark areas. In the height model is used, it is segmented into low (dark) and high (light) objects. The definition is based on defined threshold values which use the contrast between the resulting light (values above the threshold) and dark (values below the threshold) objects to generate the segmentation. The algorithm iteratively evaluates the optical course of the segment boundaries for each single object to be segmented, by checking the pixel values between the stipulated minimum and maximum special values. The ascertained threshold value is assessed as optimal when the resulting contrast between the light and dark objects is the highest; a segment boundary is then delineated. (TRIMBLE ECOGNITION, 2010: pp. 30ff).

With the aid of CSS, vegetation masks are divided into lower and higher vegetation segments, with the maximum threshold value for the NDSM at 20 dm (Figure 30). This segmentation result is then the basis for further detailed subdivision of higher vegetation into height stages.

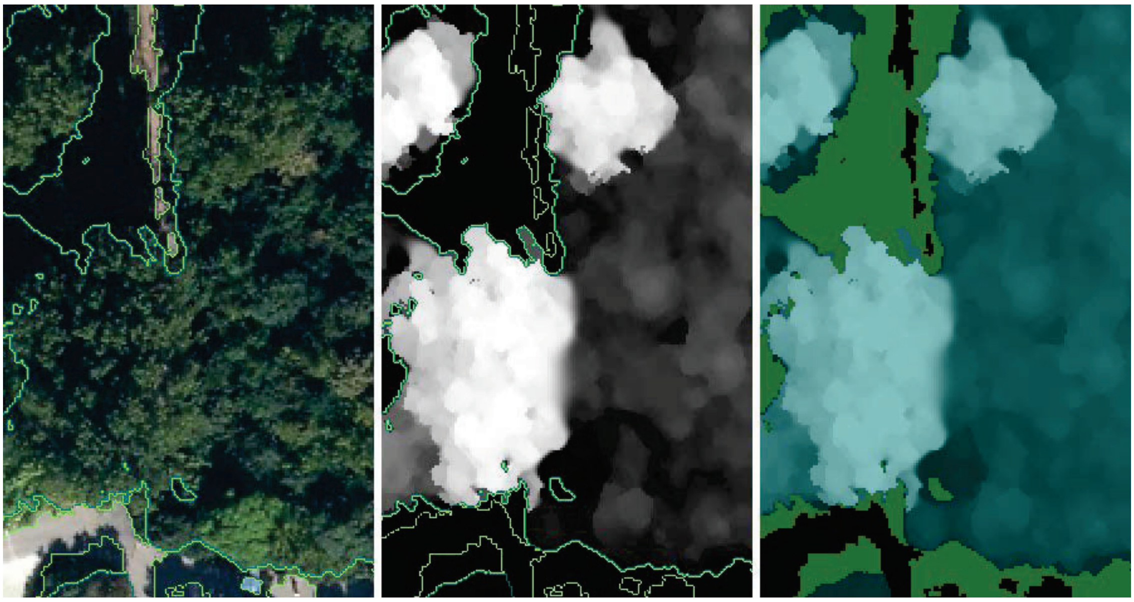


Figure 30: Results of the contrast split segmentation (CSS): Separation into lower (green) and higher (turquoise) vegetation

Multi Threshold Segmentation

For the subdivision of higher vegetation into additional height stages, *multi-threshold segmentation* (hereinafter: MTS) is used. This segmentation algorithm is based on the pixel values of the stipulated layers. In this case, the NDSM is used. It divides the existing segments along the stipulated maximum pixel values of the input layer. The user can define a number of threshold values (here, nine height stages were stipulated), among which segmentation is to be carried out. Moreover, the minimum size of the resulting objects can be defined (TRIMBLE ECOGNITION, 2010: pp. 41-42). If the height model is used as the input layer for the MTS, the procedure can be compared with a contour line generation process. The result of the MTS is shown in Figure 31.

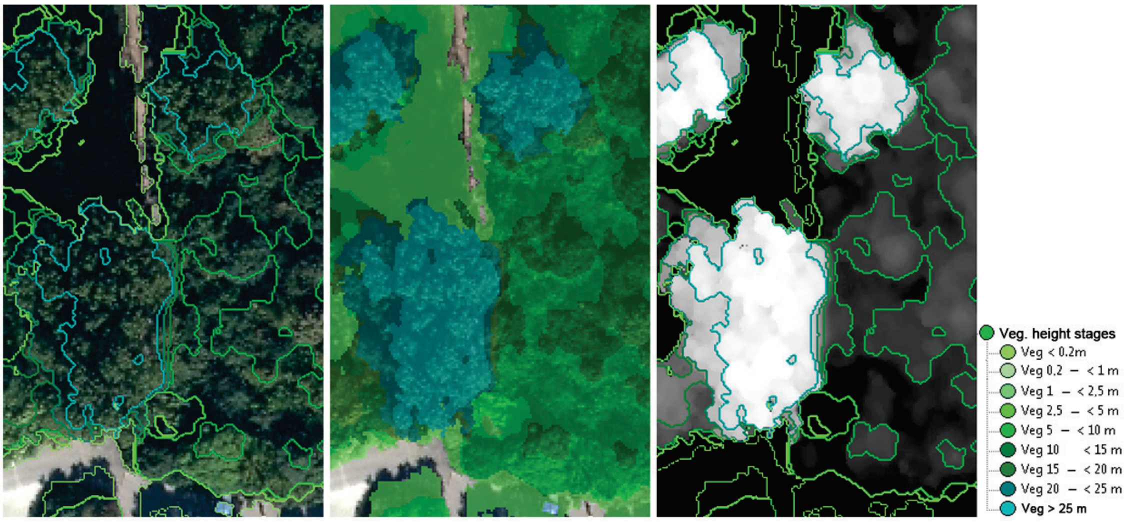


Figure 31: Results of multi-threshold segmentation *(MTS): Division of higher vegetation into nine height stages*

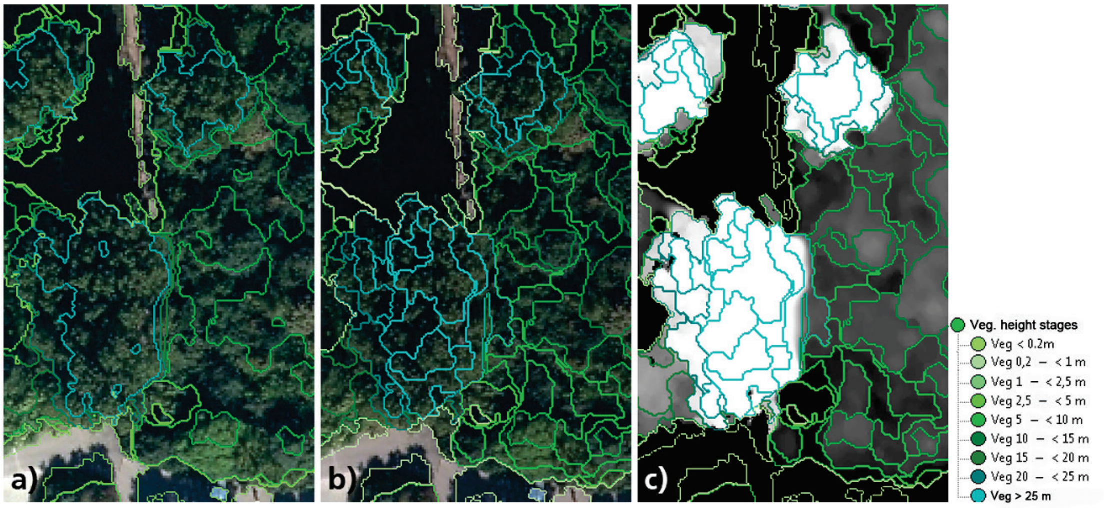


Figure 32: Results of the division of the vegetation structures with the aid of MRS segmentation (b & c) within the particular height stages, from the preceding MTS (a)

Compared with the MRS for the generation of the vegetation mask, which is carried out first, the generation of irregular vegetation shapes places greater emphasis on the shape of each vegetation segment. These irregularities are no longer so apparent, since the segmentation procedures used do not examine the spectral heterogeneity of the vegetation; only the NDSM is used. These results in homogenous, smooth segments which can at the same time depict the vegetation shape and its height levels very well and true to nature.

4.5.5 Ascertainment of buildings (part of ALK)

The classification of buildings listed in the ALK is done solely with the aid of the ALK layer.

Building objects

All objects not classified as vegetation which overlap with the ALK layer are classified as buildings. The direct “takeover” of building objects from the ALK does yet constitute complete building classification. Those building objects not listed in the ALK require supplementary treatment, which can be done fairly quickly with the aid of the NDSM, assuming that all raised objects which still remained unclassified represent building objects not listed in the ALK. However, this assumption fails to take account of the difference that results from the differing composition of the ALK and the true ortho-mosaic (TOM) (Figure 33). The ALK contains the floor plans, while that TOM shows a bird’s-eye view. Since many buildings have relatively great roof overhangs, differences in the extent of the building objects results. For this reason, these overhangs remain in the NDSM. This makes the classification of building objects which are not part of the ALK more difficult. A description of the procedure is given in Chapter 4.5.6.

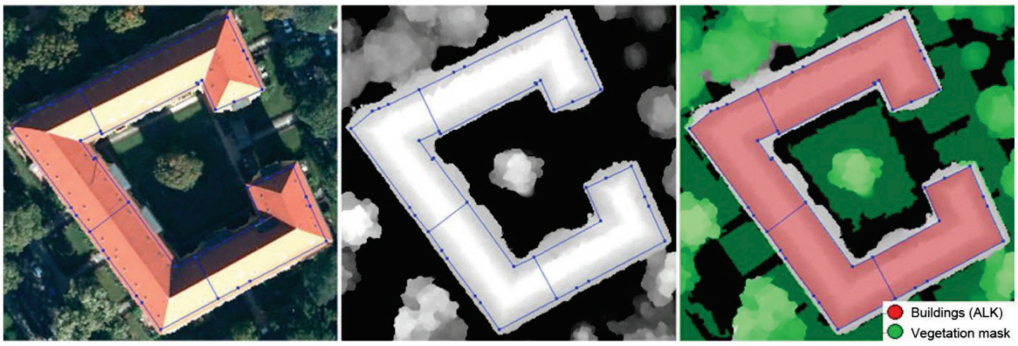


Figure 33: Roof overhangs; Left: TOM RGB, overlaid with the ALK; Centre: NDSM overlaid with the ALK; Right: classification result

Bridges and elevated railway areas

Bridge objects and elevated railway facilities, in some cases on pillars, should also be ascertained as built structures. The ALK basic and supplemental topography layers also contain additional building objects. These include, among other things, bridges and railway facilities, both above and below ground. They are classified with the aid of the corresponding OSKA key, similarly to building objects. The classification result is shown in Figure 34.

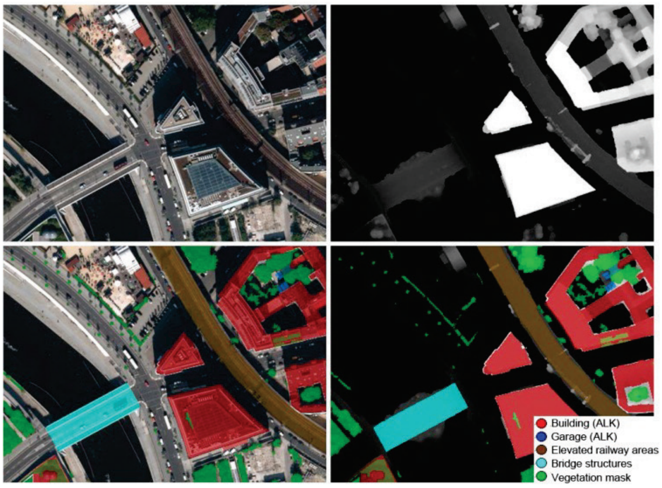


Figure 34: Classification results of bridges and elevated railway objects.

4.5.6 Ascertainment of buildings (not part of the ALK)

The building objects not shown in the ALK include garden or weekend cottages, newly built buildings, roofed inner courtyards and other free-standing roof covers. On the base of the data used, it is not possible to distinguish between temporary and permanent objects. For this reason, large construction containers and tents are also ascertained.

Since the existing NDSM shows no third dimension, but only so-called 2.5-D, it is not possible to distinguish between drive-through passageways and "open" roof structures. This problem is shown by the horizontal height profile above the Brandenburg Gate (Figure 35). It can seen that the bird's eye view fails to show the passageways through the gate, so that no true 3-D analysis, or ascertainment of the nature of the building's structure is possible. However, this does not negatively affect the extraction of the required object or its height attributes.

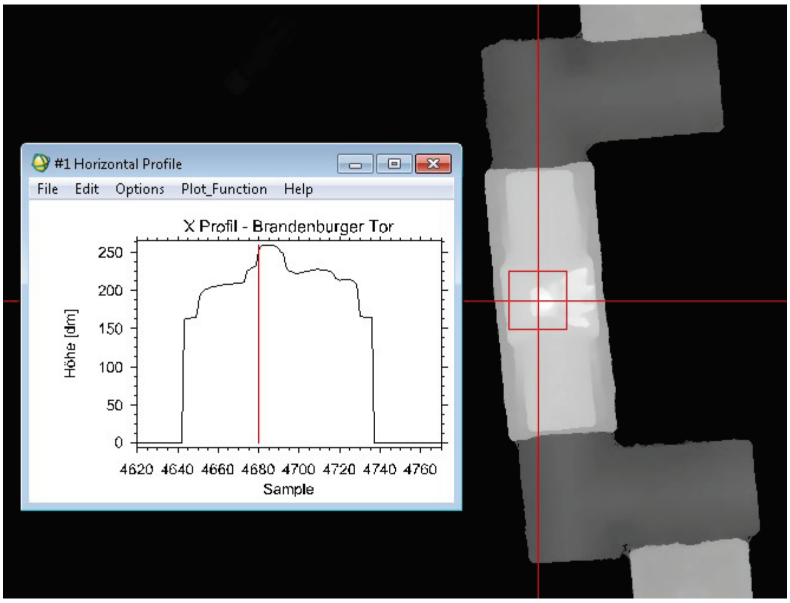


Figure 35: Horizontal height profile (NDSM) above the Brandenburg Gate

An analysis in 3-D space is currently an object of research, and would greatly enhance extraction precision. Diagonally viewing sensor systems are currently being developed in the DLR's Department for Sensor Concepts and Applications, which permits the derivation of true 3-D information from aerial images, and the extraction in 3-D space (WIEDEN & LINKIEWICZ, 2013; LINKIEWICZ, 2013; cf. DLR, 2013d).

In the following, we will describe the procedure for ascertaining building objects which are not part of the ALK in greater detail.

Garden cottages (not part of the ALK)

First, the cottages are ascertained, and the class *Sheds/cottages (not in ALK)* is set. The classification is limited to the spatial areas located in the ALK topography foil in the section *Small and allotment gardens or colonies*. In addition, a lower NDVI value is included in the class description. Since the garden cottages are generally lower and smaller objects, they are in most cases listed with a false height in the NDSM (cf. Chapter 4.5.2). For this reason, no height value can be used in the class description. However, this at the same time causes many false class attributions in the category of roads and pathways in these areas, since these also have low NDVI values. At this point, we have to make use of the shape features. A measure of rectangularity, and of the relationship of length to width, permits the exclusion of roadway areas from the cottage class.

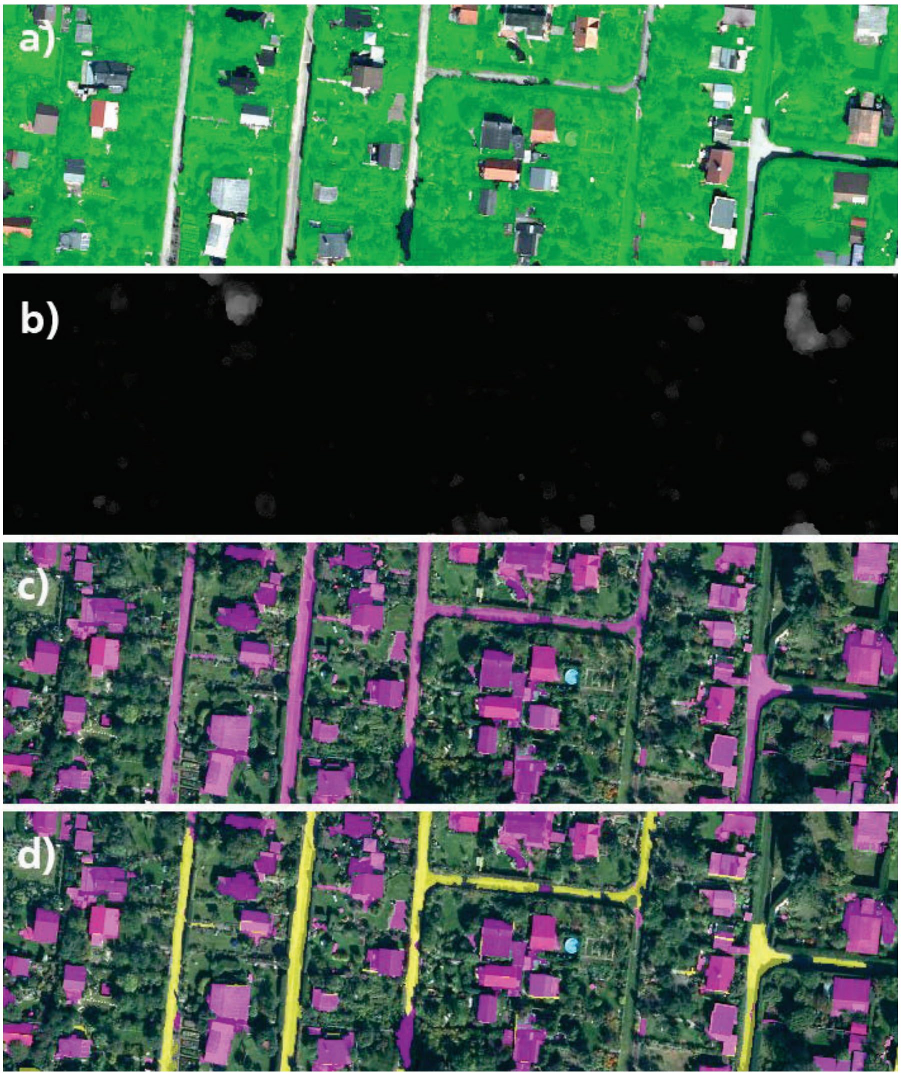


Figure 36: Classification of Garden cottages (not in ALK): *a) Former classification (vegetation mask) overlaid onto RGB; b) Excerpt from NSDM – no heights for the cottages; c) Initial classification (purple) shows errors in the area of roadways; d) Classification of cottages, with roadways removed (yellow)*

Building objects (in ALK)

For the classification of *Buildings (not in ALK)*, all remaining raised objects are classified, and false objects removed with the aid of geometrical features and of statistics from NDSM and the additional layer. Figure 37 shows a preliminary classification result. It is evident that roof overhangs and some vegetation segments are falsely classified as buildings.

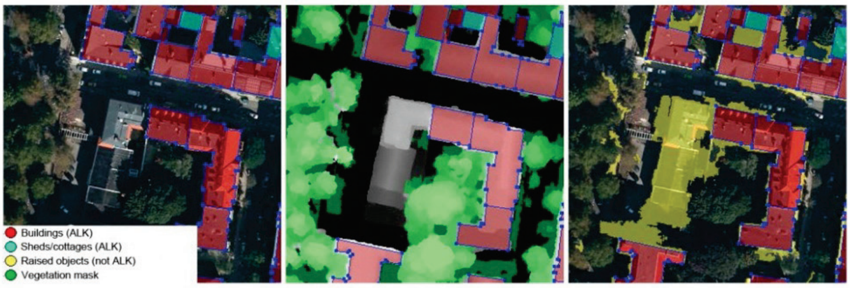


Figure 37: Preliminary classification of buildings which not in ALK (right, in yellow);

overlaid with the ALK contours (blue lines)

In the spectrally homogenous shaded areas, it is possible that during the MRS, pixels with a height value of zero will also be integrated into the segment being generated. Such a segment might for example have an average height of 20 dm, the required minimum for a building height. In order to correct the falsely classified segments, a pixel-precise analysis is therefore necessary. In this way, pixels with heights which are too low can be removed.

For this purpose, a chessboard segmentation (cf. Chapter 4.4.1) with a size parameter of “1” is used in order to generate segments of pixel size in the area of the class *Buildings (not in ALK).* As shown in Figure 38, each of these pixel sized segments is subjected to classification. Segments with a height of zero are removed from the class *Buildings (not in ALK)* (shown in orange in Figure 38).

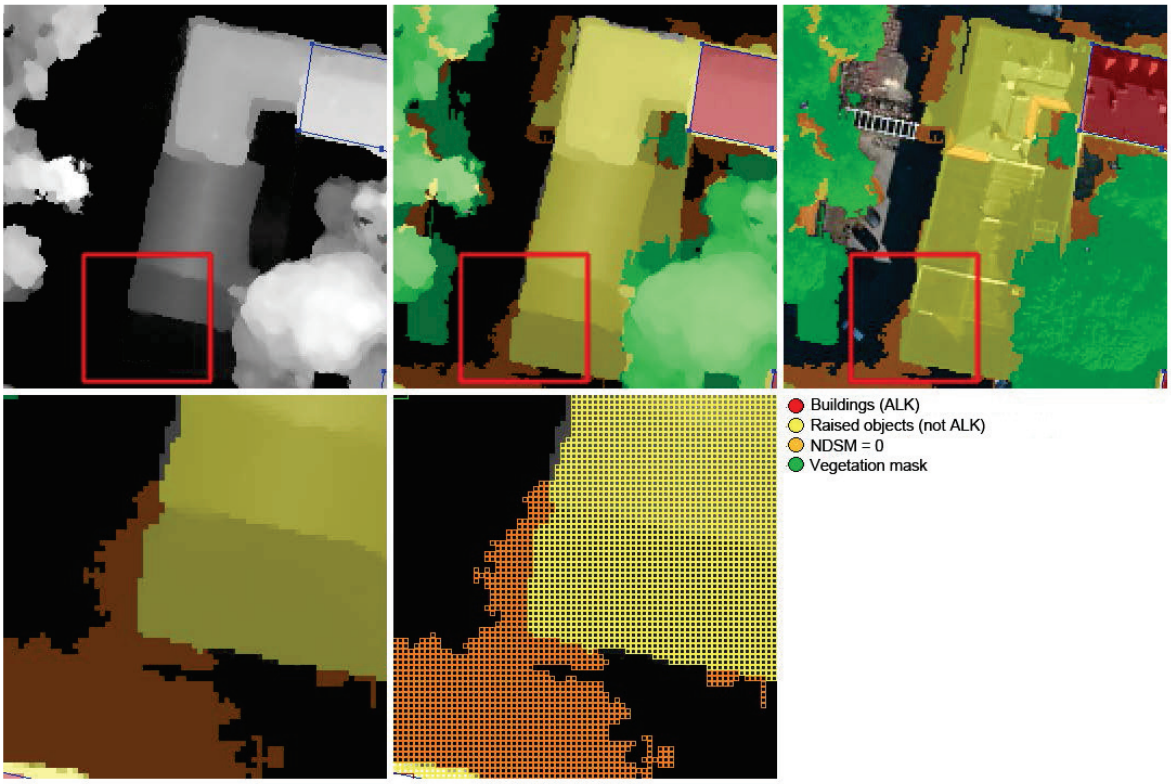


Figure 38: Correction results for Raised objects (not in ALK), *as a result of pixel-precise observation of NDSM; In orange: pixels with NDSM =0; below: detailed view with chessboard segments*

Pixels with very low values in the *Count* layer were subjected to further correction, meaning those picture elements which showed few corresponding points in DSM processing (cf. Chapter 2.1.4). For such pixels, no clear correct height value can be ascertained. Therefore they are interpolated from their neighbour pixels, so that false height values may be generated under certain circumstances. The correction of the low *Count* values is shown in

Figure 39.

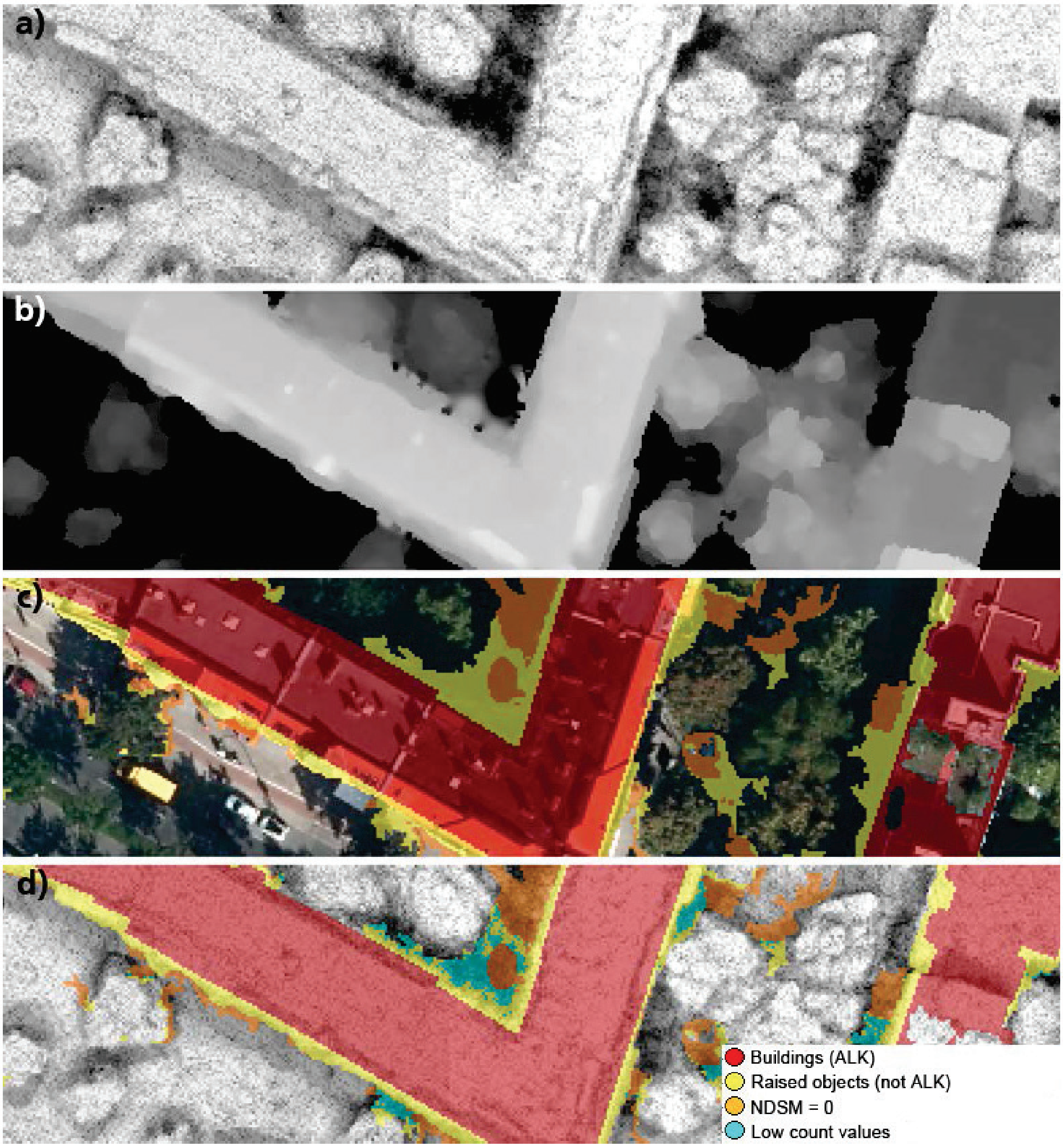


Figure 39: Correction of the low Count *value: a) Dark areas in the* Count *layer represent few corresponding image attribution points; b) The height are interpolated in DSM/NDSM; c) Interpolated heights lead to false classifications in the class* Raised objects (not in ALK); *d) Correction by means of classification of the low* Count *values (blue)*

The thus corrected segments of the class *Buildings (not in ALK)* (in yellow) now consist largely of relevant raised objects. In the previous image examples, it is evident that further corrections in the area of vegetation are necessary. There are still many small areas which are very probably part of the vegetation, but which have not been integrated into the vegetation mask due to the fact that their NDVI values are too low.

Supplementation of the vegetation mask

The existing vegetation mask is supplemented with the areas from the class *Raised objects (not in ALK)* taking NDVI values into account. Segments with positive NDVIs and relatively small NDVI differences to neighbouring vegetation objects grow iteratively into the vegetation mask (conditional region-growing). Segments which do not fulfil this condition remain unclassified. The result of the completion of the vegetation mask is shown in Figure 40.

The class *Raised objects (not in ALK)*, with the vegetation objects removed, does not yet represent the final result. The classification still has many objects representing roof overhangs. In order to preserve only the actual building objects, they are examined for shape features, for which purpose the 1-pixel objects must be merged. Only those objects of a certain size and with a certain degree of rectangular fit (normalized to a value range between 0 and 1), and of minimum width, are classified as *Buildings (not in ALK).* The remaining segments – even those representing roof overhangs – are excluded from the class. These optimized building objects are the final result of the class *Buildings (not in ALK).*

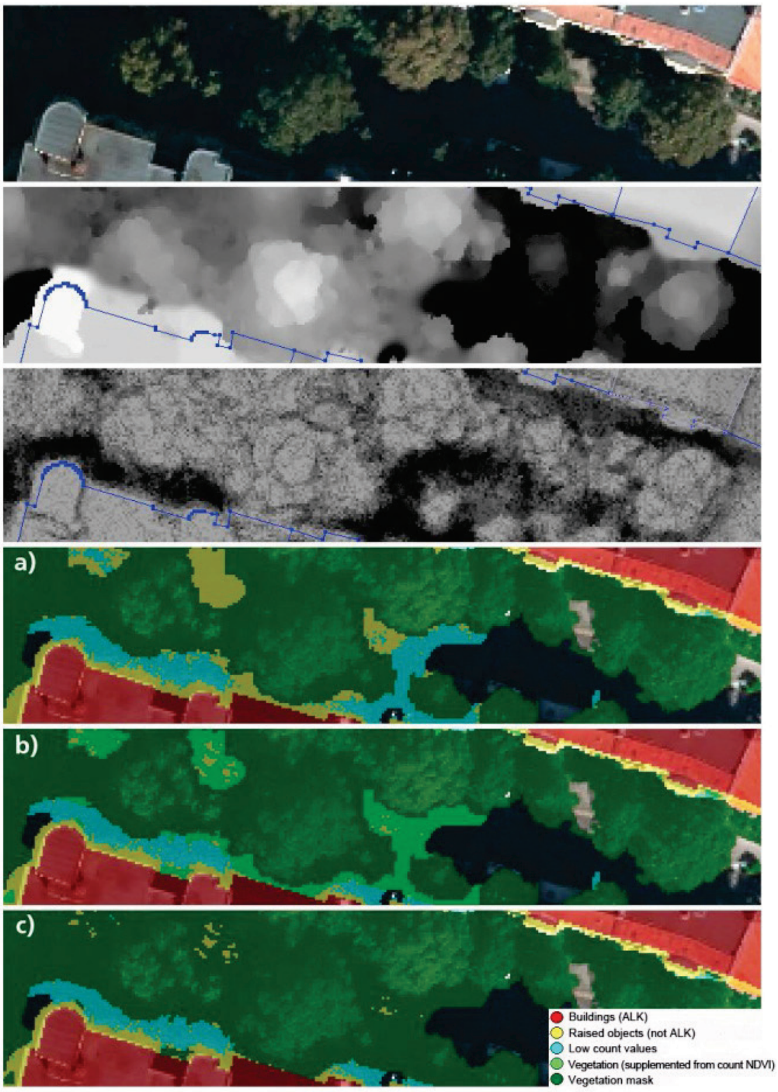


Figure 40: Results of the supplementation of the vegetation mask: a) Classification of low Count *values; b) Classification of positive NDVI values; c) Iterative pixel-by-pixel conditional growing in the vegetation mask, taking into account the relative differences today bring vegetation objects.*

Figure 41: Removal of false segments from the class Buildings (not part of ALK), *with the aid of geometric features: c) area size; d) width and rectangularity*

4.5.7 Green roofs and roof surfaces hidden by vegetation

Roof gardens are becoming increasingly popular and significant in Germany. The share of intensively used greened roof surfaces increased from 11.4% in 2008 to 16.9% in 2010, as a proportion of all greened roof surfaces in Germany (FACHVEREINIGUNG BAUWERKSBEGRÜNUNG, 2011: p. 6). Being able to detect these roof surfaces automatically and to ascertain potential areas for so-called urban gardening or for targeted greening of buildings is of great interest. Greened roofs moreover have a positive effect on certain environmental aspects, such as urban climate or rainwater use. To date, there has been no complete overview of the stock of greened roofs in Berlin.

In the class *Greened roofs*, no distinction is made between different intensities of roof greening, such as intensively used roof gardens on the one hand and simple moss covered roof surfaces on the other. The goal of these work steps is purely the initial ascertainment, in an approach encompassing the entire area being investigated. The simple merger of the vegetation mask with an existing ALK building layer provides no final result, since parts of trees which cover portions of the roof surface are also encompassed in the ascertainment. It is precisely these surfaces that will later be needed for the correction of the height calculations of roof surfaces partially hidden by vegetation. A preliminary classification of greened roof surfaces by means of merger with the ALK building layer is shown in Figure 42.

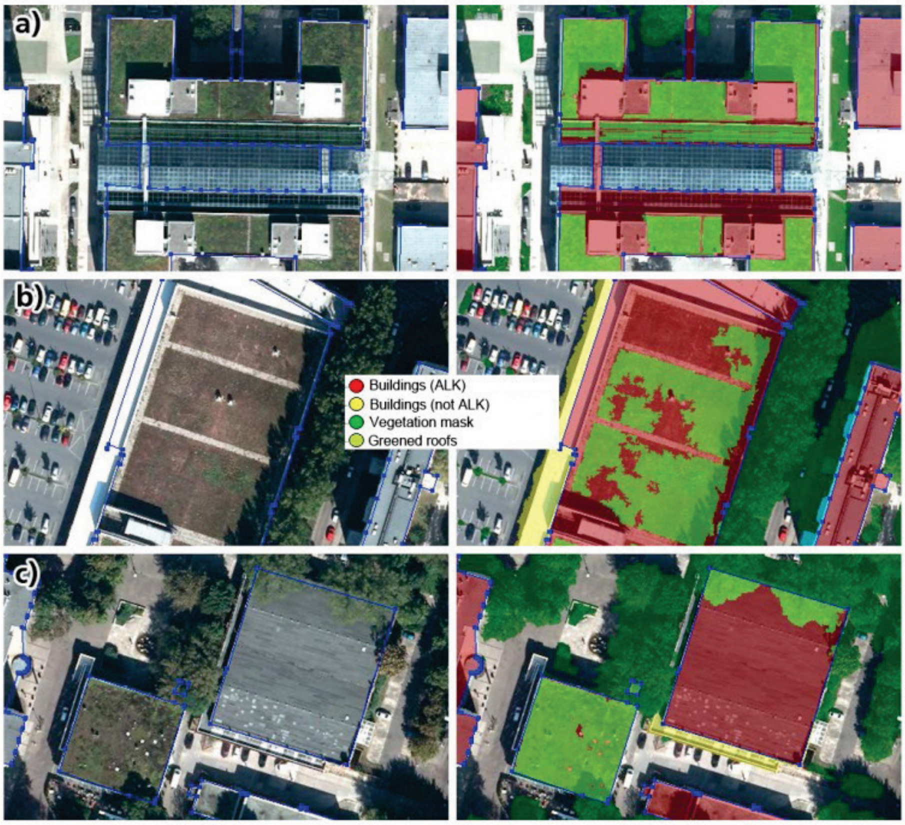


Figure 42: Greened roof surfaces from the merger of the vegetation mask with the ALK building layer

In Figure 42, it is evident that the classification of greened roofs works very well in many places, since these surfaces have a high NDVI value, as a result of which there been incorporated into the vegetation mask (Figure 42, Example a). In places where the roof greening is less vital, only some irregular portions have been ascertained. Where the NDVI value does not exceed the threshold value, no vegetation mask is generated, so that no greened roof surfaces are classified (Figure 42, Example b). From example c), however, it can be seen that portions of the roof concealed by the adjacent trees were initially classified as greened roofs. In the examples a) and b), discontinuities in the shaded areas are also evident.

In order to classify vegetation objects which conceal portions of a roof, rather than being greened roof surfaces, the class *Greened roofs* is investigated for differences in NDSM and

NDVI to the adjacent objects. If the object of the class *Greened roofs* have only a slight difference in height compared with neighbouring tree objects, and a greater difference to the building objects, and also very similar spectral features to the trees, they will be iteratively pushed into the class *Roof hidden by vegetation*. In Figure 43, it is evident from the attached NDSM image that the formation of this class is necessary. If they were to remain classified as buildings, that would lead to a falsification of the average building height.

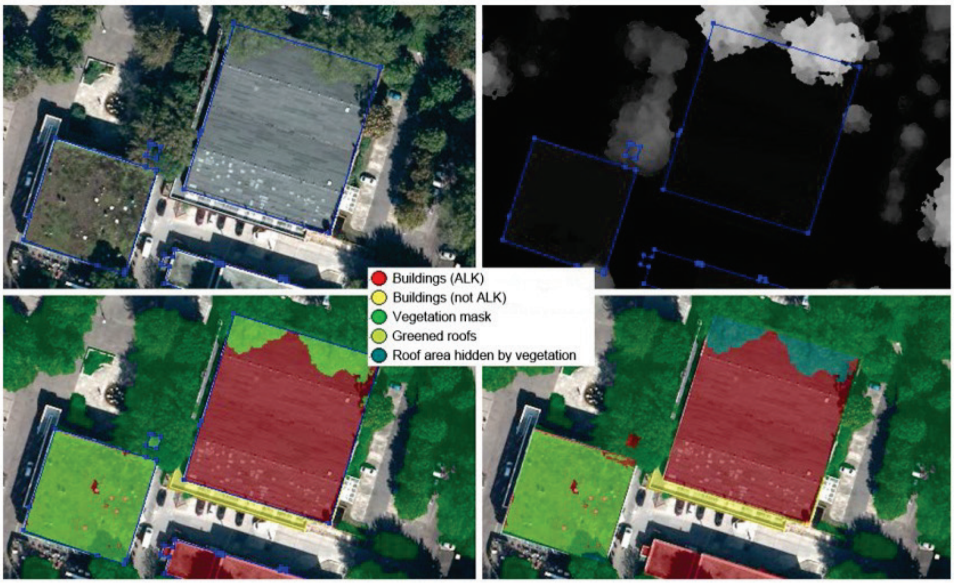


Figure 43: Classification result of the class Roofs hidden by vegetation *(below right)*

The classification *Greened roofs* also includes several additional errors, particularly in shaded areas where the NDVI value is less than the required threshold value. For this reason, the neighbouring segments of existing objects of the class *Greened roofs* were examined for similarities. At this point, only a simple comparison of the spectral features is carried out. The comparison of the geometric features of the partial roof surfaces affected, and the probability analysis, promised improved classification results, but were not pursued for reasons of time. Figure 44 shows the result of the neighbourhood comparison. It was evident that the green roof surfaces are better represented, but continue to lack ascertainment in the shaded areas.

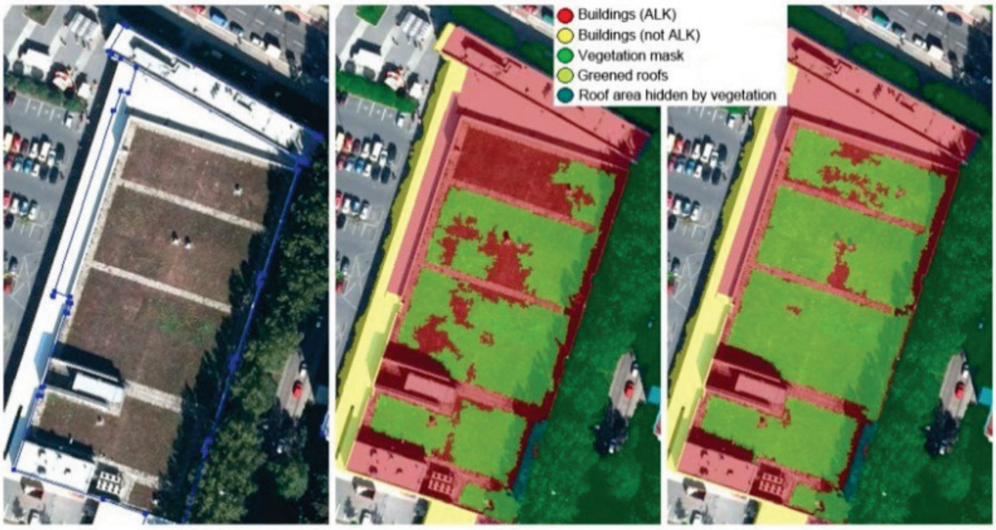


Figure 44: Improved classification results for greened roof surfaces,
based on spectral neighbourhood analysis (right)

The greened surfaces are found in the class *Buildings (not in ALK),* albeit to a smaller degree. It can be expected that in some new buildings, naturalized roofs with growing vegetation, or roof gardens have been installed, or that freestanding roofs are greened, but not listed in the ALK. For an exact classification of greened roof surfaces not in the ALK, other methods and further features are needed so as to be able to distinguish them from the crowns of trees. First, vegetation objects are sought which are completely surrounded by the class *Buildings (not in ALK).* At this point, tree objects which conceal the roof surfaces remain unaffected. In order to avoid classification of any vegetation present in the inner courtyards, it is moreover assumed that the greened roof surfaces have a different texture (minimal standard deviation of the NDSM and slope values) than do free surfaces, and also a somewhat smaller height difference to the adjacent objects of the class *Buildings (not in ALK).* Major divergences in height and slope values are characteristic for the crowns of trees. One exemplary classification result of *Greened roofs (not in ALK)* is shown in Figure 45. This involves a freestanding roof which is not shown in the ALK (cf. image example, left), and is a greened surface.

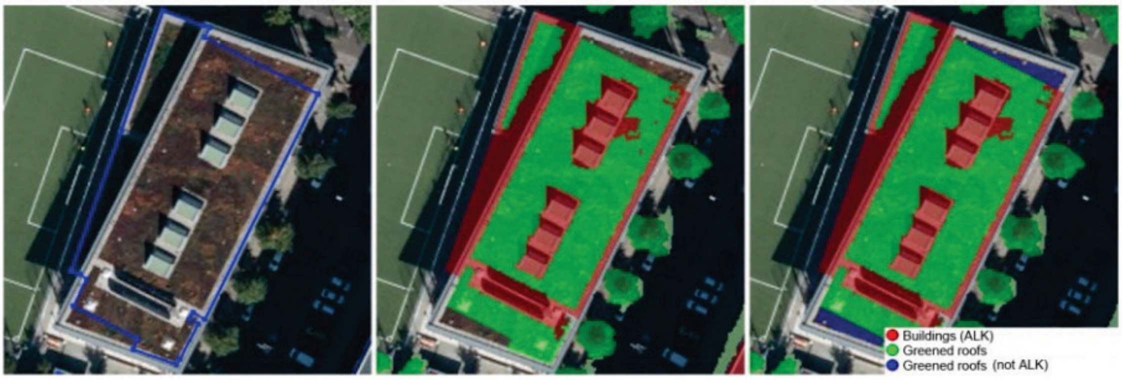


Figure 45: Classification result of Greened roofs (not in ALK)

4.5.8 Separate ascertainment of roof surfaces

The building mask so far created is complete, however it has a much too fine segmentation structure. For various uses, it is important that the building objects in the vegetation objects be distinguished according to their height structures. Often, building objects are not shown sufficiently differentiated in the ALK, i.e. that the divergent number of storeys within the building is not stored in the polygon attributes.

Therefore it is necessary to undertake a separated ascertainment of the class *ALK buildings* according to the roof portions, as provided by geometry and height differences. The methodology used is being developed at the DLR in the context of a dissertation by Ms. Poznańska (to be submitted to the Free University of Berlin); however, this is still in the stage of valuation and optimization, and will therefore be used in a modified form during the second project phase.

As the basis for the separation of roof surfaces, a new MRF segmentation in which the *aspect* layer attains the highest weighting is to be carried out. Moreover, the NDSM will be incorporated into the segmentation process with a relatively high weighting, while the spectral layers will have minimum weighting. The *aspect* layer reflects the features of the roof geometries very well; however, some problems have arisen for the roofs facing north, which show values both in the range of 0 to 15° and, at the same time, the range of 345° through 360°. This “background noise” affects the segment structure. For this reason, the spectral layers must be incorporated into the segmentation process. Although this does favour the merger of segments in the problematic northern portions of the roof, it at the same time increases the spectral sensitivity of the MRS, causing segment edges to be formed along the shadow areas. The result of the MRS is shown in Figure 46. It is clear that, along with the relatively clean geometrical ascertainment of the roof edges, there are also disturbances in the shaded areas. Small elements which are spectrally strongly delimited, such as skylights or chimneys, are also ascertained. These roof elements are removed in a further step, which provides improved results for the roof geometries.

The removal of small objects is done with the aid of so-called *image object fusion*, which is one of the region-growing procedures. This method permits an exact definition for the merger of neighbouring objects. Parameters for the so-called initial cells and for the candidate objects can be defined (fitting functions). Moreover, conditions for the growth process are determined including the fitting mode, the fitting function threshold, and the weighted sum, which permits the weighting of the selected parameters (Trimble eCognition, 2010: pp. 85ff). This complex determination of parameters and growth conditions provides good results. The result of the removal of the small objects is shown in Figure 47. Clearly, these have been incorporated into the neighbouring roof segments relatively reliably. Nonetheless, segments still remained which exceed the maximum allowable threshold value for size (e.g. large roof windows).

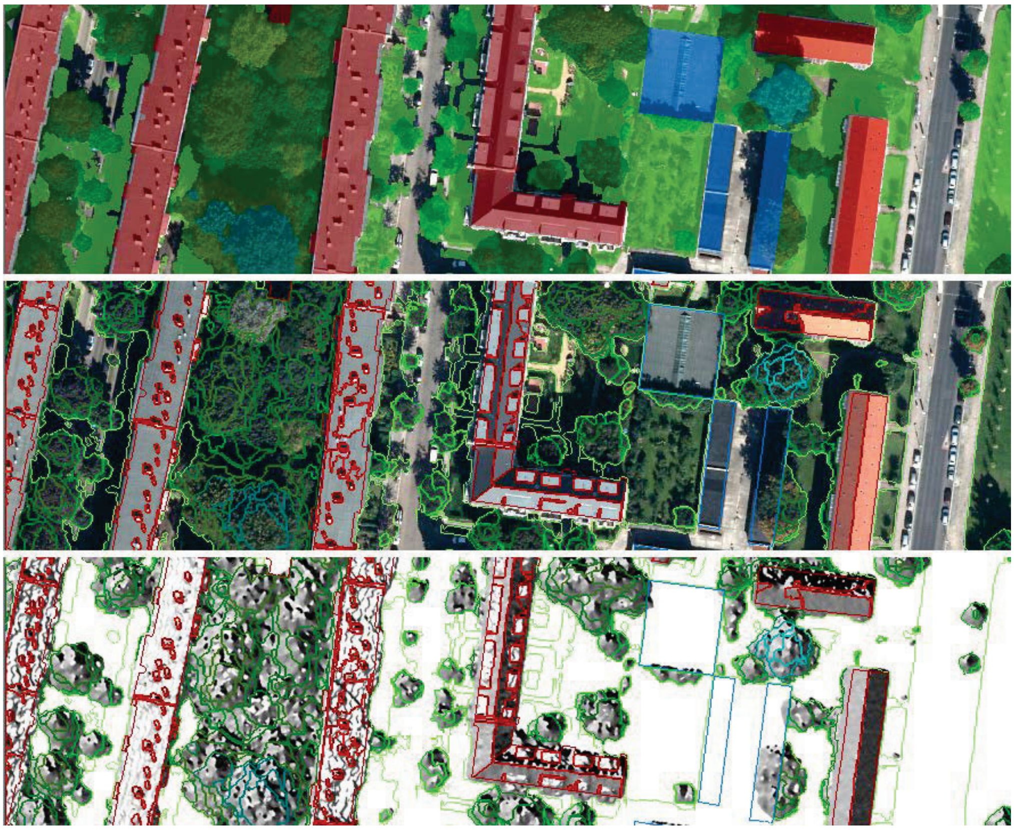


Figure 46: Result of the new MRF as the basis for further separation of roof areas

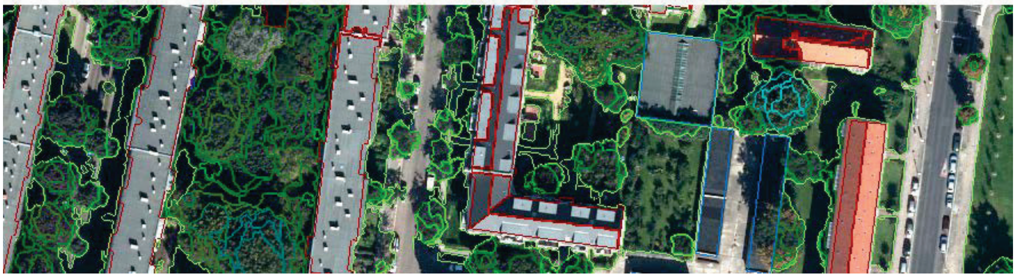


Figure 47: Result of conditional image object fusion: Objects are merged with neighbouring parts of roof segments

In order to separate building parts with unusual geometries or strong height differences, the standard deviation of the NDSM is also used, albeit only for flat roofs, i.e. those with a slope layer value of <7°. These buildings are again segmented with a stronger weighting of the

NDSM and *slope* layers, so that different building height stages can be better segmented (Figure 48). It is evident that in spite of the relatively good separation of the height stages, many spectral disturbances still affect the segment shapes.

The building objects and roof portions thus ascertained are automated, and exported into versions (combined and as single roof portions), together with their height attributes. It can be seen that the building heights for ascertained building segments are output as averages (NDSM means). By the same token, attributes for the minimum and maximum NDSM values occurring within the segments (min NDSM & max NDSM) are entered into the tables. Only in certain cases, such as optimally designed flat roofs, does the average height value correspond to the absolute building value. For Berlin’s typical pitched roofs, this is not the case.

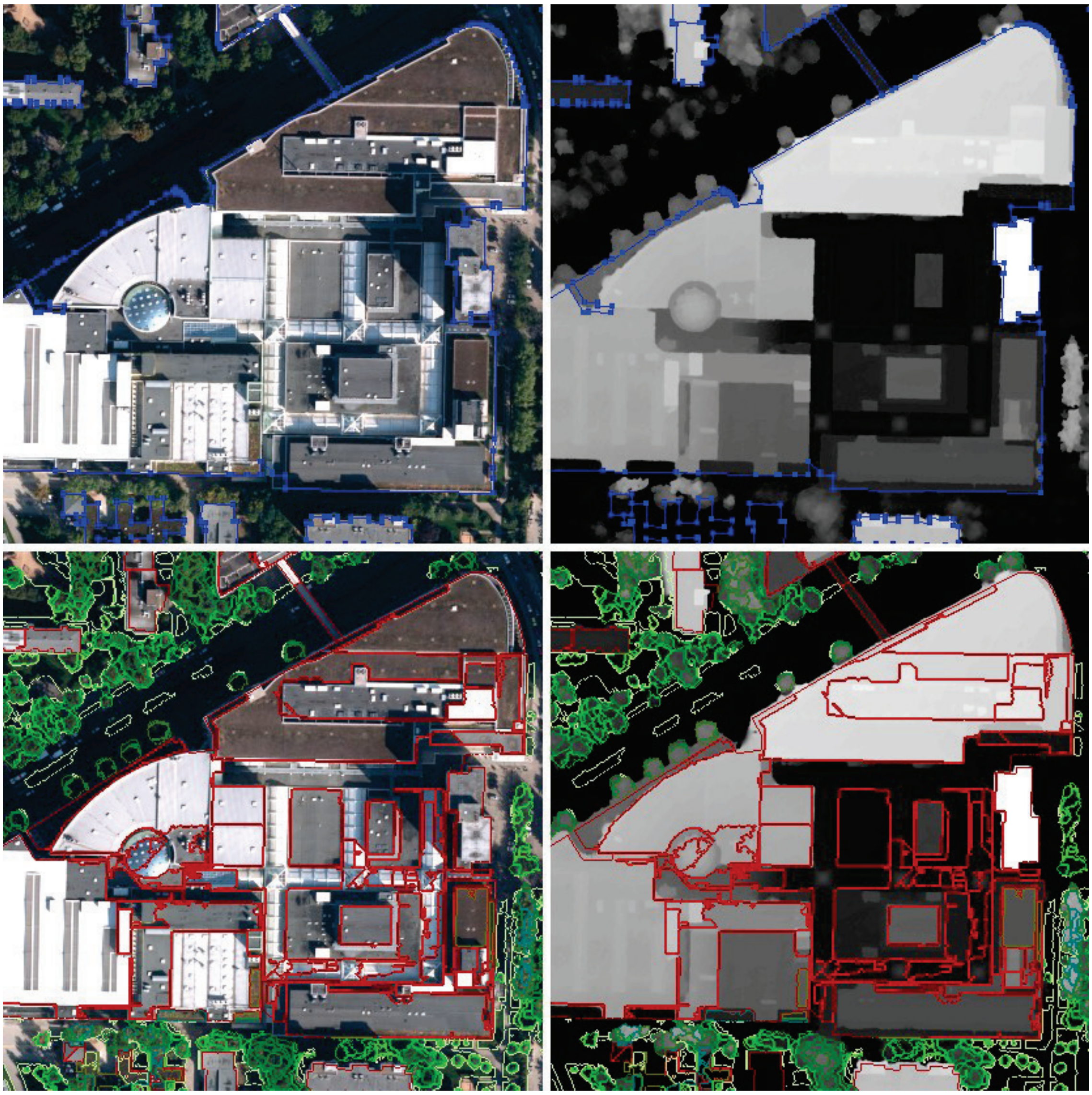


Figure 48: Separation of building objects with significant height differences (bottom); A building as an object in the ALK (top)

5 Results: Ascertainment Quality

The rule base for automated object based analysis and ascertainment of buildings and vegetation objects in the Berlin inner city, developed and optimized for Berlin, was used in all 12 borough areas contained within the project area. A total of 54 *ProgSpace* areas were subjected to the analysis. The computer time required was approx. 12 days, on a computer with 24 GB RAM, a 64 bit operating system and a 2.93 GHz Intel Core i7 processor. The input of the data, and the analysis and export of the results was accomplished automatically by stack processing.

The resulting building and vegetation objects were satisfactorily ascertained (Figures 52 through 55); however, they do show certain weaknesses. We will discuss the quality of the results in the following chapter.

5.1 Building objects

The class *Buildings* encompasses a total of 10 different classes, some of which are based on ALK objects, and others which cover objects not listed in the ALK. The methods used in the project are exclusively computer-based and automated procedures of object extraction, which greatly affects the quality of the results.

The completeness and correctness of the buildings ascertained within the ALK polygons can be considered very good, since here, it was possible to make use of the existing ALK directory. Here, an additional check for precision is not necessary, since the quality of ascertainment corresponds to the correctness of the ALK.

Although the precision examination of building objects not in the ALK has not yet been accomplished, the results could already be assessed as very good. Only such temporary objects as circus tents or large construction containers were mistakenly ascertained as well; however, this is inevitable without manual reworking. The object of the class *Buildings (not in ALK)* are exported as merged segments, since, due to their very heterogeneous structures – e.g., on construction sites – no correct segment formation or height determination can often be provided.

The number of building objects ascertained and the number and share of objects of the class *Buildings (not in ALK)* are compiled in Table 1. It is evident that within the project area, there is a relatively large number of building objects not listed in the ALK. Not including garden cottages, this involves an average of 273 building objects per borough, which comes out to an average share of the total of ascertained building objects of approx. 1.6%. Particularly notable is the borough of Marzahn-Hellersdorf, where a total of 6.4% of the building objects detected are not in the ALK. This is due in large part to the fact that only a very small part of the borough was included in the project area, and that portion is largely an industrial area with many roofed-over spaces and newly built warehouses which have not yet been listed in the ALK, as of June 2012 (Figure 49).

Tab. 1: Number of greened roofs/roof portions, per borough and their respective uses (as of: July 2013)

Borough	Number of greened building roofs	Ascertained surface area of greened roofs (sqm)	of which			
			Buildings with predominantly residential use	Buildings with predominantly trade, service, commercial or industrial use	Buildings with predominantly public utility, transport or special use	Buildings of unknown use
Mitte	774	196,392	429	123	206	16
Friedrichshain-Kreuzberg	572	121,092	390	78	87	17
Pankow [1]	343	102,182	185	67	76	15
Charlottenburg-Wilmersdorf	728	153,213	467	50	189	22
Spandau [1]	311	58,579	223	39	47	2
Steglitz-Zehlendorf [2]	685	104,364	476	62	133	14
Tempelhof-Schöneberg [2]	471	99,997	294	54	115	8
Neukölln [2]	559	127,230	394	59	86	20
Treptow-Köpenick [1]	372	94,578	177	119	71	5
Marzahn-Hellersdorf [1]	27	9,869	2	22	1	2
Lichtenberg [1]	109	45,560	71	16	22	0
Reinickendorf [1]	105	24,835	55	23	19	8
Total	5056	1,137,891	3163	712	1052	129

[1] Borough only partially ascertained to date

[2] Borough more than 90% ascertained

Table 1: Compilation of the ascertained Buildings (in ALK) *and* Buildings (not in ALK)

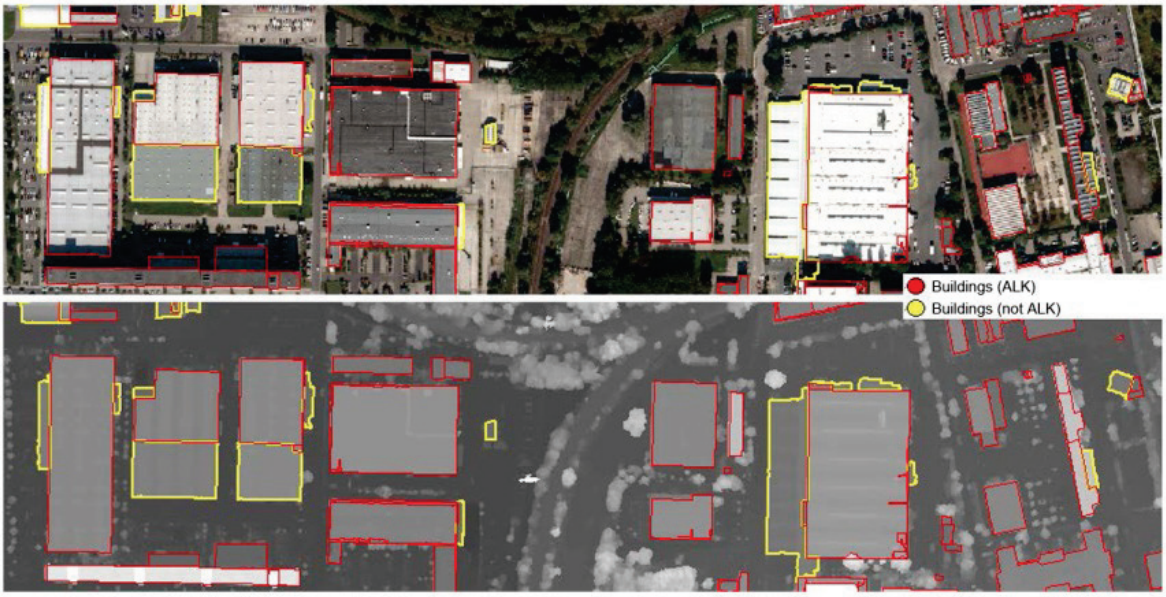


Figure 49: Building objects ascertained in the Berlin borough of Marzahn-Hellersdorf (excerpt)

The separation of buildings into logical roof portions oriented toward the roof geometry works to a satisfactory precision only to some extent. The sensitivity of MRS segmentation with the aid of the spectral channels causes the results to be somewhat unreliable, especially in the shaded areas. Work is continuing on the optimization of this methodology.

Greened roofs are also ascertained satisfactorily and largely correctly. The completeness of the extraction is however disturbed by the shaded areas. Within the context of a precision examination undertaken by SenStadtUm on a total of 60 selected greened roof surfaces, it is already possible to demonstrate a high degree of precision with regard to completeness and correctness of the results. The completeness of the ascertainment was estimated, and output as a percentage value. Approx. one third of the correctly detected surfaces have a completeness rate of below 50%, and approx. half have a completeness rate of over 75%. Taking into account the various disturbing factors in the classification, such as shadows or small ventilation outlets, which are also ascertained, this result can be considered good.

5.2 Vegetation

The class *Vegetation* contains nine height stages. These are also exported with the height attributes, so that an independent height breakdown can be undertaken. The vegetation mask upon which it is based represents the existing local vegetation very precisely. The breakdown into height stages and structures is very precise and true-to-nature. The appearance of the segments is homogeneous.

Only in the interpolated NDSM areas do misclassifications of the vegetation occur (Figure 15). However, this is evidently due to the input data and not to the classification rule. This error caused by the database cannot be corrected everywhere, not even with the aid of the *Count* mask or the NDVI. Occasionally, positive NDVI values (Figure 50, b) and high *Count* values (Figure 50, c & e) still occur, presumably as erratic values. Where such interpolation errors occur with high buildings, vegetation heights of over 40 m can be output (Figure 15, d & f) – greatly in excess of the real situation. Manual correction is the only way to ensure that such errors do not occur in follow-up procedures.

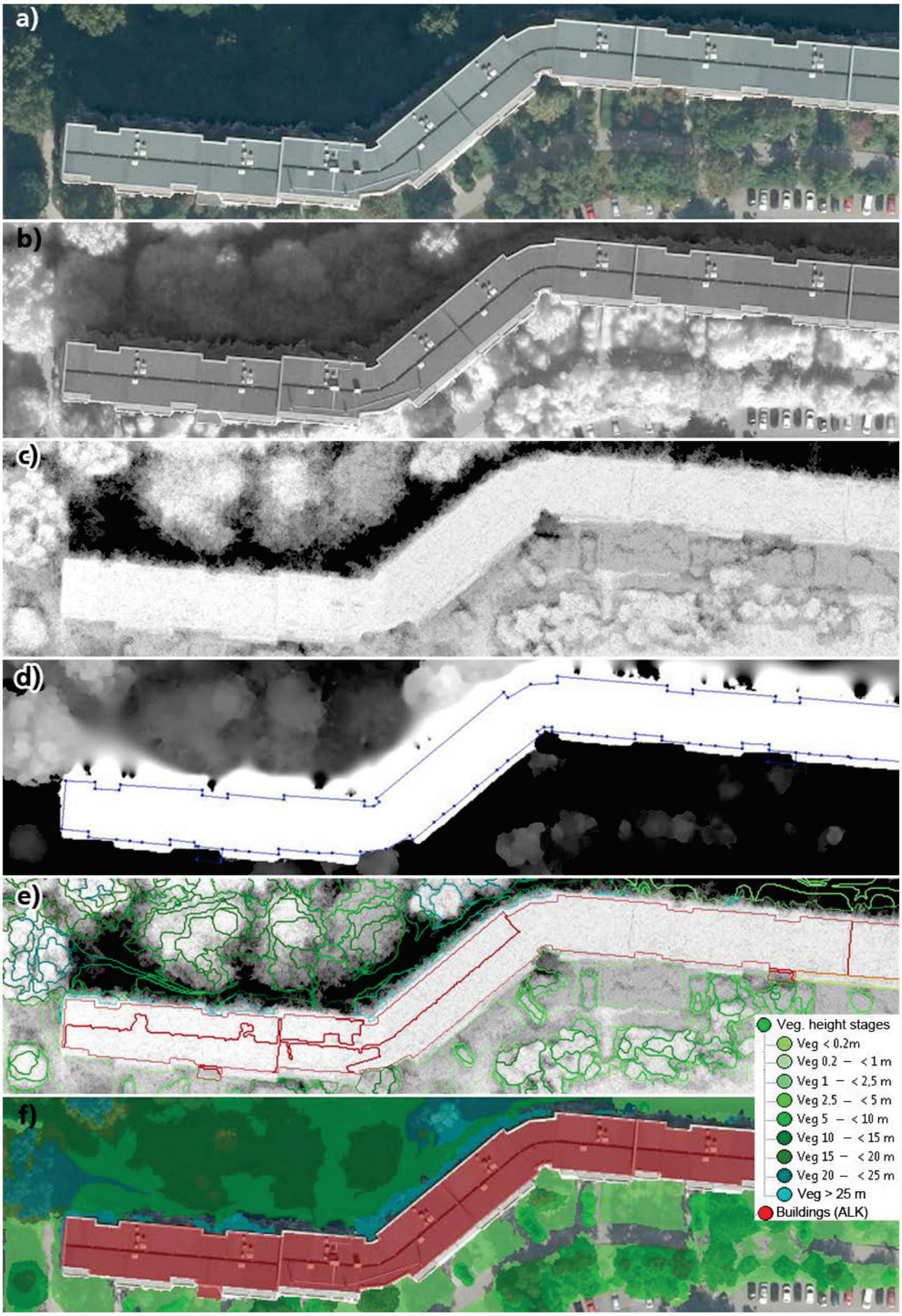


Figure 50: Misclassification of vegetation height stages, caused by interpolation of view shadows in DSM/NDSM

5.3 Export of the results and generation of a geo-database

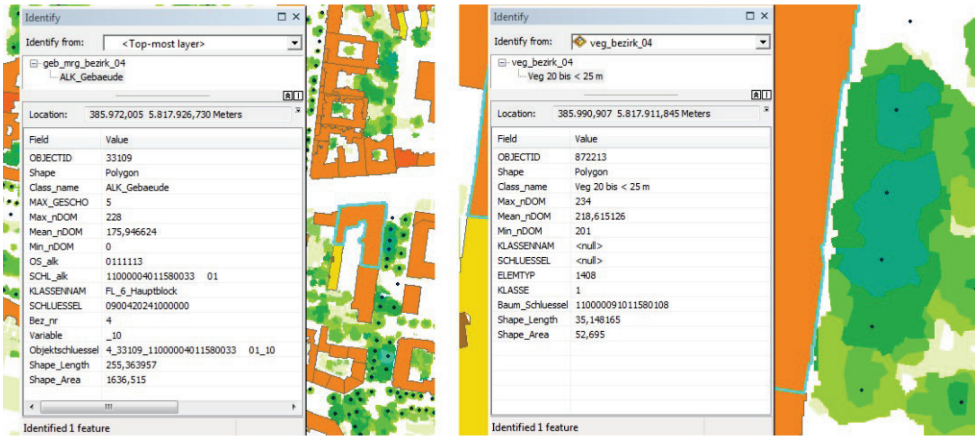
In order to ensure the integration of the results into a consistent geo-database (GDB), the latter was automatically exported with the corresponding attributes, taking into account the uniform designation. In this export process, it is possible to choose between two different edge modes for the polygons: They can be exported either rastered or smoothed. In case of rastered edges, each polygon support point is also exported, which on the one hand ensures pixel-precise data output, but on the other causes a fractal polygon structure. In case of smoothed edges, we obtain simplified polygons which, while they provide a homogenous image, may also lead to minor distortion of the results, due to the simplification. Neither of these export modes is optimal. Due to the smaller data quantities in the more homogenous phenomenology of the results, the smoothed polygon option was used for final export.

In the export of the results, all features and statistics available as attributes in eCognition can be attached. Thus, not only the automated height object extraction is carried out in eCognition; the assignment of relevant attributes also is. This assignment of a semantical significance and of attributes to the polygons created is of great use value for more far-reaching urban analyses.

The exported objects with their attribute tables are processed further in ArcGIS. The objects from the *ProgSpace* areas are merged at the borough surfaces. For each borough, a geo-database (GDB) is generated, in which the building and vegetation objects are stored with a distinct key. The idem code consists of the borough number, an object ID (which is established for each object at the time of import into the GDB), the ALK idem code and a variable for the object class. In this manner, a distinct key is created for each single element in the entire project area. For the building objects which are not in the ALK, a running numbering system is used in place of the ALK idem code.

The other attributes listed in the GDB include the class name (used for classification in eCognition), the maximum number of storeys, the maximum, minimum and average NDSMs, the idem codes of the OSKA, the block keys, and the polygon sizes and lengths (Figure 51). This complex attribute assignment of the objects in the GDB allows not only their precise assignment of position by borough, block and object, but also a description of their features based on class association and non-height and geometric features. The vegetation objects are then merged with the block areas and with the existing street tree register. Only the vegetation objects which intersect street tree points receive distinct tree keys.

The integration of the results into the GDB, and the compilation and creation of the idem codes are carried out in ArcGIS *ModelBuilder*, so that up uniform data structure and the distinct key assignment to the objects is provided for each of the 12 borough GDBs.



Identify from: <Top-most layer>

geb_mrg_bezirk_04
ALK_Gebaeude

Location: 385.972,005 5.817.926,730 Meters

Field	Value
OBJECTID	33109
Shape	Polygon
Class_name	ALK_Gebaeude
MAX_GESCHO	5
Max_nDOM	228
Mean_nDOM	175,946624
Min_nDOM	0
OS_alk	0111113
SCHL_alk	11000004011580033 01
KLASSENNAM	FL_6_Hauptblock
SCHLUESSEL	0900420241000000
Bez_nr	4
Variable	_10
Objektschluessel	4_33109_11000004011580033 01_10
Shape_Length	255,363957
Shape_Area	1636,515

Identified 1 feature

Identify from: veg_bezirk_04

veg_bezirk_04
Veg 20 bis < 25 m

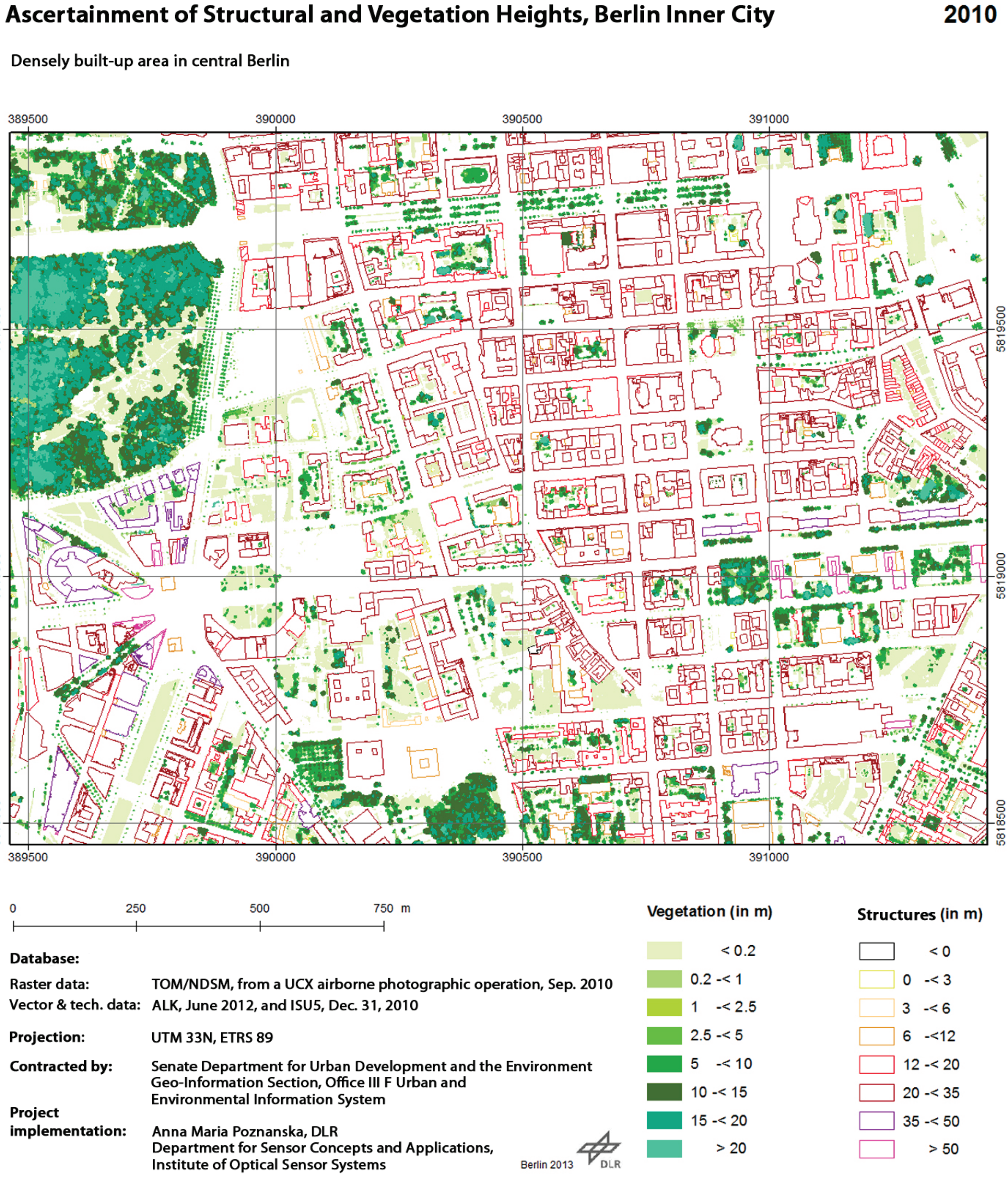
Location: 385.990,907 5.817.911,845 Meters

Field	Value
OBJECTID	872213
Shape	Polygon
Class_name	Veg 20 bis < 25 m
Max_nDOM	234
Mean_nDOM	218,615126
Min_nDOM	201
KLASSENNAM	<null>
SCHLUESSEL	<null>
ELEMTYP	1408
KLASSE	1
Baum_Schluessel	110000091011580108
Shape_Length	35,148165
Shape_Area	52,695

Identified 1 feature

Figure 51: Attributes of the GDB: building attributes (left); vegetation attributes (right)

In the following, examples of object extraction results are shown on maps:



Database:

Raster data: TOM/NDSM, from a UCX airborne photographic operation, Sep. 2010

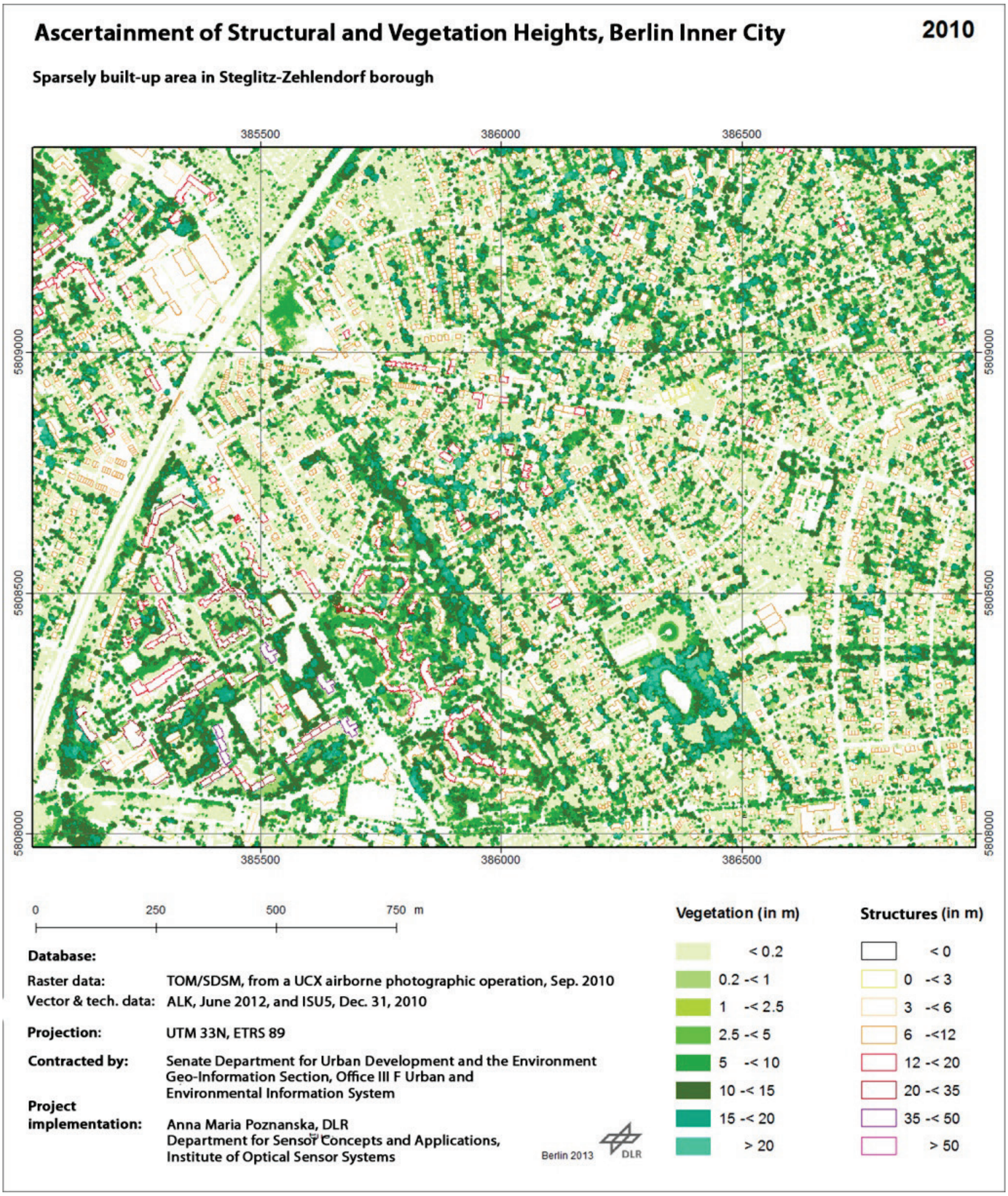
Vector & tech. data: ALK, June 2012, and ISU5, Dec. 31, 2010

Projection: UTM 33N, ETRS 89

Contracted by: Senate Department for Urban Development and the Environment Geo-Information Section, Office III F Urban and Environmental Information System

Project implementation: Anna Maria Poznanska, DLR Department for Sensor Concepts and Applications, Institute of Optical Sensor Systems

Figure 52: Map representation of the classification results in a densely built-up area of central Berlin



Database:

Raster data: TOM/SDSM, from a UCX airborne photographic operation, Sep. 2010

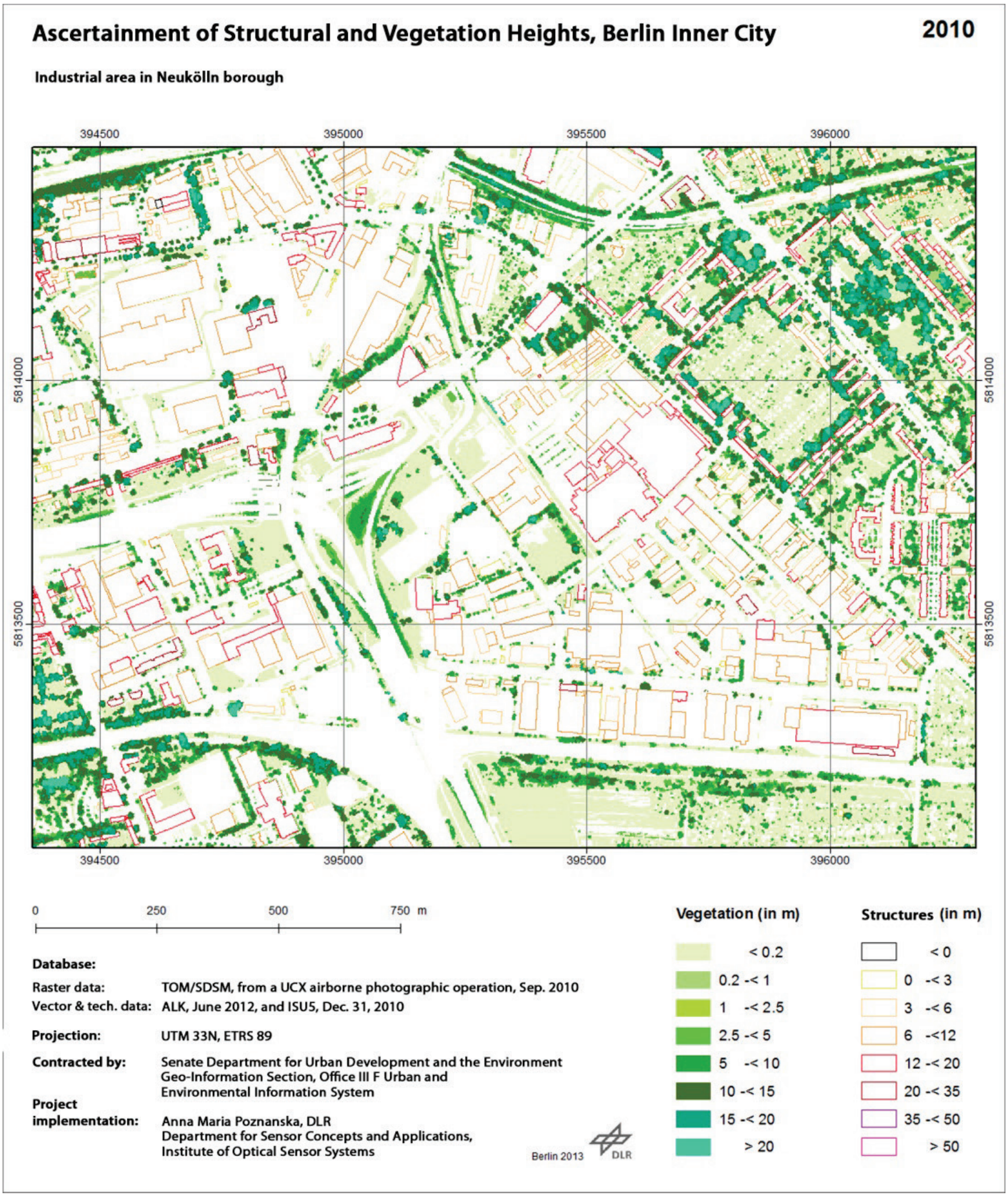
Vector & tech. data: ALK, June 2012, and ISU5, Dec. 31, 2010

Projection: UTM 33N, ETRS 89

Contracted by: Senate Department for Urban Development and the Environment
Geo-Information Section, Office III F Urban and
Environmental Information System

Project implementation: Anna Maria Poznanska, DLR
Department for Sensor Concepts and Applications,
Institute of Optical Sensor Systems

Figure 53: Map representation of the classification results in a loosely built-up area of the borough of Steglitz-Zehlendorf



Ascertainment of Structural and Vegetation Heights, Berlin Inner City **2010**

Industrial area in Neukölln borough

Database:

Raster data:	TOM/SDSM, from a UCX airborne photographic operation, Sep. 2010
Vector & tech. data:	ALK, June 2012, and ISU5, Dec. 31, 2010
Projection:	UTM 33N, ETRS 89
Contracted by:	Senate Department for Urban Development and the Environment Geo-Information Section, Office III F Urban and Environmental Information System
Project implementation:	Anna Maria Poznanska, DLR Department for Sensor Concepts and Applications, Institute of Optical Sensor Systems

Figure 54: Map representation of the classification results in an industrial area of the borough of Neukölln

Ascertainment of Structural and Vegetation Heights, Berlin Inner City 2010

Structural classes in central Berlin

Database:

Raster data: TOM/NDSM from a UCX airborne photographic operation, Sep. 2010

Vector & tech. data: ALK, June 2012, and ISU5, Dec. 31, 2010

Projection: UTM 33N, ETRS 89

Contracted by: Senate Department for Urban Development and the Environment Geo-Information Section, Office III F Urban and Environmental Information System

Project implementation: Anna Maria Poznanska, DLR Department for Sensor Concepts and Applications, Institute of Optical Sensor Systems

Berlin 2013

Figure 55: Map representation of building classes in central Berlin (in the background: TOM, RGB)

6 Conclusion and Outlook

The very high resolution digital aerial image data in the form of true ortho-mosaics (TOM) and standardized digital surface models (NDSM) have established themselves as an indispensable database for the automated object extraction in dense and heterogeneously built-up urban areas. In the interplay with the data of the ALK Berlin and the basic ISU5 map of a scale of 1:5000 of the Senate Department for Urban Development and the Environment, they constitute a reliable base for the ascertainment of building and vegetation objects, and for the derivation of their heights and structures. Moreover, the object based classification has proven to be a reliable method of extraction. The eCognition software provides a suitable environment for the development of a robust segmentation and classification rule base is. Moreover, an adaptation and optimization of the rules for the ensuing project phase or even for other areas is possible.

The rules developed during the first project phase are being adapted for the ensuing processing of the areas in the outskirts of the city and the adjacent surrounding areas. The results of both project phases are to be published in the Berlin Environmental Atlas, and in the Geo-Portal of the State of Berlin.

For further examination of the class *Buildings (not in ALK),* a change analysis is being developed at the time of the present publication. In this manner, potential objects can be shown that require updating of the ALK.

For the greened roof surfaces, possibilities for a conditional expansion of the detection of greening to areas hidden by shade are being evaluated. For example, shape and geometric properties of the roof surfaces are to be incorporated into the analysis. Moreover, the question of how more information from the shadow areas can be detected ´should also be investigated.

The ascertainment of vegetation structures can be considered very good. For further investigation, the ascertainment of single trees in the urban area is a priority. At this point, we should note the extraction approaches oriented toward the tips of trees and the determination of the circumference of crowns in BAYER et al. (2013). Although these analyses referred to forest areas, they are based on the same raster data foundations used in this project. The first transfer to other areas of the city of the rule bases developed in BAYER et al. (2013) has already been carried out, and has yielded promising results (BAYER et al. in press; POZNAŃSKA et al. 2013, accepted).

With reference to the database, an optimization of the NDSM would be desirable. Important for the analysis in the urban area is the extractability of all building categories, i.e. including the lower and smaller objects. Moreover, an optimization of the image attribution procedure would be useful, so that fewer interpolated areas occur.

In the framework of the first project phase, a complex and reliable set of rules for the automated object extraction of building and vegetation objects, and their semantical attributes in urban spaces was established. This can be used as a very good basis for the detailed urban application of small-scale climatic modelling, biomass determination, or urban planning analyses. By using standard datasets, transfer to other areas in Germany is possible.

7 Directory of Sources

Sources from the Literature Used

ALBERTZ, J. (2001): Einführung *in die Fernerkundung. Grundlagen der Interpretation von Luft- und Satellitenbildern* [Introduction to remote sensing: Foundations of the interpretation of aerial and satellite images], 2nd ed., Darmstadt.

BAATZ, M. & SCHÄPE, A. (2000): Multiresolution Segmentation: An optimization approach for high quality multi-scale image segmentation. In: STROBL, J. (ed.): *Angewandte Geographische Informationsverarbeitung* [applied geographic information processing] XIIth papers for the AGIT Symposium, Salzburg 2000, Karlsruhe, Herbert Wichmann Verlag, pp. 12-23.

BAATZ, M., BENZ, U., DEHGHANI, S., HEYNEN, M., HÖLTJE, A., HOFMANN, P., LINGENFELDER I., MIMLER, M., SOHLBACH, M., WEBER, M. & WILLHAUCK, G. (2004): *Definiens Imaging – eCognition*. User's Guide 4, Munich.

BAYER, S., MIRI, M. & BUCHER, T. (2013): Automatisierte Einzelbaumerfassung auf Basis von hochaufgelösten TrueOrtho-Mosaiken und photogrammetrisch abgeleiteten Oberflächenmodellen [Automated single tree ascertainment based on high resolution true ortho mosaics and photogrammetrically derived surface models]. In: *Publikationen zu 33. Wissenschaftlich-Technischen Jahrestagung der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation e.V.* (33rd DGPF Proceedings), vol. 22, pp. 26-35.

BAYER, S., POZNAŃSKA, A.M., DAHLKE, D., PILTZ, B. & BUCHER, T. (in press): Extracting Individual Tree Crown and Building Objects based on True ortho-mosaic and NDSM at Vaihingen Test Site. In: *Photogrammetry and Remote Sensing*

BLASCHKE, T: (2000): Ohne Salz und Pfeffer [Without salt-and-pepper]. In: *GeoBIT*, Vol. 2, pp. 19-21.

BLASCHKE, T. & STROBL, J. (2001): What's wrong with pixels? Some recent developments interfacing remote sensing and GIS. In: *GeoBIT/GIS,* Vol. 6/01, pp. 12-17.

DEFINIENS AG (2007): *Definiens Developer 7*– User's Guide. Munich

FACHVEREINIGUNG BAUWERKSBEGRÜNUNG (2011): Umfrage der Fachvereinigung Bauwerksbegrünung. Intensivbegrünung bei fast 17 %. [Survey of the Green Buildings Business Association: Intensive greening at almost 17%] In: *Dach + Grün*, Vol. 20 (3), 6.

GRUBER, M., PONTICELLI, M., BERNÖGGER, S. & LEBERL, F. (2008): UltracamX, the Large Format Digital Aerial Camera System by Vexcel Imaging/Microsoft. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. 37, pp. 665-670.

HEIPKE, C. (2003): Photogrammetrie & Fernerkundung – vom Elektronenmikroskop bis zur Planetenbeobachtung. In: *Photogrammetrie Fernerkundung Geoinformation* [photogrammetry and remote sensing: from the electron microscope to planetary observation], Vol. 3, pp. 165-180.

HIRSCHMÜLLER, H., (2005): Accurate and Efficient Stereo Processing by Semi-Global Matching and Mutual Information. In *Proc. of the IEEE International Conference on Computer Vision and Pattern Recognition* (CVPR 2005), San Diego, CA, USA, pp. 807-814.

HIRSCHMÜLLER, H. (2008): Stereo Processing by Semi-Global Matching and Mutual Information. In: *IEEE Transactions on Pattern Analysis and Machine Intelligence,* 30 (2), pp. 328-341.

HIRSCHMÜLLER, H. (2011): Semi-Global Matching. Motivation, Developments and Applications. In: *Proc. of the Invited Paper at the 54th Photogrammetric Week,* Stuttgart, Germany, pp. 5-11.

HIRSCHMÜLLER, H. & BUCHER, T. (2010): Evaluation of Digital Surface Models by Semi-Global Matching. In: *Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation* (DGPF), Vol. 19, pp. 571-580.

KINCHLA, R.A. & WOLFE, J.M. (1979): The order of visual processing: "Top-down", "bottom-up" or "middle-out". In: *Perception & Psychophysics* 1979, Vol. 25 (3), pp. 225-231.

KRAUS, K. (2004): Photogrammetrie (vol. 1). *Geometrische Informationen aus Photographien und Laserscanneraufnahmen* [geometric information from photographs and laser scan images], 7th ed., Berlin.

LEBERL, F. & GRUBER, M. (2003): Flying the new large format digital aerial camera Ultracam. In: *Photogrammetric*

Week, Vol. 3, pp. 67-76.

LEHMANN, F., BUCHER, T., PLESS S. & WIEDEN, A. (2011): Hochauflösende Oberflächenmodelle und True-Ortho Photos aus digitalen Luftbildkameras: Die Entwicklung anhand von Beispielen der letzten 10 Jahre [high resolution surface models and true ortho photos from digital airborne cameras: the development is illustrated by examples from the past 10 years]. In: *DGPF Proceedings* vol. 20/2011.

LINKIEWICZ, M. (2013): Extraktion von senkrechten Fassadenebenen aus 3D-Punktwolken von Schrägluftbildern [Extraction of vertical façade levels from 3-D point clouds from diagonal airborne images]. In: *DGPF Proceedings,* Vol 22, pp. 354-362.

MAYER, S. (2000): Retrieving object borders and height from high-resolution digital surface models. In: *Proc. of the World Multiconference on Systems, Cybernetics and Informatics*, Vol. 5, Orlando, FL, USA, pp. 433-438.

MAYER, S. (2004): *Automatisierte Objekterkennung zur Interpretation hochauflösender Bilddaten in der Erdfernerkundung* [automated object recognition for the interpretation of high resolution image data in terrestrial remote sensing]. Dissertation at the Humboldt University of Berlin.

MODER, F., OCZIPKA, M., SIEGERT, F., LEHMANN, F., DJAJADIHARDAJA, Y.S., KLEIN, R. & WAHL, R. (2008): Last-Mile – Large-Scale topographic mapping of densely populated coasts in support of risk assessment of tsunami hazards. In: *International conference on tsunami warning*, Bali, Indonesia, pp. 12-14.

MYINT, S.W., GOBER, P., BRAZEL, A., GROSSMAN-CLARKE, S. & WENG, Q. (2011): Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. In: *Remote Sensing of Environment,* Vol. 115/5, pp. 1145-1161.

POZNAŃSKA, A.M., BAYER, S. & BUCHER, T. (2013 ACCEPTED): 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. In: *SPIE Remote Sensing Conference in Dresden*, Germany.

Schiewe, J. (2002): Segmentation of high-resolution remotely sensed data concepts, applications and problems. In: *International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences,* 34(4), pp. 380-385.

SEBARI, I & He, D.-C. (2013): Automatic fuzzy object-based analysis of VHSR images for urban objects extraction. In: *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 79, pp. 171-184.

TRIMBLE eCognition (2010): *Trimble Documentation: eCognition Developer* 8.64.0. Reference Book, Munich, Germany.

TROSSET, A.M., BUCHER, T. & LEHMANN, F. (2009): Adaption of building extraction rule sets derived from MFC3 and UltraCamD aerial image data sets. In: *Proc. of SPIE*, vol. 7478.

WIEDEN, A. & LINKIEWICZ, M. (2013): True- Oblique- Orthomosaik aus Schrägluftbildern zur Extraktion von 3D-Geoinformationen [true, oblique, and ortho-mosaics from diagonal airborne images for the extraction in 3-D Geo information]. In: *DGPF Proceedings*, Vol 22, pp. 373-383.

ZADEH, L.A. (1965): Fuzzy Sets. In: *Information and Control,* New York & London, Vol. 8/3, pp. 338-353

Internet Sources Used

[*Links to English versions given where available; the German versions were generally used for the original article*]

DLR (2013a): DLR overview. Online in the Internet: http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10002/#/DLR/Start/About/ [As of: Feb. 1, 2014].

DLR (2013b): DLR, Institute of Optical Sensor Systems. Online in the Internet: http://www.dlr.de/os/en/desktopdefault.aspx [As of: Feb. 1, 2014].

DLR (2013c): DLR, Department of Sensor Concepts and Applications, Institute of Optical Sensor Systems. Online in the Internet: http://www.dlr.de/os/en/desktopdefault.aspx/tabid-7257/12172_read-10438/ [As of: Feb. 1, 2014].

DLR (2013d): DLR, Department of Sensor Concepts and Applications, Institute of Optical Sensor Systems: Modular Airborne Camera Systems. Online in the Internet: http://www.dlr.de/os/en/desktopdefault.aspx/tabid-8078/12173_read-28835/ [As of: Feb. 1, 2014].

ESRI (2013): ArcGIS: das umfassende GeoInformationssystem [The comprehensive geo-information system]. Online in the Internet: http://esri.de/products/arcgis/ [As of: July 1, 2013].

ESRI RESOURCES (2013a): ArcGIS Help 10.1. How Aspect works. Online in the Internet: http://resources.arcgis.com/en/help/main/10.1/index.html#/How_Aspect_works/009z000000vp000000/ [As of: July 12, 2013, no more available].

ESRI RESOURCES (2013b): ArcGIS Help 10.1. How Surface Slope works. Online in the Internet: http://resources.arcgis.com/en/help/main/10.1/index.html#/na/00q900000061000000/ [As of: July 12, 2013, no more available].

ISU (2013): Geoportal – Urban and Environmental Information System. Online in the Internet: http://www.stadtentwicklung.berlin.de/umwelt/info_system/index_en.shtml [As of: Feb. 1, 2014].

SENSTADTUM (2013a): Geoportal Berlin: FIS Broker. Online in the Internet: http://www.stadtentwicklung.berlin.de/geoinformation/fis-broker/index_en.shtml [As of: Feb. 1, 2014].

SENSTADTUM (2013b): Geoportal Berlin: Berlin Environmental Atlas. Online in the Internet: http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/edua_index.shtml [As of: Feb. 1, 2014].

SENSTADTUM (2013c): Geoportal. Liegenschaftskataster: Automatisierte Liegenschaftskarte (ALK-Berlin) [Automated Register of Properties]. Online in the Internet: http://www.stadtentwicklung.berlin.de/geoinformation/liegenschaftskataster/ [Feb. 1, 2014].

SENSTADTUM (2013d): Planen – Stadtwissen und Daten: Lebensweltlich orientierte Räume (LOR) in Berlin – Planungsgrundlagen [Planning, urban knowledge and data: Real-world oriented spaces in Berlin: Baes for planning]. Online in the Internet: http://www.stadtentwicklung.berlin.de/planen/basisdaten_stadtentwicklung/lor/ [As of: July 29, 2013].

TRIMBLE (2013): Trimble eCognition Software – Overview. Online in the Internet: http://www.ecognition.com/products [As of: July 1, 2013].

Directory of Figures

Directory of Tables