

06.10 Building and Vegetation Heights (2014 Edition)

Overview

The urban structural development of Berlin, with its effects both on the structure of residential and commercial areas and on the distribution and use of non-built-up areas, is shown in various ways on various Environmental Atlas maps:

- [06.01 Actual Use of Built-Up Areas](#)
- [06.02 Inventory of Green and Open Spaces](#)
- [06.07 Urban Structures](#)

The maps on [Urban Structural Density \(06.09\)](#) supplement this information with evaluations of the extent of structural use.

However, all these information items permit only indirect statements to be derived regarding the **vertical extent** of the natural and artificial structures in the city. This is true in spite of the fact that the **Automated Properties Map (ALK)**, the graphical part of the so-called Register of Properties, provides a cartographic foundation for buildings, is an up-to-date source of information on high-rises, with precise representation of ground space, and including information on numbers of stories. It also permits an approximate derivation of heights in meters above ground level (cf. Figure 1).

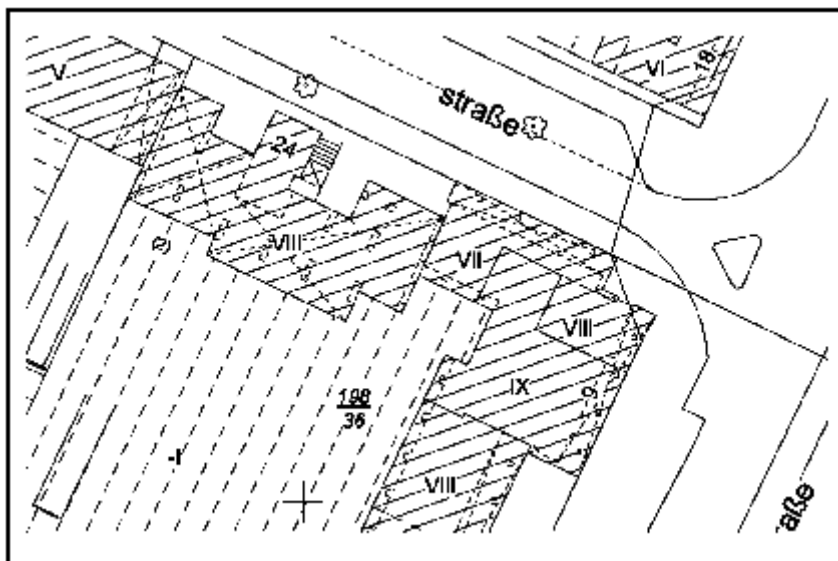


Fig. 1: Segment from the Automated Properties Map (ALK; number of storeys in Roman numerals)

Precise and detailed statements on the height and structure of buildings and vegetational areas can be of great significance for various utilization purposes. The usefulness of such a database includes its ability to provide information on:

- complete mapping of greened roofs
- more precise urban climate modelling
- additional differentiation in the mapping of uses in green areas, and
- detailed ascertainment of air and noise pollution in residential areas.

The precision of any modelling of course depends to a large extent on the quality of the input data. For example, in order to permit a detailed calculation of the course of air channels and ventilation conditions, the **aerodynamic surface roughness**, including its geometrical dimensions, must be known as

precisely as possible. Elevated objects, such as buildings or entire blocks of buildings, and also high and dense tree structures, constitute barriers, the effect of which may be to brake the wind even to the point of complete standstill, or else they may have a channelling effect, leading to accelerated wind flows.

With the aid of airborne remote sensing, information on the urban climatic conditions can be derived not only from thermal image procedures, but also indirectly, by means of object-referenced information. The shaping of the urban terrain profile by anthropogenic impervious residential and commercial structures, industrial facilities, and traffic and car-park surfaces, is the key factor here. The types of imperviousness, as well as the building and vegetation structures, have been determined in some detail by means of remote sensing.

The main goal of the present map is the derivation of **building heights** and the extraction of **vegetation height levels** for Berlin and the immediate surroundings. An additional goal is the preparation of a **geo-database** with specific object information, and the provision of this data as a basis for further urban analyses.

All necessary work steps have been undertaken by the Optical Sensing Systems section of the German Aerospace Centre (DLR); they were structured into two project phases. The results of the first phase cover an area of the city of approx. 450 sq km, which, in addition to the entire inner city, includes primarily parts of the southern half of Berlin. The mapping of the rest of the city during the second project phase was also concluded in mid-2014. Due to the different quality of the data, the two areas are to remain separate during the further processing and presentation phases (see also Map Description). The following text is based largely on the [Project Report](#) of the first phase.

Statistical Base

Breakdown into project phases

The full-coverage processing of the area of the City of Berlin and its immediate surroundings is being carried out in two separate processing steps, which are distinguished both in terms of the available data bases and of the different morphological characters of the two working areas.

While in Phase 1 for an area of approx. 445 sq km in the city of Berlin, data very rich in detail were gathered, the data resolution was significantly less in Phase 2 on the remaining urban area and the immediate surrounding area of Berlin, an area of approx. 1,800 sq km (cf. Figure 2). This difference was due to the much more homogeneous structural and vegetation characteristics of the marginal areas of Berlin and the surrounding region. In the following, primarily the data collection and its processing during the first phase of the project, and with regard to the territory covered during that phase, are described.

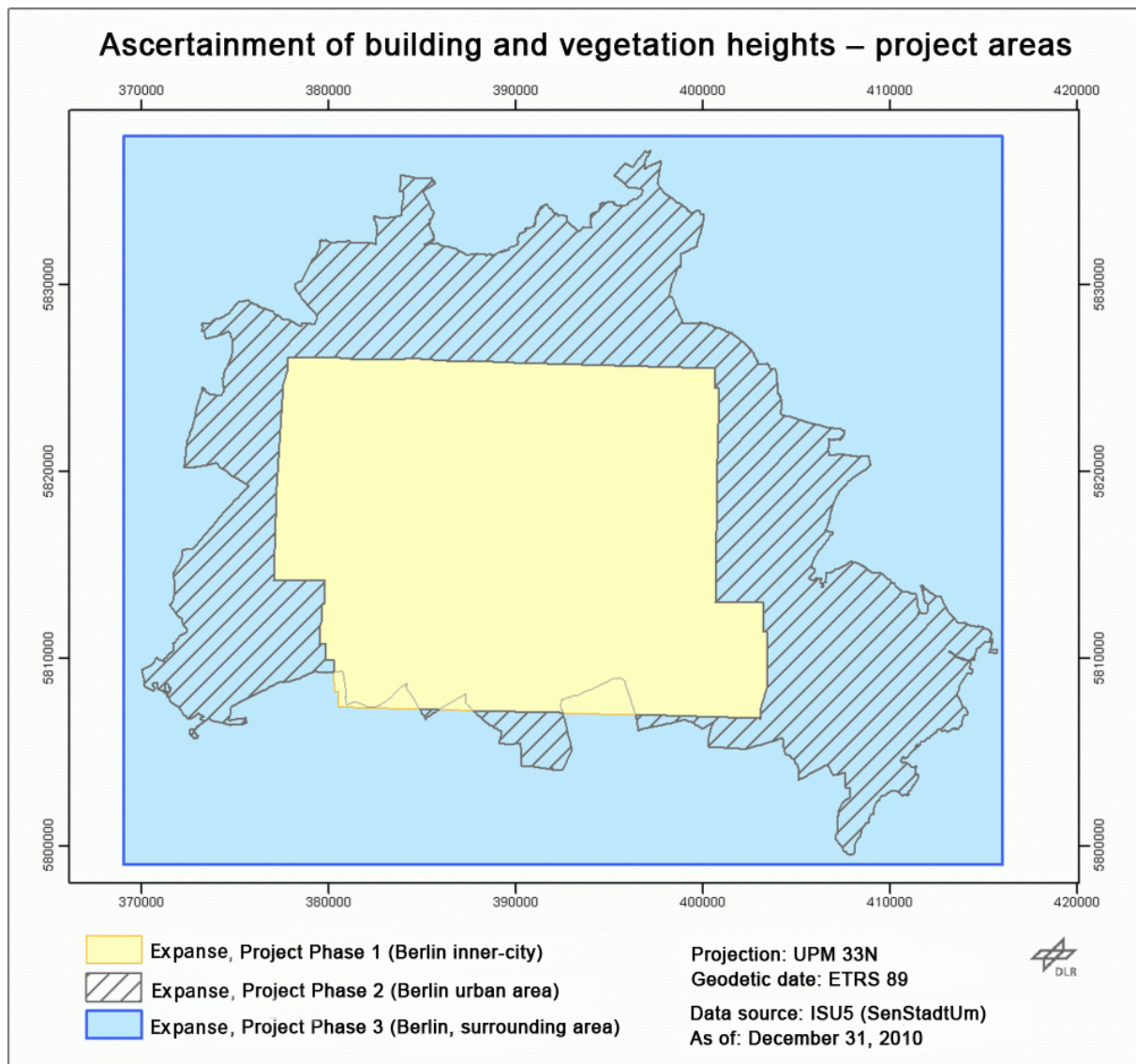


Figure 2: Extent of the project area: Area of the city of Berlin and surrounding areas (Source: DLR 2013)

The 2009/2010 aerial photography flights and the images obtained

A **Vexcel UltraCam X** digital aerial photography camera was used to obtain the images. The basic principle of this camera model is the separation into two classes, each with various lenses, with one class providing the panchromatic image, and the other colour images in the channels red, green, blue and infrared, in this case with a pixel resolution of 14,430 x 9,420, via a CCD sensor.

Matrix camera photography uses digital matrix-shaped large-area sensors and central projection. The depiction of the earth's surface is thus limited to a rectangular, usually square image segment. Adjacent image segments overlap by approx. 60%; this overlap serves to subsequently compile an overall mosaic, and also to generate the surface model of the image area depicted. The GPS/INS (Inertial Navigation System) provides a highly precise orientation of the image data.

The aerial photography flight project over the Berlin inner city was conducted during the early autumn of 2010, and that of the outskirts of the city and the surrounding areas during late summer of 2009. The most important aerial photography parameters from the flight logs in the technical report are compiled below.

They show that the quality of the aerial photographic material during the two project phases was very different. This fact, for example with regard to the radiometric resolution of 10 cm in Phase 1 as opposed to 50 cm in Phase 2, is also reflected in divergence of precision of the ascertainment results, the quality of which must be considered in the context of these different input data.

	Project Phase 1 (inner-city area)	Project Phase 2 (outskirts area)
Camera and product data::		
Sensor	UltraCam X matrix camera (Vexcel GmbH, today Microsoft)	UltraCam X matrix camera (Vexcel GmbH, today Microsoft)
Photographic products	True-colour image (TCI) and infrared channel (IR), digital surface model (DSM)	True-colour image (TCI) and infrared channel (IR), digital surface model (DSM)
Ascertainment data:		
Date of photography	Sep. 23, 2010 8:05 / 11:24 a.m. CEST	Aug. 24, 2009 7:55 - 11:50 a.m. and 2:05 - 4 p.m. CEST
Flight carried out by	BSF Swissphoto GmbH	BSF Swissphoto GmbH
Ground resolution	10 cm	50 cm
Longitudinal/ transversal overlap	80 / 60 %	80 / 40 %
Flight strips	17	13
Total number of images	1,793	416
Aero-triangulation	Trimble Inpho	Trimble Inpho
Surface generation	Software UltraMap (Microsoft)	Semi-Global Matching (DLR)
Altitude above ground	Approx. 2,090 m	Approx. 7,000 m
Extent:		
Geographic extent	445 km ²	1,800 sq km
Coordinates:		
Coordinate system	UTM, Zone 33N	UTM, Zone 33N
Geodetic date	ETRS89	ETRS89
Reference ellipsoid	GRS80	GRS80
GPS:		
GPS reference station	SAPOS Station, Wilmersdorf, Berlin	unknown
GPS processing precision	Position and height theoretically 5-6 cm; realistically 10 cm	Position and height theoretically 10-15 cm; realistically 15-20 cm

Geo-base and planning data

In addition to the above stated data, vector data in the form of statistical blocks and block segments, as well as building and street tree data (SenStadtUm 2010, 2013b) were also available, both for Project Phase 1 and for that part of the area of Project Phase 2 located within the city of Berlin. These data are completely available for all of Berlin, and include the following layers:

- **Automated Map of Properties (ALK) as of June 2012**
 - The Building Layer: Buildings existing, planned or under construction, with information on actual uses and numbers of stories
 - The Street Tree Layer (as of October 2009)
 - The Topographic Layer, with basic and supplemental topography
- **City and Environment Information System Block Map 1:5000 (ISU5), as of December 2010**

- The Block Layer: Blocks and block segments, with information on urban structure and use type
- The State and Borough Layers
- The Prognosis Area Layer.

The ISU5 Block Map constitutes the reference geometry for the ascertainment of the items to be determined, and their heights. The area of the city includes some 25,000 blocks and block segments. The extracted objects are cross-referenced to the block keys with a specific building key, so that each item is identifiable not only by its precise position, but also by its attribution to a certain type, and to a block and a block segment number (cf. Figure 3).

For the surrounding areas in the state of Brandenburg (Project Phase 2), the following additional vector and create data were also available:

- **ALKIS as of October 2013**, with the layers
 - buildings, and
 - actual use areas
- **Digital terrain model (DTM)**, at a spatial resolution of 1 m (DTM1)

Note: The altitude data ascertained for the surrounding areas in the State of Brandenburg are not available online



Figure 3: Section of the geo-base and technical data used: ALK building layer (red), ISU5 block boundaries (yellow), street trees (green), with a TrueOrtho-photo background (Source: DLR 2013).

Methodology

Procedure

The procedure for determining the building and vegetational height involves a high-effort process which can be described only roughly here. For detailed information, especially with regard to the details of particular procedural steps, which nonetheless have a considerable effect on the quality of the results, please refer to the [Project Report](#), the technical literature, e.g. Bayer et al. (in publication), or the appropriate websites, e.g. that of the [DLR](#).

Figure 4 shows the basic course of the procedure, which is then described in the sections below.

The main work steps are shown in various colours: segmentation steps in orange, classification steps in blue, and the export of the results in grey.

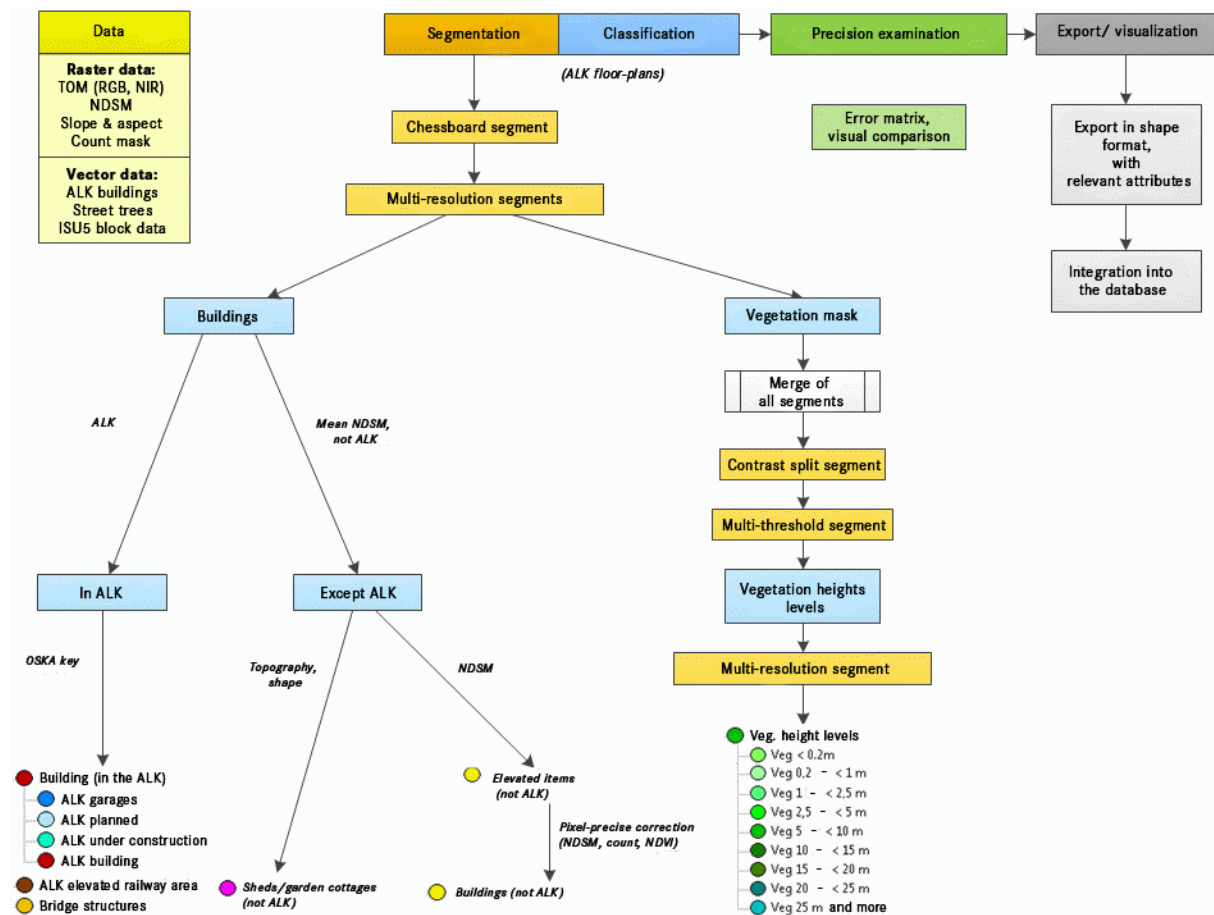


Fig. 4 Work procedure for the ascertainment of buildings and vegetation items in the Berlin urban area (Source: DLR 2013).

Data processing (DSM/TOM generation)

The **Digital Surface Model (DSM)** and the **TrueOrthoMosaic (TOM)**, which is generated on the basis of the former, are processed on the basis of stereo photography. If the orientation parameters of the GPS, the Inertial Navigation System (INS) and the Satellite Positioning Service of the German Ordnance Survey System (SAPOS) are available, the single overlapping aerial photographs are linked via so-called tie points, compiled into a composite image, and simultaneously transferred to the required coordinate system (Kraus 2004).

The DSM provides coded elevation points of the earth's surface, including all items located upon it (buildings, roads, vegetation growth, etc.). This is done by adding the terrain elevation to the height of the item. Since the terrain elevation in Berlin, while not showing particularly great differences of topography – the range is between 35 m and 100 m above sea level – is nonetheless not constant, no conclusions regarding the respective absolute item height can be drawn at this time. For this, a **Normalized Digital Surface Model (NDSM)**, in which the terrain is everywhere set to a standard of zero, would be required. The NDSM is accordingly generated by subtracting the **Digital Terrain Model (DTM)** from the digital surface model (DSM):

$$\text{NDSM} = \text{DSM} - \text{DTM}$$

With respect to the ensuing segmentation and classification, this simplifies the distinction between elevated and non-elevated objects, and permits direct measurement of object heights. It permits the distinction between streets, elevated vegetation, and structures, and provides precise height information (cf. Fig. 5).

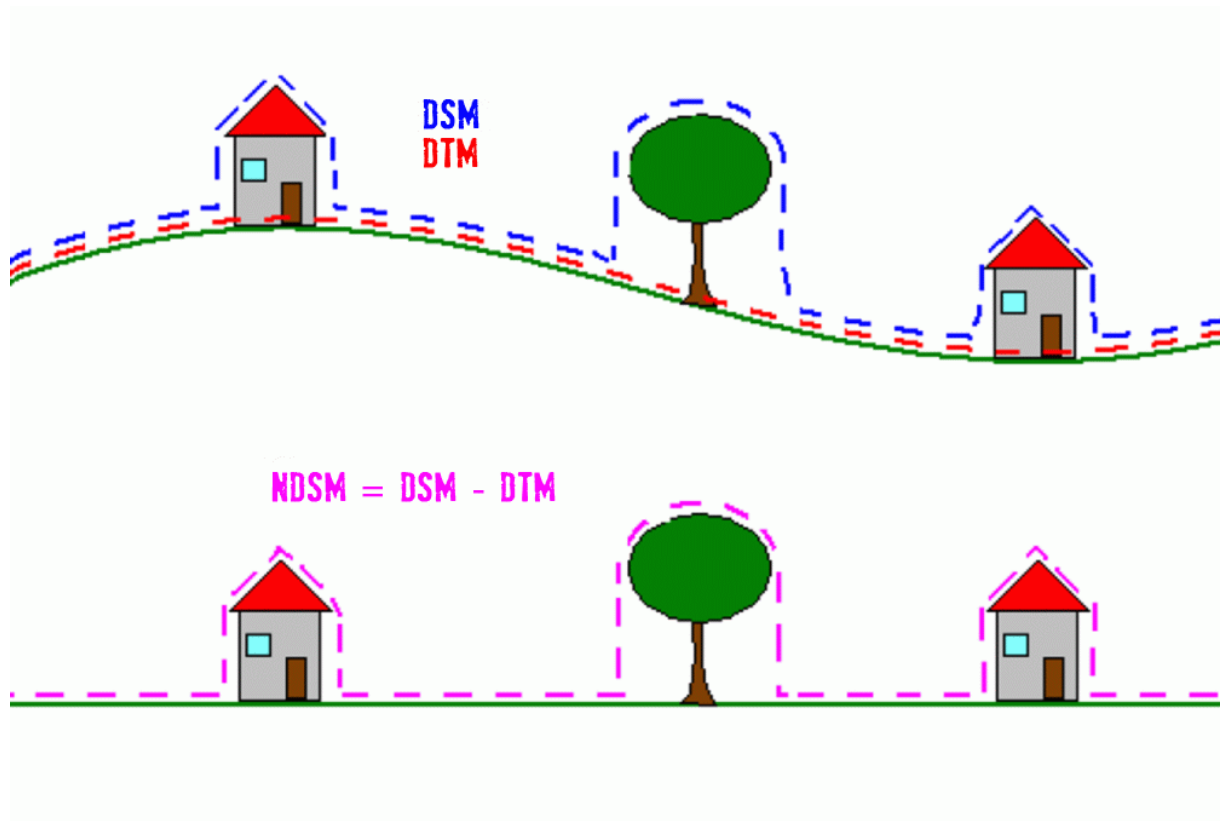


Fig. 5: The principle for the generation of a Normalized Digital Surface Model (NDSM)
(Source DLR 2013, cf. Mayer 2004)

The basic material provided by the aerial photography flight prior to data processing is a composite aerial image with a central perspective depiction. This type of projection results in an image of the object which is geometrically distorted toward the edges. Hence, no uniform scale is present in the image, and no realistic distances can be calculated. In order for the image data to be useful in the geo-information system (GIS), a differential rectification must be carried out with the aid of a DSM. This procedure results in a **TrueOrthoMosaic** (TOM). With the aid of TrueOrtho image generation, it is then possible to determine the geometrically exact position of pixel precision, since each pixel only has one position within the DSM. The result is that there is no longer any tilting, which, e.g., might permit building façades to be visible; at the same time, it is only this correction of the image data of the measurement that makes real distances possible (Heipke 2003, cf. Figure 7). The existence of a DSM and its TOM is accordingly the basic precondition for precise analysis in densely built-up urban areas, and considerably increases the reliability of statements.

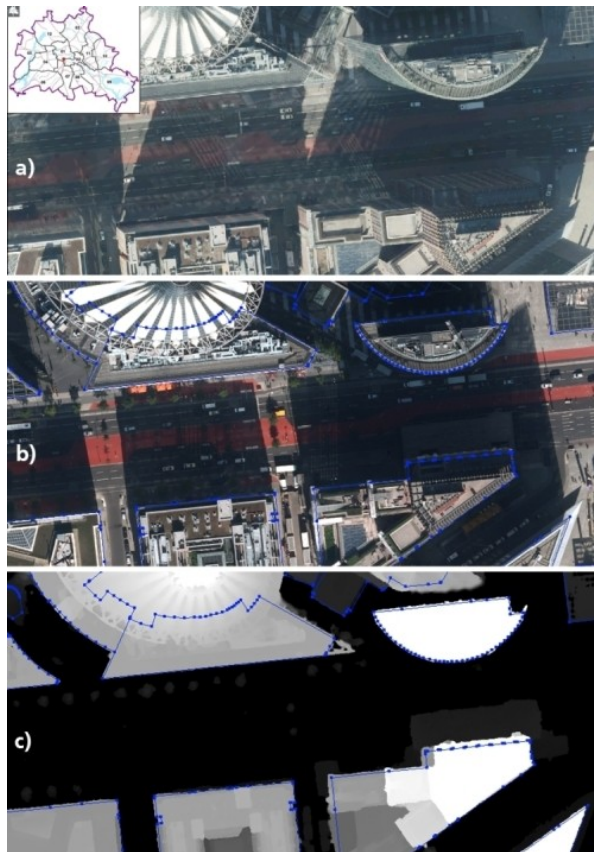


Fig. 6: A comparison of the DOP and the TOM: a) DSP 20RGB 2011, with tilted building images (Source: SenStadtUm – FIS-Broker); b) TOM RGB, with ALK building contours and building edges superimposed and corrected true to the position; c) NDSM with ALK building contours superimposed (Source: DLR 2013).

The further procedure described below refers, inasmuch as values are stated, to the **consistently qualitatively better input material from Phase 1**. Hence, not all corrective steps, e.g. for the ascertainment of vegetation in shaded areas, can be carried out in the areas of Phase 2.

The existing TOM database consists of four channels: red, green, blue (true colours RGB) and near-infrared (NIR) in a geometric resolution in x/y of 15 cm. Similar to the NDSM, spectral data are reduced to a resolution of 30 cm. This primarily serves to reduce the data quantity, but also takes into account the spectral geometrical heterogeneity of the item being ascertained (Trosset et al. 2009). Due to the fact that the aerial photography for both phases was conducted relatively late in the year (cf. flight parameters), the photographic products show a large amount of shading. Thanks the high radiometric resolution of more than 12 bits, and the simultaneously generated DSM, many objects in the shaded areas can nonetheless be correctly identified; however, this is true only for Project Phase 1. Particularly by means of the NIR channel, in which the vegetation heights show spectral values, it is possible to reliably ascertain the vegetation share (cf. Figure 7).



Fig. 7: Quality of the TrueOrthoMosaic (TOM) data produced: Use of the near-infrared (NIR) channel (below); the bright areas indicate high spectral values and good ascertainability of the vegetation shares (Source: DLR 2013)

With the increasing availability of **Very High Spatial Resolution (VSHR)** remote sensing data, the suitable methods for processing them and the yield of information from these data also increases. Particularly in densely built-up urban areas characterized by a high degree of heterogeneity of structures, this task has proven to be very complex. Even though it has been the VHRS data which have made possible the satisfactory analysis of urban spaces, the high degree of resolution and the resulting greater degree of heterogeneity of the data has generated additional problems. Given the large quantity of data, it is therefore necessary to use suitable methods for the large-scale processing of data.

Analysis and segmentation

In remote sensing, two different approaches of image analysis are used: the object based approach and the pixel-based approach. In the object based analysis used here, single items are analysed in their respective contexts. As a result, not only the spectral properties, but also the object forms, textures and especially the neighbourhood relationships – all of that information which cannot be derived from a single pixel – are taken into account. In this way, the object based procedure attempts to model itself upon the human method of perception. Unlike with pixel-based analysis, it is not single image elements, but the **more expressive homogenous segments** consisting of a number of pixels which form the basis of classification (Blaschke 2000).

The data driven procedure used in this project thus segments the entire image scene with the aid of certain statistical procedures and defined parameters. The resulting segments are pixel clusters which do not yet have any particular semantical significance. Only the ensuing classification assigns these items to those classes with the class description of which they most closely correspond. The quality of segmentation is determinant for the following classification. For this reason, the software used also contains various segmentation algorithms which can be applied.

The segmentation method known as **Multi-Resolution Segmentation (MRS)** is of exceptional importance, especially for the generation of the vegetation masks. Here, adjacent pixels which fulfil certain homogeneity criteria are compiled into ever larger segments. This is carried out as long as a certain threshold value of homogeneity is not exceeded. The more precisely the desired item or item segment reflects its real shape, the easier it is to carry out the ensuing classification (Baatz & Schäpe 2000).

Figure 8 shows this segmentation procedure via a number of object hierarchy stages, in which smaller items (e.g. parts of buildings) are classed at the lower levels and the larger ones (ALK buildings) at the upper levels. By means of this procedure, the item segments “inherit” the properties (e.g. item keys) of the respective “mother” items, e.g., of the ALK buildings.

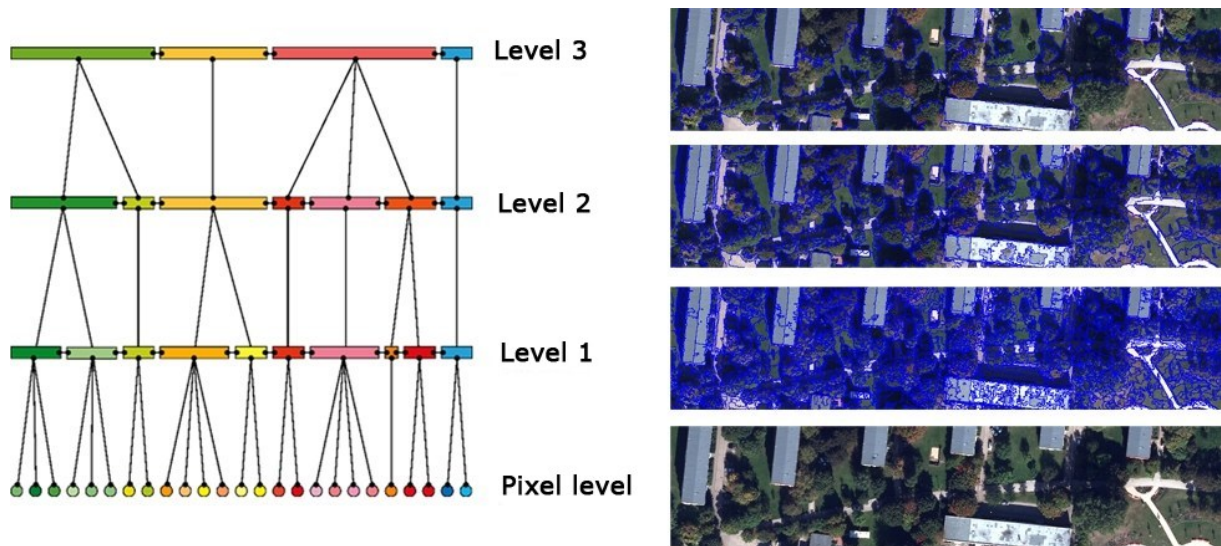


Fig. 8: Abstract depiction of the object hierarchy and several scale levels (left), and with image examples (right) (Source: DLR 2013)

Object-based classification

Based on the existing digital aerial photography images and the NDSM, it was possible to define certain **item classes** with the aid of ALK building data. Object based classification is a multi-stage procedure. The particular steps are processed hierarchically along the so-called process tree (cf. Figure 9), and then stored; they are thus available for use in later procedures (e.g. in the context of monitoring by means of change analyses).

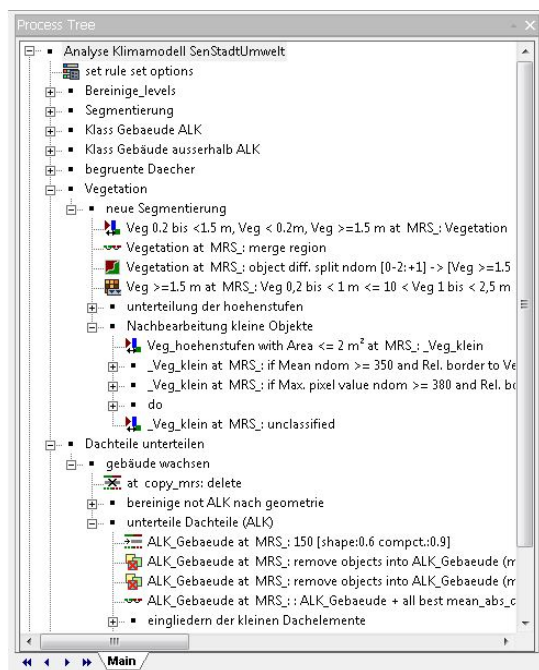


Fig. 9: Process tree developed for object-based classification (depiction of a segment) (Source: DLR 2013)

The classification is structured for the following areas of evaluation emphasis:

First, two main classes are distinguished (Buildings and Vegetation). In addition, other sub-classes are defined for the vegetation and for the buildings, respectively, in the form of height levels; moreover, the buildings are also broken down into further semantical classes (e.g. garages, sheds, garden houses and "Buildings planned or under construction").

Ascertainment of the buildings

In the area of buildings, various item classes are distinguished, which are also to be kept separate in the further procedure, and in the data storage in the GIS:

- **ALK-Level Buildings, in the categories:**
 - Existing
 - Planned/under construction
 - Special ascertainment of the following use types: garages, sheds, garden and weekend cottages
 - Special category: "Roof area under trees"
- **ALK-Level Topography (bridges, above-ground railway areas)**
- **Above-ground structures which are not part of the ALK, in the categories**
 - Sheds/garden cottages under the ALK building key system "Allotment gardens or cottage colonies"
 - Buildings
- **Greened roofs, distinguished by location as:**
 - ALK buildings
 - Non-ALK buildings.

In a generalized segmentation process, the higher buildings are separated from the lower ones on the basis of certain homogeneity criteria. Next, a more detailed **segmentation** of the vegetation from the anthropogenic items is carried out. For this purpose, adjacent pixels which fulfil certain homogeneity criteria are compiled into ever greater segments. This is continued until a pre-established homogeneity threshold value is no longer exceeded. Distributed across the entire scene, all segments grow simultaneously, which ensures that they are of equal size, and hence comparable (Baatz & Schäpe 2000).

The classification of the measured buildings is carried out with the aid of the ALK building layer, so that, e.g., even large roof eaves ascertained in the aerial photography data can be corrected for. In addition, bridge-type items and above-ground railway areas of various types – especially railway stations and elevated railway tracks – can be ascertained as part of the ALK topography.

Low buildings such as sheds, garages or cottages which can often not be masked out under the interpolation rules of the surface model, can subsequently be ascertained in the ensuing step on the basis of the respective key from the ALK item key catalogue. The later assignment of heights is in this case carried out by reference to type of use (number of stories = 1 * 2.8 m).

The ALK level "Planned buildings" is also a separate item class which includes surface or subsurface buildings planned or under construction. For these items – some 1400 in the city, according to the ALK as of June 2010 – no conclusive heights can be determined. There are likely candidates for later change analyses (cf. Figure 10). However, it should be noted in this respect that structural changes or new structures are far more numerous than those documented in the ALK data.

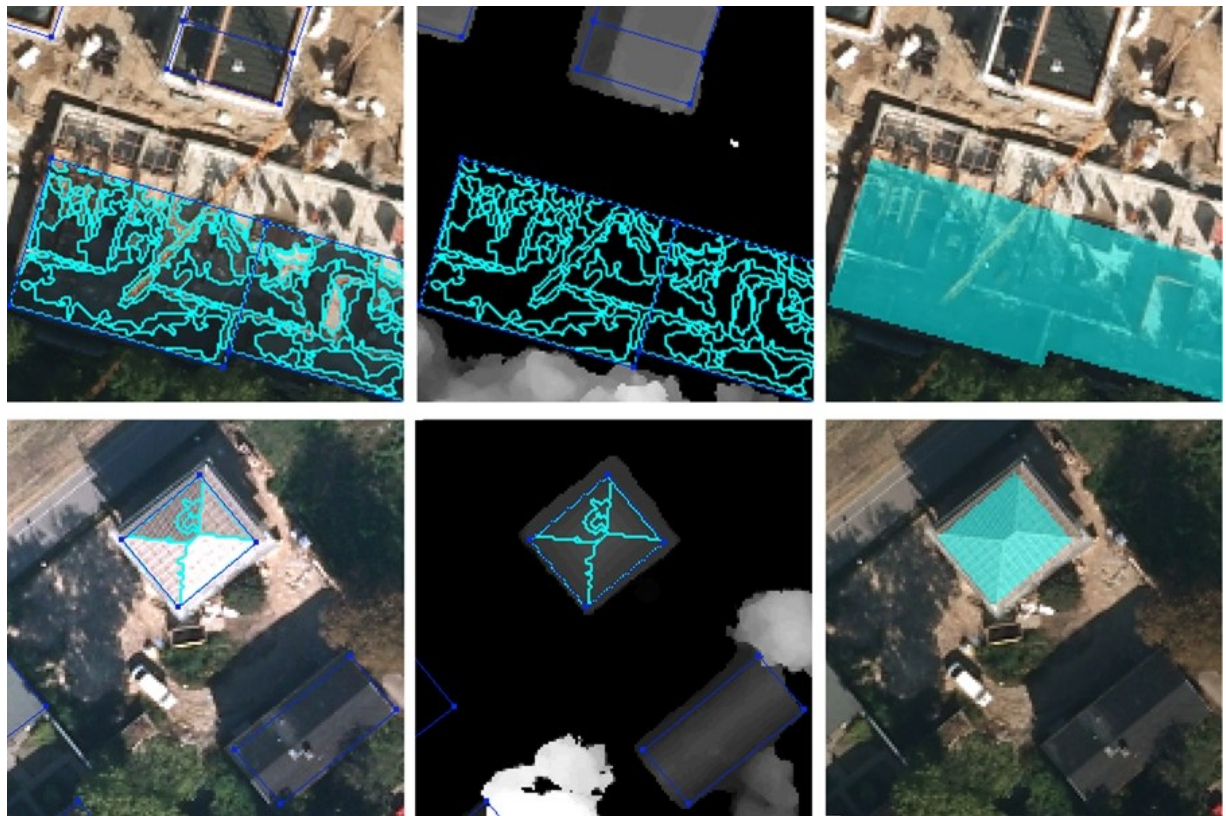


Fig. 10: Two classification examples for buildings of the item class “Buildings planned or under construction” (as of June 2012); left and middle: certain classified segments, and, right, as compiled items; in the top row is an example of the construction project in progress; below it is a building already completed at the time of the aerial photography flight in September 2010 (Source: DLR 2013).

All building items which are not part of the ALK structures but which are nonetheless structural entities, have been ascertained just as comprehensively. The example of the item class “Sheds/garden cottages” in allotment garden and cottage colonies illustrates the detailed precision of the procedure with which all built-up areas are to be largely classified without error, even prior to the generation of the vegetation mass. In the case of low garden cottages, the shape characteristics have been used to delimit them from road and pathway surfaces (cf. Figure 11).

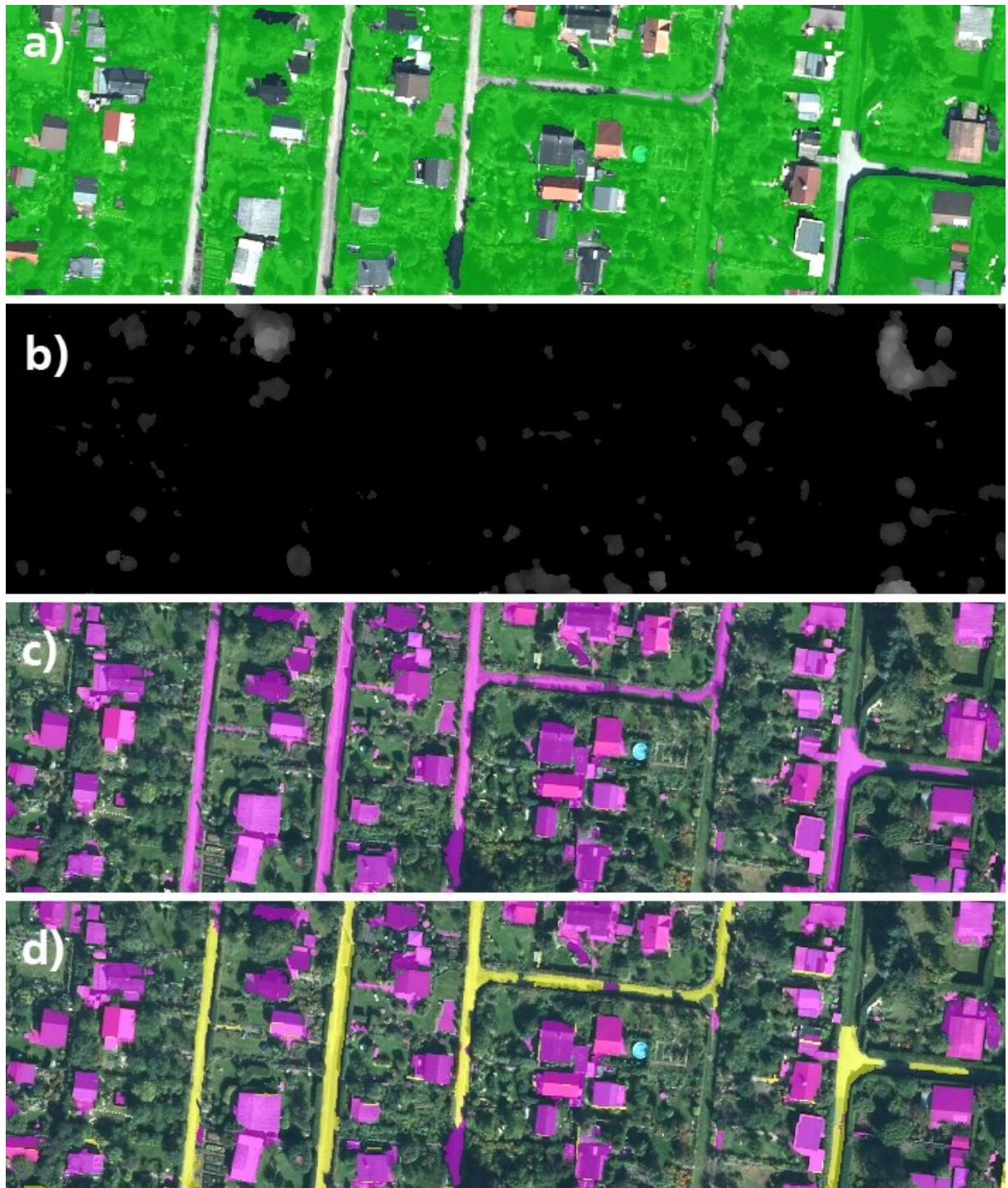


Fig. 11: Classification steps for the determination of the item classes "Garden cottages" outside the ALK system: a) The classification of the vegetation mask attained prior to this step, with real colour RGB aerial photography data superimposed; b) Situation-precise section of the surface model NDSM – no heights of garden cottages can be directly derived; c) Initial classification attempt yields errors in the area of streets; d) Ensuuing classification step, with correction for the street areas (Source: DLR 2013).

For buildings listed in the ALK, building heights are conclusively presented on the basis of the ALK building outlines and their storey lines. For this purpose, the ALK building polygons are first of all separated into ALK building portions by means of the storey lines. The heights of the building segments are then aggregated proportionately to these ALK building portions (Fig. 12).

Thus, the mean heights of ALK buildings are represented on the basis of ALK geometries. Buildings not listed in the ALK are therefore still presented by means of building segments.

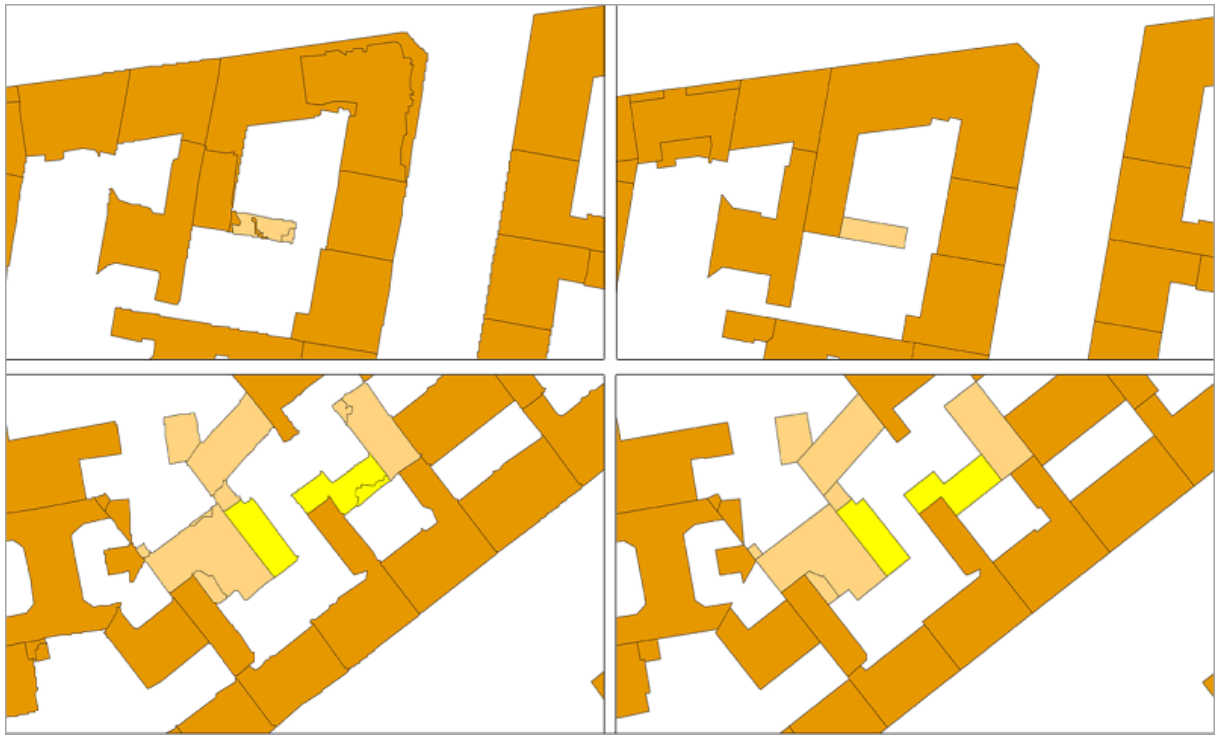


Fig. 12: Aggregation of heights of building segments to the ALK building portions; left: building segments; right: ALK building portions

Ascertainment of vegetation

After the classification of buildings, the classification of the vegetation mask is carried out. By means of the preceding multi-resolution segmentation (MRS), the existing items are very finely structured, so that the differentiated diversity of the existing vegetation can be shown. The usual method of vegetation extraction used in digital remote sensing is based on a vegetation index calculated by means of the channels red (R) and infrared (NIR) ascertained by aerial photography. This **Normalized Difference Vegetation Index (NDVI)** is derived as follows:

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R}).$$

The index uses the fact that vital vegetation yields particularly high values in the near-infrared range, and much lower values in the red spectral range, a constellation not found in any other class of items, which makes possible a simple separation between vegetation and other classes (Albertz 2001).

In order to ascertain the existing vegetation structures and heights, a **Contrast Split Segmentation (CSS)** process is carried out. In this way, the vegetation mask can be subdivided into lower and higher vegetation segments. The resulting detailed results provide a very suitable basis for the ensuing calculations with regard to further differentiation of vegetation height data. For this purpose, the **Multi-Threshold Segmentation (MTS)** method is used. This procedure uses the pixel values of the NDOM, and subdivides the existing segments according to the stipulated nine height levels, comparable to the drafting of a contour line map (cf. Figure 13).

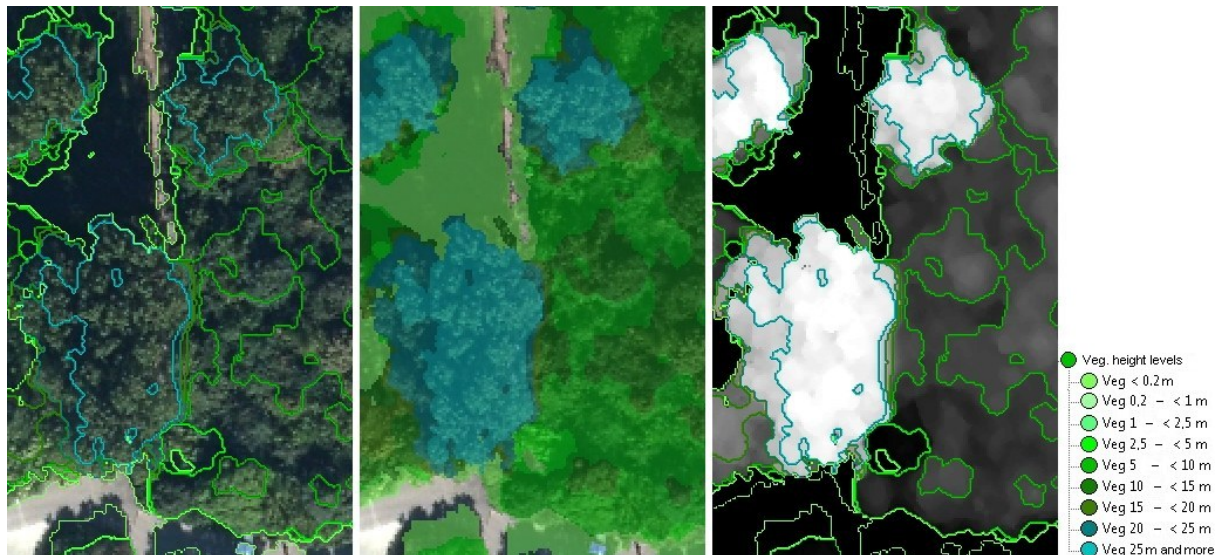


Fig. 13: Results of Multi-Threshold Segmentation (MTS) – Subdivision of the vegetation into nine height levels (Source: DLR 2013)

In order to address the differentiated diversity of vegetation on a still more detailed scale, the existing nine vegetation height layers are further subdivided by taking their height structures into account. With the aid of the already described MRS, it is thus possible to ascertain which different vegetation structures exist (cf. Figure 14).

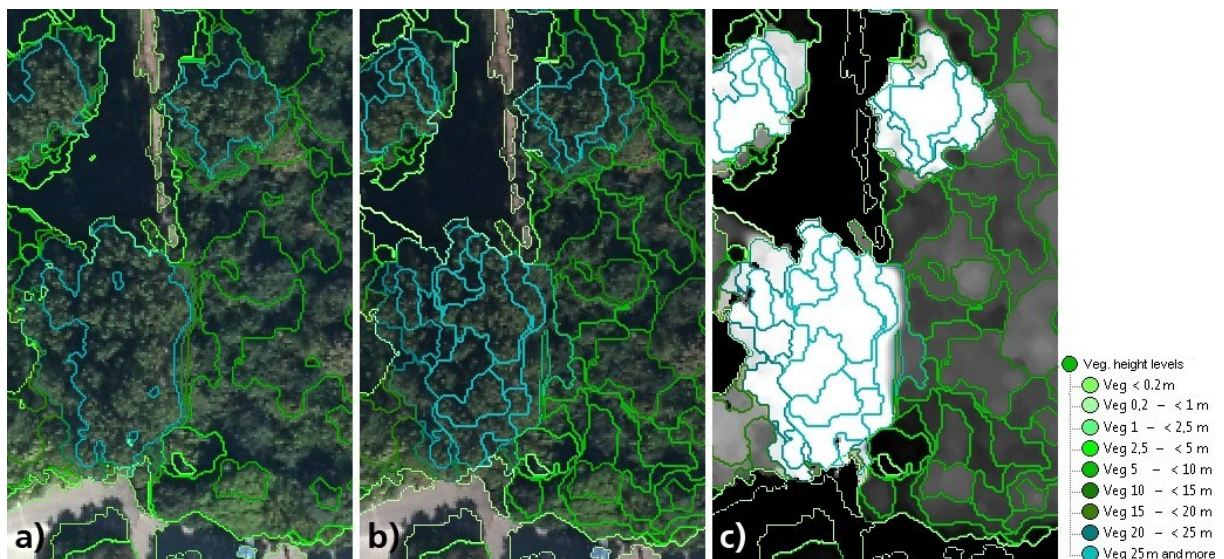


Fig. 14: Results of the subdivision into vegetation structures with the aid of multi-resolution segmentation (b & c) within particular height levels, from the preceding multi-threshold segmentation (a, cf. Figure 13) (Source: DLR 2013).

Greened roof surfaces

In connection with the measures for the adaptation to climate change or efforts for [sustainable concepts for rainwater use](#) [German only], the **ecological value of greened roofs** has increasingly been discussed. While Berlin has a long tradition of greening roof surfaces, there has to date been no full scale mapping of these types of roofs.

In the **initial ascertainment** carried out in the context of this project, no differentiation has been made with regard to varying intensities of roof greening, such as intensively used roof gardens or exclusively moss-covered roof surfaces (cf. Figure 15). The correlation of the vegetation mask with the building layer based on the ALK was to serve the purpose of categorization of surfaces as greened roofs, but it provided no conclusive result. Here, no account was taken of adjacent vegetation which might partially cover the roof and hence distort the result somewhat.

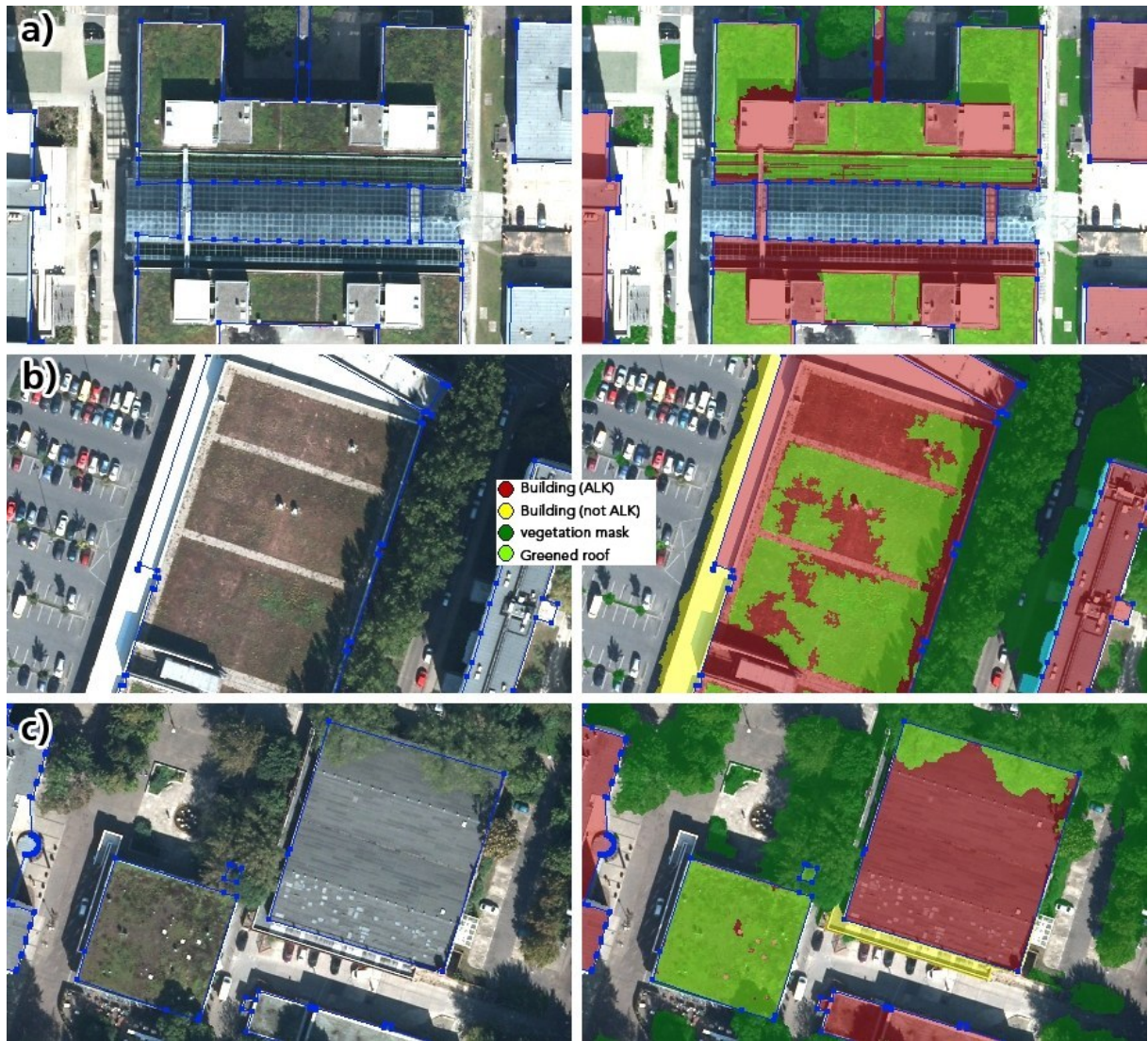


Fig. 15: Greened roof surfaces, as a result of the correlation of the vegetation mask with the ALK building layer (Source: DLR 2013).

In order to classify the vegetation items which cover roof segments, but are not themselves greened roof surfaces, the class of greened roofs was examined in NDOM and in NDVI for its differences from the adjacent items. If the items in the class “Greened roofs” showed only a slight **difference in height** with respect to adjacent tree items, and a greater difference in height with respect to the buildings, as well as very **similar spectral properties** to the trees, they were iteratively shifted to the class “Roof segments covered by vegetation”. In Figure 16, the necessity of this formation of classes can be clearly seen with reference to the attached NDOM image. If they were to remain classified as buildings, they would lead to a distortion of the figures for average building heights.

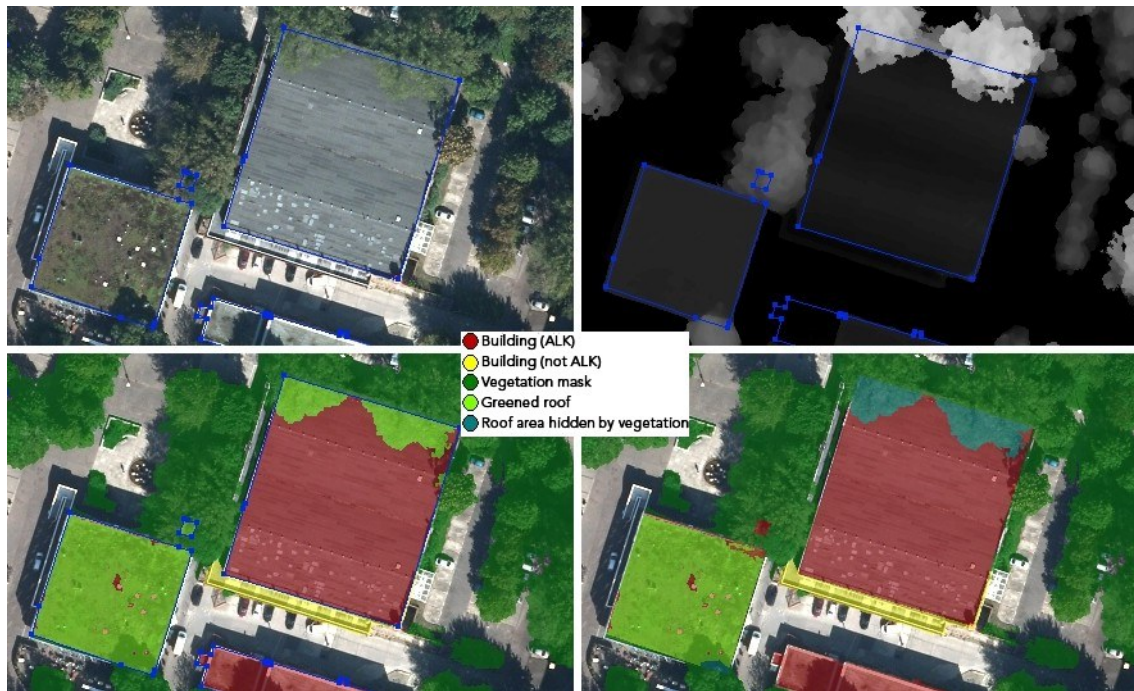



Fig. 16: Classification results of the class “Roof segments covered by vegetation” (conclusive representation below right) (Source: DLR 2013).

The classification of greened roofs also yielded several further errors which could be largely eliminated via spectral analysis of adjacent segments. The analyses carried out in the context of this project are insufficient to provide a very precise detection of greened roof surfaces with regard to their delimitation, and possibly also their vegetational stock; however, they do provide a largely complete **overview** of the generally greened roof surfaces. The initial ascertainment in the inner-city area shows that in the 445 sq km area processed, there were approx. 10,000 roof surface areas (a figure which does not equal the number of buildings) which have been greened to various degrees of intensity. Due to the poor resolution of the data obtained from the outlying areas, the information on greened roofs obtained in Project Phase 2 was not of satisfactory precision. For this reason, greened roofs in the outlying areas have not been marked.

Overall assessment of the quality of ascertainment

The assessment of the quality of the results requires differentiation between the two project phases. Overall, the resulting buildings and vegetation items in the inner-city area have been ascertained satisfactorily, and in some cases, particularly for buildings in the ALK inventory, the ascertainment has been very good. However, they have also shown certain weaknesses, which will be examined more closely in the following, and which are considerably more evident in the results from Project Phase 2, due to the less precise input data, which could only be corrected to a certain degree.

Exactness for buildings

Project Phase 1 (area shown in red )

The methods used involve exclusively computer-based and automated procedures of item extraction, which has a major effect on the quality of the results. The completeness and correlation of ascertained buildings can always be assumed to be very good if it can be supported by the ALK inventory of buildings.

The precision of ascertainment of buildings which are not part of the ALK can also be evaluated as very good, with some exceptions. These involve temporary objects such as circus tents or large construction containers, the ascertainment of which can only be corrected by manual post-processing.

Further subdivision of buildings according to their roof segments, which is based on the respective roof geometry, can often be implemented to a degree which is only satisfactory. The sensitivity of the MRS method achieved to date, using the spectral channels, is insufficient for an exact determination of problematic areas involving shading. The problems of these limits of ascertainment procedures can be

clearly seen in the context of the ascertainment of greened roofs in the shadows of overhanging trees and vegetation objects with visible shadows of buildings (cf. precision of vegetation heights).

The greened roofs have also been satisfactorily determined with respect to the targeted initial ascertainment. The completeness of their extraction has however on occasion been distorted by shading. With the aid of an initial relatively precise investigation of 20 selected greened roofs, a high degree of correspondence with regard to correctness and completeness of the results can be demonstrated. Approx. one third of the correctly detected surfaces show a completeness of the ascertained surface of below 50 %, while half show a completeness of more than 75 %. Taking into account the various factors which can interfere with this classification, this result can be considered good.

In addition to the realization of an ascertainment of the surface extent of items which is as close as possible to reality, the **quality of determination of item types** is of particular importance. With regard to the “average value of ascertained heights” indicated in the factual data representation, it should be noted that such average values can in some cases in which several areas of the building have very different heights and expanses, lead to arithmetic combined values which deviate considerably from the maximum height of one part of the building. In the context of the item determination of buildings, therefore, maximum heights are also ascertained which are, however, of less importance for the major part of the building, e.g., if they involve only small smokestack areas, etc. On the other hand, the Victory Column is given with an average height of only approx. 20 m, although its maximum height is almost 70 m (cf. Figure 17). In other cases, such as, e.g., ordinary residential buildings, this type of calculation is, however, advantageous, since the maximum heights here are much less significant than the calculated average heights.

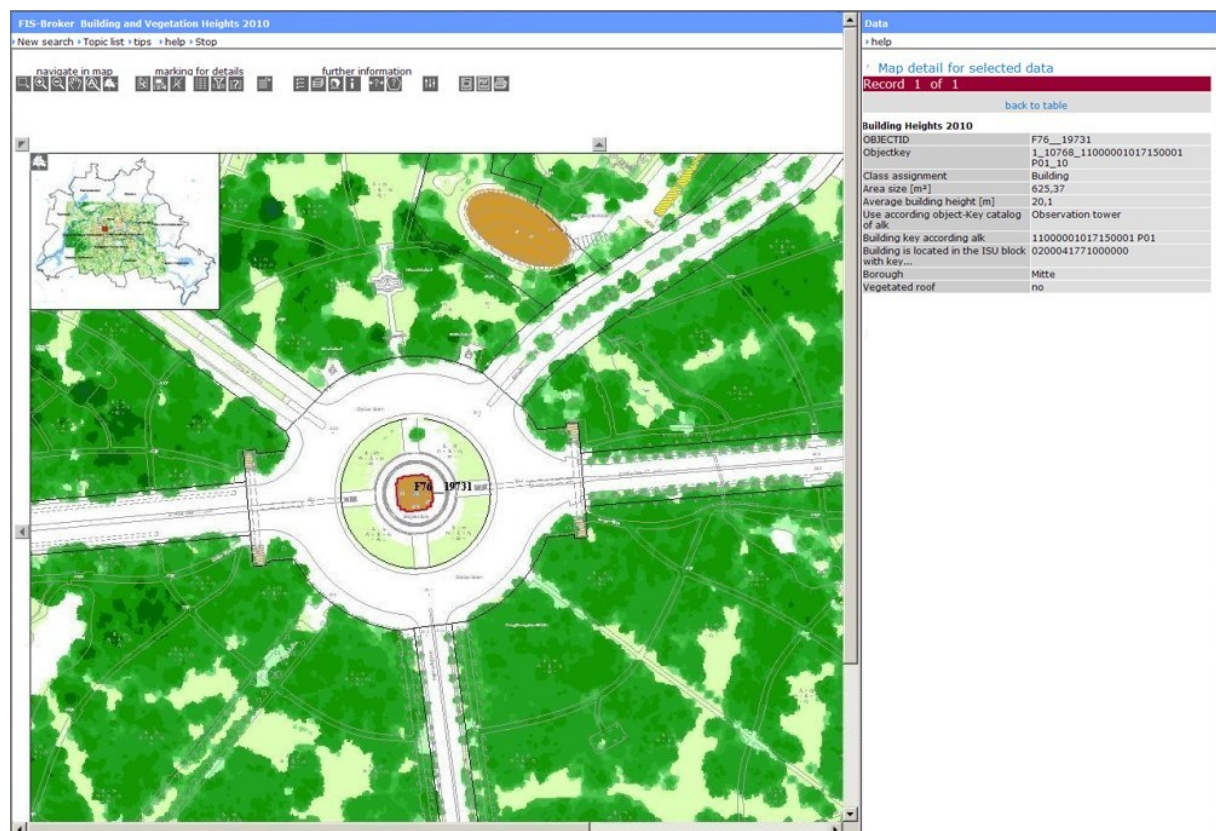


Fig. 17: Building height ascertainment, using the example of the Victory Column: Here, the calculated average height of approx. 20 m deviates considerably from the maximum height of the item, which is 67 m (Source: FIS Broker 2013).

Project Phase 2 (area shown in blue, plus surrounding areas )

Although the quality of the ascertained building items has indeed been noticeably improved by means of later correction procedures, it is still conspicuously different from that of Phase 1. As it was not possible to carry out manual corrections, certain buildings, particularly not in the ALK inventory, have inevitably been detected which do not really exist. Moreover, particularly with lower objects, heights have tended to be underestimated. For this reason, the information from the “Maximum Number of Full

Storeys as per ALK" have been integrated into the data display in order to provide additional information (in the context of this investigation, heights of 2.8 m per full storey have been assumed).

Moreover, it is recommended, especially in the case of small-scale analyses in the FIS Broker presentation, to use the possibility of overlaying current aerial photography.

Exactness for vegetation items

Project Phase 1 (area shown in red)

The class Vegetation includes a total of nine height levels. These are also exported together with the height attributes, so that vegetation, too, can be assigned to its own system of height differentiation. This categorization into height levels and structures it is very precise and true to nature, and the phenomenology of the segments is homogeneous. Only in the interpolated areas of the digital terrain model are there cases of misclassification of vegetation, which is, however, due to the inadequate input data in these areas, and not to the determination methodology. In these cases, too, imprecision can only be corrected by manual follow-up correction.

Project Phase 2 (area shown in blue, plus surrounding areas)

The quality restrictions in the interpolation area of the terrain model that also apply to Phase 1 are, depending on the location, even more apparent in the outlying areas, due to the less precise input data of 50 cm ground resolution, as opposed to 10 cm in the inner city area. The greatest distortions of altitude occur in orographically moving terrain; they have been largely corrected by means of manual altitude point setting, so that they ultimately ascertained height values for vegetation largely conform to reality. However, reduced output quality has a negative effect on the segmentation of vegetational objects, which can be seen in the large number of 'error points', where no statement on the vegetational stock can be made.

Figure 18 shows this very clearly in the transitional area between Phases 1 and 2, in an area in the western portion of the Grunewald Forest.




Fig. 18: Segmentation gaps in Project Phase 2, due to reduced quality of the image data material (using the example of Grunewald Forest)

Data display

The data display in the [FIS Broker](#) includes the following information on the selected buildings and building segments, and the respective vegetational areas:

- **Buildings**
 - Building ID
 - Building key as per ALK
 - Classification
 - Berlin item key catalogue (buildings use code)
 - Use as per ALK item key catalogue as of June 30, 2012)
 - Maximum number of full storeys, as per ALK
 - Ascertained average height, in meters
 - Greened Roof [yes/no] (only in the Phase 1 area; see Fig. 2)
 - Building is located in the block/block segment with the key...
 - Borough
 - Area size (sq m)
- **Vegetation items**
 - Item ID
 - Item key
 - Area size, in sq m
 - Ascertained average height, in meters
 - Vegetation is located in the block/block segment with the key...

Moreover, it is still useful to call up the current aerial photography images as ortho-photos or colour infrared (CIR) versions, via the corresponding button  in the FIS Broker map presentation, as a background map for the selected map segment.


Map Description

For the first time, Berlin has a record of the “**vertical extent**” of the city which is largely very precise. In project Phase 1, an area of approx. 445 sq km, covering the entire inner city and also a large part of the southern half of the city, has been assessed. In project Phase 2, the assessment of the rest of the cities area and of the surrounding area of Berlin amounting to a total of 1,800 sq km, was also assessed. Especially with regard to vegetation, there is now a new and very suitable information base for many types of utilization.

Based on the ALK building outlines and their storey lines, amine height has been provided for each building portion. Mean height values are also provided for the vegetational items.

For the first time, roofs with a green component have been ascertained in this context, albeit, due to the data quality, they have been published only for the inner city area examined the Project Phase 1. In the context of the project, some 5,000 buildings with roofs which have been partially or completely greened have been “initially ascertained” with sufficient precision. Upon conclusion of the determination of the remaining areas of the city currently being processed, a complete overview of the city will be available. Table 1 gives an overview of the state of ascertainment of the area of Project Phase 1 (the inner city and the southern half of the city), broken down by borough.

Tab. 1: Number of greened roofs/ portions of roofs per borough, and their respective uses (as of: July 2013)						
Borough	Number of greened building roofs	Ascertained area of greened building roofs (sq m)	of which			
			Buildings with predominantly residential use	Buildings with predominantly commercial, service, trade and industrial use	Buildings with predominantly public facilities, 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- Wilmerdorf	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	5.056	1.137.891	3.163	712	1.052	129
¹ Borough only partially ascertained						
² Borough more than 90% ascertained to date						

Tab. 1: Number of greened roofs/ portions of roofs per borough, and their respective uses
(area ascertained shown in red,  as of: July 2013);
the ascertainment of green roofs in the rest of the city did not provide sufficient data quality to
permit an assessment.

By bringing together both the built-up and green shares, the areas with various green segments in the urban area are very well recognizable. It is noticeable that even in the inner city, not all areas are densely built-up or impervious. Rather, in the old neighbourhoods dating back to the Imperial era, for instance to the north and south of the former Görlitz Station (now a park), there is not only a high share of trees, but rather a significant amount of green space is recognizable in private and semi-public areas, often with very old stands of trees. Here, it is clear that at least in those parts of the inner city built after 1918, residentially oriented open spaces were accorded very great significance (cf. Figure 19).

This effect is even more obvious in residential estates in which an open design interspersed with gardens was used. Figure 20 shows this effect clearly in two areas at the edge of the inner city, the Neu-Tempelhof estate, and the row-house construction with landscape residential greenery along An der Wuhlheide in the borough of Treptow-Köpenick.



Figure 1: Classification results in the Berlin inner city: Highly impervious inner-city buildings on both sides of Friedrichstraße (left), and Imperial era block construction with a high share of green space in the area of “Görlitz Park (right) (scale 1: 7500)

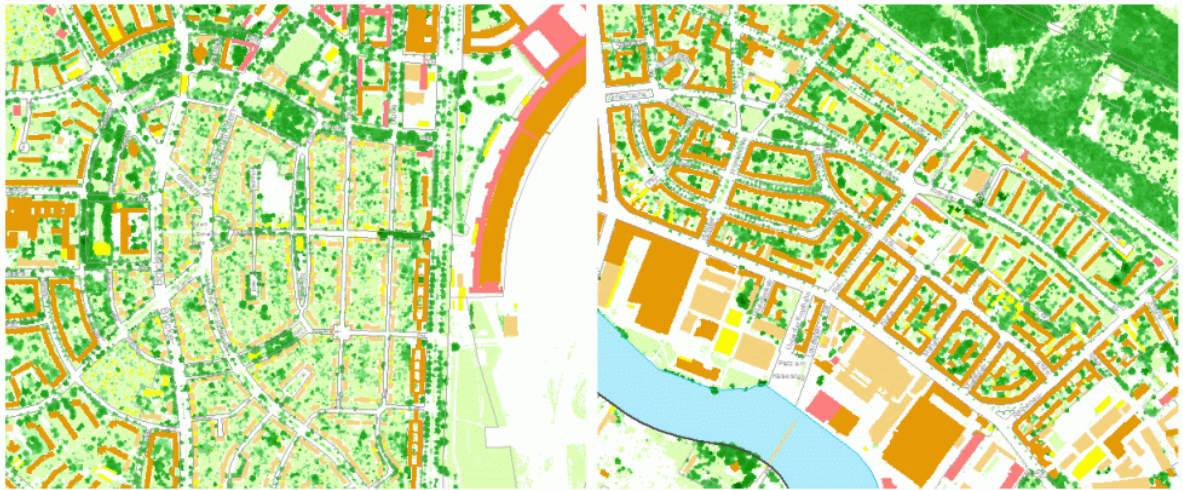


Figure 20: Classification results in the area of loose, intensively green construction at the edge of the inner city (inside the Circle Line): Row-houses and duplexes with gardens in Neu-Tempelhof (left) and row-houses with landscaped residential greenery south of An der Wuhlheide in Treptow-Köpenick (right) (scale 1: 7500)

The structure, including the vertical structure, within parks, such as the Great Tiergarten, the green space around Gleisdreieck, or the Görlitz Station Park is very impressively visible, thanks to the classification system selected; the share of the area covered by lawns can be clearly distinguished from the higher standing vegetation and from the trees. This is also true in forests and forest-like stands of trees.

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