AUTOMATED LULC CLASSIFICATION OF VHR OPTICAL SATELLITE DATA IN THE CONTEXT OF URBAN PLANNING

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KEY WORDS: Urban Planning, QuickBird, Automation, Classification, Land Use, Decision Support, Inter-operability

ABSTRACT:

One of the major accompaniments of the globalization is the rapid growth of urban areas. Whereas at the end of the 1970th only 38% of people lived in cities, this number increased up to 50% in 2008. In 2030 two third of all people worldwide are expected to live in cities (United Nations, 2008). Urban sprawl is a major environmental concern affecting these cities and urban regions across different continents. Besides a quantitative reduction of land consumption, sustainable handling of the limited resource land and smart growth are acknowledged as key tasks for urban planning (Patacchini and Zenou, 2009, Siedentop, 2005). Coping with these tasks requires precise and adaptive planning instruments. The study is part of the GAUS-project (Gaining additional urban space (GAUS) - Detection and valuation of potential areas for inner urban development with remote sensing and GIS). This study is dedicated to the development of a Multi-criteria Decision Support System (MDSS) as a tool for supporting the municipal management authorities with regard to urban consolidation and smart growth. The presented classification framework aims at feeding the MDSS with up-to-date land use and land cover (LULC) information. This work deals with the strategy and workflow (data, preprocessing, classification processes, accuracy assessment) towards a semi-automated LULC classification of urban areas, following an object-oriented approach. Furthermore, an overall goal of this work is to figure out generic methods and strategies towards LULC classification with very high resolution (VHR) optical data to ensure robustness and transferability, which are crucial preconditions in order to automate processes. Different QuickBird and Ikonos scenes of the Ruhr Area (Nordrhein-Westfalen, Germany) and Berlin (Germany) allow to consider potential variabilities of the input data (spatial resolution, seasonal effects, plurality of LULC occurances) when developing the framework for the classification.

1 INTRODUCTION

Since the availability of VHR satellite data with spatial resolution from 1 m and higher new application ranges were explored. Applied urban planners are often inhibited to use satellite data due to absence of remote sensing software and know how. Therefore a semi-automated LULC classification has been developed.

2 URBAN PLANNING ISSUES

2.1 Theoretical Background

The 20th century is characterized by a rapid urbanization process and accelerated growth of urban population. The United Nation Department for Economic and Social Affairs prospected an increasing urban population (see table 1) which causes not only a increasing number of cities but also spreading of urban land use resulting in the condition of urban sprawl.

Population in bn	1950	1975	2007	2025	2050
Total population	2.54	4.08	6.67	8.01	9.19
Urban population	0.74	1.52	3.29	4.58	6.40
Rural population	1.80	2.56	3.38	3.43	2.79
Percentage urban	29.1	37.3	43.8	53.2	67.0

Table 1: Urban vs. Rural Worldpopulation, Source: United Nations World Urbanization Prospects The 2007 Revision.

Although there is no common definition of urban sprawl (Siedentop, 2005) it can be understood as expansion of urban development into rural areas in the urban fringe and the development of urban splinter with low density and high land consumption (Cho et al., 2009). In Germany 106 hectar a day were sealed in 2008 due to the development of new infrastructure and settlements. The Federal Republic of Germany wants to decrease this land consumption down to 30 hectar a day until 2020 (Statistisches Bundesamt, 2008). For the first time, in 2008 more people lived in cities than in rural areas while urbanization is increasing rapidly and is expected to do so within the next decades (Kötter, 2004). Impacts of these developments are of wide variety ranging from environmental and social to economic aftermaths (Patacchini and Zenou, 2009). Amongst others, the main outcomes of urban sprawl are sealing of groundsurface, contaminant loads, loss of flora and fauna, expansion of built-up areas, increasing traffic volume, infrastructural problems and loss of social interactions (Cho et al., 2009, Cervero, 2001, Brueckner et al., 2001, Banister, 2006, Kötter, 2004). The key tasks for urban planners are therefore the reduction of land consumption and the sustainable handling of the limited resource land. However, there is a lack of adequate methods to monitor the rapid changing facettes and complex structures of urban environments. GIS-data is often not up to date and human resources dealing with the regulation of urban sprawl are strongly limited. There are no common strategies how to measure or quantify nor how to hold urban sprawl. Principles like 'spare the urban fringe, develop the inner suburbs first' are operation guidelines without detailed actions or instructions. In the face of those facts municipal management authorities feel to faint when combating urban sprawl (Uhel, 2006). There is an increasing necessity for updated geodata in combination with new semi-automated processes to retrieve relevant information in the context of urbanization. For urban planners the advantages of semi-automated methods for analyzing remote sensing data become more and more attractive due to the described rapid changes in urban landscapes.

2.2 Investigation Area

The investigation area for the development of the described algorithms are Berlin and Ruhr Area in Germany as well as Istanbul in Turkey. This paper focusses on the two german study areas.

Berlin is a capital city, emerged within a historic context starting after the World War II and the seperation until 1989. The city covers 892 sqkm and has about 3.4 million inhabitants. Since reunion rapid changes in urban structure took place. The face of Berlin in present time is characterized by multiple urban cores and a mixture of urban functions within small structures (Senatsverwaltung für Stadtentwicklung Industrie- und Handelskammer zu Berlin, 2005). Built-up and non-built-up areas alternate with green spaces like parks and forests as well as different types of infrastructures, commercial, public facilities, small business and industrial areas. In the years between 2001 and 2005 the urban development in Berlin can be described with a high amount of urban sprawl. An increasing land consumption for new infrastructure and large scale retail sales can be recognized (Mücke, 2006). Due to population development sustainable changes and urban expansion took place: After reunification, Berlin has experienced an initial phase of strong population growth. From 1994 in consequence of decline in the birth rate in the east of the city and the suburbanization, the population decreased until 2000. Only with the increased immigration from the rest of the Federal Republic ("capital effect") but also very low death rate temporarily stabilized the population since 2000. In the years 2005-2007 significant growth of population can be reported which was in contrast to the nationwide trend. Until 2020 the population of Berlin will increase by appr. 2% because of migration (Senatsverwaltung für Stadtentwicklung, 2009).

The Ruhr Area is a highly urbanized region in the west of Germany. With a total of 53 cities and municipalities, the region covers 4435 skqm and has a population of 5.2 million. The Ruhr Area owes its cohesion from the common history as the largest industrial mining region of Europe. Nowadays the population is decreasing and estimated to fall under five million until 2020. This development affects especially the inner core of the cities and less the suburban areas, which is resulting in a process of de-urbanization and suburbanization (Butzin et al., 2009).

3 REMOTE SENSING FOR URBAN PLANNING

3.1 Data

In the context of the research for the GAUS-project, VHR satellite imagery were used to extract different land cover and land use information of the investigation areas. For the selection of remote sensing data, different aspects were taken into account. In compliance with the requirements, the decision was made in favour of QuickBird. This sensor provides one of the highest spatial resolution of 0.61 m in panchromatic spectrum and 2.40 m in the visible and near infrared range. In several studies QuickBird data was a feasible source for the extraction of land use and land cover information (Liu et al., 2005, Wei et al., 2005).

The investigation areas are covered by several QuickBird and Ikonos scenes as illustrated in figure 1 and 2. Two recently acquired QuickBird scenes covering Berlin (5/2009, 350 sqkm) and Bochum/Herne (8/2009, 240 sqkm) will be treated with higher priority as their classification outputs are used for the development of the MDSS. The remaining scenes have been used to assure robustness and tranferability of the automated image interpretation rules.

Although there are comparable satellite images of the two investigation areas from the same remote sensing sensor (QuickBird II) some differences in the metadata can be pointed out.

As shown in table 2 especially the off-nadir angle as well as satellite azimuth and cloud cover are different. These are important
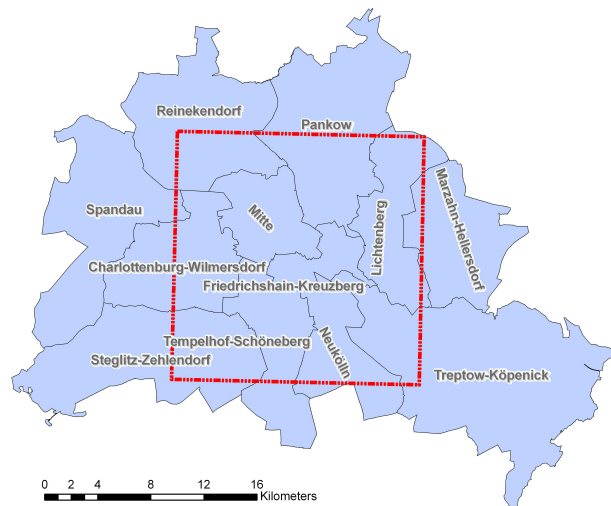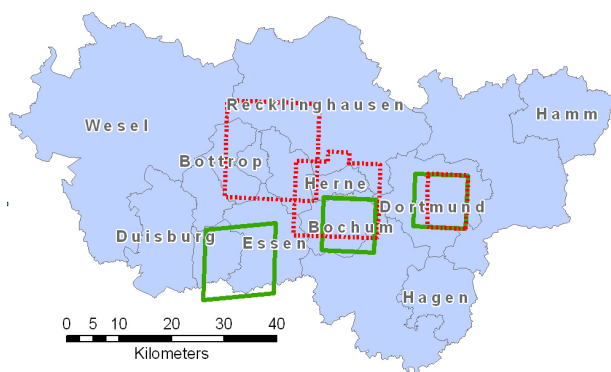

Figure 1: Investigation area: Berlin

Figure 2: Investigation area: Ruhr Area (red dotted: QuickBird, green line: Ikonos)

parameters influencing spatial distortion, shadows and also phenology due to different auqisition times.

3.2 Image Preprocessing

The preprocessing of the remote sensing input data consists of two main steps as described subsequently:

Orthorectification: In order to achieve results in GIS-ready format with a high geometric accuracy, the QuickBird images have been ortho-corrected. QuickBird imagery in the processing level Standard Ortho-ready is suitable for accurate orthorectification (Commission, 2003, Volpe, 2003). For this product level, the vendor provides the RPC-file (relational polynomial coefficient) to model the geometric properties of the image capture. Standard Ortho-ready images have been mapped to a cartographic projection by using a base ground level of the WGS84 ellipsoid; thus the standard appliance by the vendor of the coarse GTOPO30 (or similar) with less accurate results (as it would be with the product level Standard) can be circumvented. The customer can use a DEM, the RPC-file and GCPs to derive a higher quality product, *ERDAS Imagine 9.3* served as software for this preprocessing step. In case of the study area Bochum, the DEM is based on governmental laser scanning (Bezirksregierung Köln, Section Geobasis.nrw, Nordrhein-Westfalen), captured between the years 2000 and 2006. The average point cloud density is 1-5 m and has been resampled into 5 GSD image format. The DEM is complete,

Scene	GSD [m]	Clouds [%]	Sun el. [deg.]	Off-nadir [deg.]	Date
treatment group					
QB Be	0.6/2.4	1	57.4	8.7	05/09
QB Bo	0.6/2.4	14	51.1	13.3	08/09
control group					
QB Re	0.6/2.4	1	42.20	13.5	09/04
QB Do	0.6/2.4	1	51.10	7.6	04/06
IK Bo	1.0/4.0	1	48.77	25.5	04/05
IK Es	1.0/4.0	0	44.54	26.2	06/05
IK Do	1.0/4.0	1	41.69	22.7	04/07

Table 2: Metadata of the QuickBird and Ikonos data

continuous and without any gross anomalies. The vertical accuracy is +/- 5 dm and fulfills the requirements for very high resolution data below 15 degree off-nadir angle (Commission, 2003). The DEM applied for Berlin is based on governmental field surveying from 2005. With a pixelsize of 3.5 meter and a vertical accuracy of +/- 1 meter, the requirements for orthorectification of very high resolution imagery are fulfilled. Relief displacements are amongst the crucial factors concerning positional accuracies. They depend on the harshness of the relief, the quality of the terrain model and the off-nadir viewing angle. In the case of the areas of investigation the relief is rather smooth and does not cause major distortions. The GCP collection has been based on the reference of aerial ortho images with 15 cm GSD for Bochum and 10 cm GSD for Berlin. The output is resampled by the Bilinear Interpolation to 0.6 m (panchromatic) respectively 2.4 m (multispectral data). The RMS-Errors obtained are listed in table 3. Also the visual evaluation confirms the positional quality as ground objects of the ortho-corrected images matches those in the aerial images.

Data	RMSE [m]
Ruhr Area multispectral data	0.33
Ruhr Area panchromatic data	0.32
Berlin multispectral data	0.14
Berlin panchromatic data	0.57

Table 3: RMSE for the QuickBird Orthorectification

Pansharpening: Pansharpening has been applied to examine its gain for the information retrieval. While there is no distinct improvement for the image objects feature space, pansharpened data has its value in initial low level image segmentation and fine border optimization processes. A quantitative measurement of this information gain is beyond the scope of this study. In order to maintain adaptability of the proposed workflow, the pansharpened data input is implemented as *option* for the image classification.

3.3 Classification Scheme

A LULC classification scheme was elaborated with regard to the overall goal of developing a transferable tool for urban planning tasks in the context of the project GAUS. In order to meet those requirements, the scheme has to represent urban structures, which are common throughout european urban areas. Those classes are split up in the categories of land cover (e.g. built-up, tree/shrub, water) and land use (e.g. residential, industrial, agricultural) and extracted by automatic image interpretation. At the same time, local phenomena (e.g. the hobby gardens as they are present in Berlin and the Ruhr Area) and more specialized classes beyond the scope of automatic and transferable routines have to be taken into account. They are extracted by manual delineation respectively by additional thematic data input (see also section 3.6).

Altogether three categories are set up that will lead to three overlaying thematic outputs (see table 4).

Automatic extraction		Manual extraction
Land cover	Land use	Land use
Built-up	Residential	Airport
Grass/Mixed veg.	Industrial/	Harbor
Tree/Shrub	Commercial/	Mining/Dump
Open surface	Services	Sport/leisure fac.
Water	Agricultural	Park
	(Semi)-Natural	Hobby garden

Table 4: LULC scheme for automatic and manual image intepretation

3.4 Multi-scale Representation

The proposed framework for the automated image interpretation follows an object-oriented approach and can be categorized in low and high level image interpretation, which differ regarding the scale, the degree of abstraction and the implementation of knowledge. The low level interpretation extracts the basic land cover classes. Several fine scale segmentations result in object primitives, which are labeled mainly regarding intrinsic object characteristics, e.g. by mean values, standard deviation or various ratios such as the NDVI. Those objects represent for example rooftops, small green patches aside streets as well as gardens, parking lots and individual tree canopies. For a fine scale interpretation (in case of QuickBird imagery between 1:5000 - 1:10000), shadowed surfaces have to be treated also as they are omnipresent in urban areas. All segments represent their corresponding objects of interest in a slightly oversegmented manner to assure a proper representation of the spectral signal of surfaces. Beside the intrinsic object properties, spatial auto-correlation and multi-scale context play a crucial role. The fuzzy weighting of those three factors compose the objects towards the target classes of the category land cover. The high level extraction of the land use category is more generalized. While the scale for the low level interpretation ranks between 1:5000 and 1:10000, which is the inherent potential mapping scale for QuickBird imagery (Jacobsen, 2003), the high level interpretation corresponds to scales about 1:50000 - 1:100000. Concerning the positional delineation and the thematic labeling, classes like residential, industrial or agricultural areas are rather vague. Even by manual interpretation one is confronted with vagueness and ambiguities, which could be a favor for automatic methodes, because they allow to measure properties like the extent, shape or the relative degree of pervious surface in a faster and more accurate manner and enable an objective course of action.

3.5 Classification Strategies

The automated image analysis has been conducted using the software *Definiens eCognition 8 Developer/Architect*. This software package enables the user to write sequences of rules for a specific image analysis task. This solution meets the requirements of transferability and robustness, because it can be applied to large amounts of data and make use of the advantages of automation due to the possibility to run rulesets on different datasets again.

The developed solution requires the VHR satellite data as sole input. While it was developed and applied to QuickBird and Ikonos data, other recent satellite systems (e.g. WorldView 2, Pleiades) meet or even exceed those requirements and might be also suitable as minor differences concerning the image resolution and the spectral properties are treated at runtime of the automatic interpretation. Keeping down the input requirements eases the straight
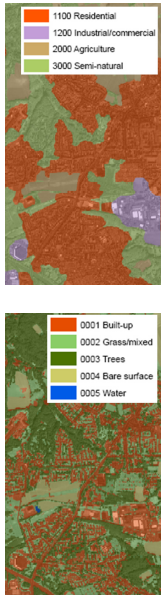
High level interpretation (land use) *use of semantic network* • specific mix of land cover • functional network • knowledge driven Low level interpretation (land cover) *intrinsic object properties* • brightness/ratios • variance • texture	

Table 5: Low and high level image interpretation

forward transferability of a method to other areas of investigation. This fact will be discussed more in detail under section 3.6.

The above described OBIA workflow starts at a knowledge-free stage by creating object primitives as primary units for the analysis. Further on multiple and iterative processes of object creation, reshaping and attributing evolve the analysis by a gradual knowledge build-up. This approach refers to Baatz et al. (2008) and Lang (2008), who draw the attention on the iterative character of OBIA workflows and its interlinked concept of segmentation and classification. The key-features, which enables to classify image objects by their common characteristics, usually reveal by a trivial description of their appearance and composition. Distinct colors, textures, shapes and spatial relations can be described intuitively and serve as linkage between the real world phenomena and the image data. Beyond those key-features, less obvious ones, which are not instantly recognizable by visual examination, can be revealed by quantitative methods, e.g. by using the *Bhattacharya distance* as applied by Marpu et al. (2008). The *Bhattacharya distance* is a separability measurement, which calculates the distance for probability functions (here: based on object attributes for selected classes).

3.6 Processing and Automation

The underlying goal of the GEOBIA concept (Castilla and Hay, 2008) is to automate the intepretation of earth observation (EO) data. It is questioned under which circumstances and up to which degree automation can be achieved. In contrast to some applications of OBIA in the field of material and medical/life science, optical satellite data can be regarded as unstable data source, which varies over time and space largely depending on geometric and illumination conditions during image capturing (see table 2). The main requirements for a feasible method in the context auf GAUS are automation, transferability and information. The unpredictability of the input data leads either to less transferability of automated methods or to less information, namely the level of detail and the accuracy of the results. Thus different aspects are in contention as shown in figure 3.

The aspects of transferability, automation and information are not accordable in an acceptable form due to mutual interferences.

Figure 3: Automation-transferability-information in the relationship of dependence
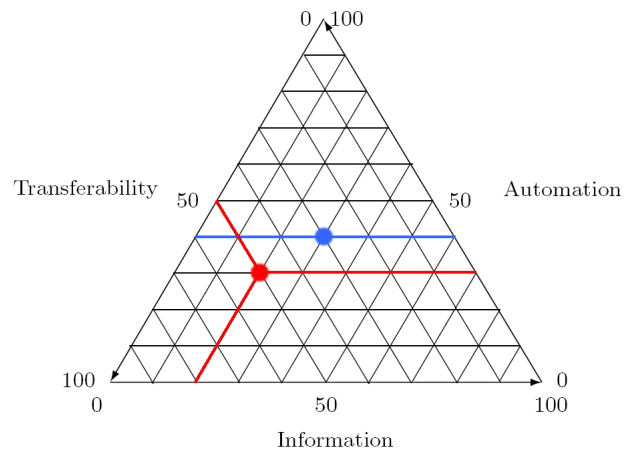
This constellation disembogue in a predicament of finding a balance without concede (indicated with the red dot). In order to obtain high quality LULC data and to develop a method which can be adapted to various sites and data sources, some user interactions have been implemented. Using the easy to handle GUI of *eCognition Architect*, the user is guided through analysis sequences for the adjustment of required scene-specific parameters (see figure 4). Up to a certain degree the rules for image interpretation can auto-adapt to scene-specific conditions; whenever this is not possible, the sequential chain of rules is interrupted and requires an user input, e.g. the adjustment of parameters by sliders or textfields. The implementation of some user interactions and/or additional data dissolves the stringent relationship of dependence between automation, transferability and information. In this case (as shown in figure 3 with the blue dot) only the aspects of automation and transferabilty have to be in balance. The quality and detail of information can be gained by additional inputs.
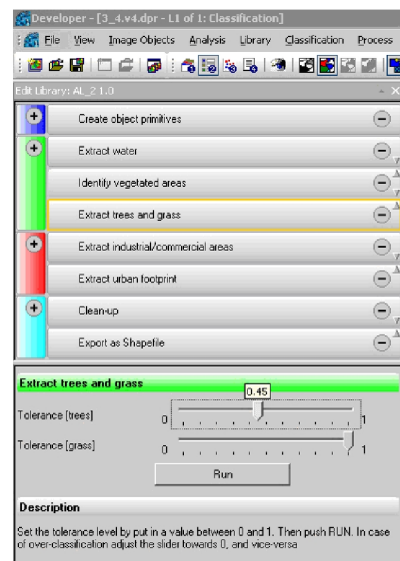

Figure 4: User interaction with *eCognition Architect*

Tiling and Stitching: Due to main storage restrictions of 32-bit software, the image interpretation rules can be only applied to an image extent of 35 million pixel. Accordingly, large scenes had to be tiled as illustrated in figure 5.
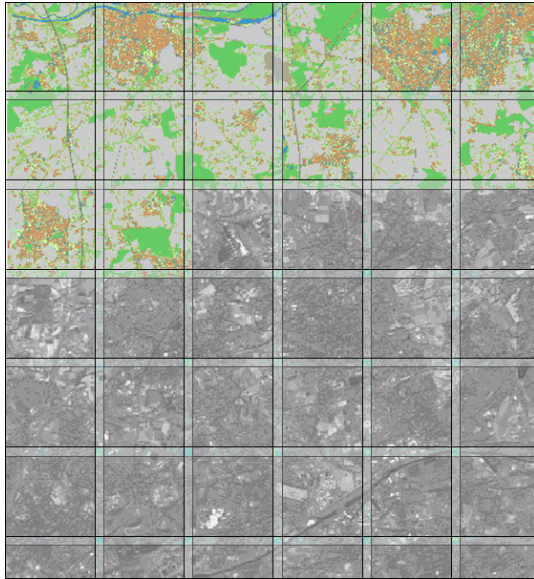
Figure 5: Subsetting the scene in overlapping tiles

The tiles have to overlap to a fair degree to enable a stitching afterwards without visible cutlines. The second advantage of maintaining overlap areas is the fact, that classifaction rules employ spatial context of object neighborhood, which can be significantly distorted for objects near the border of a scene.

3.7 Results and Evaluation

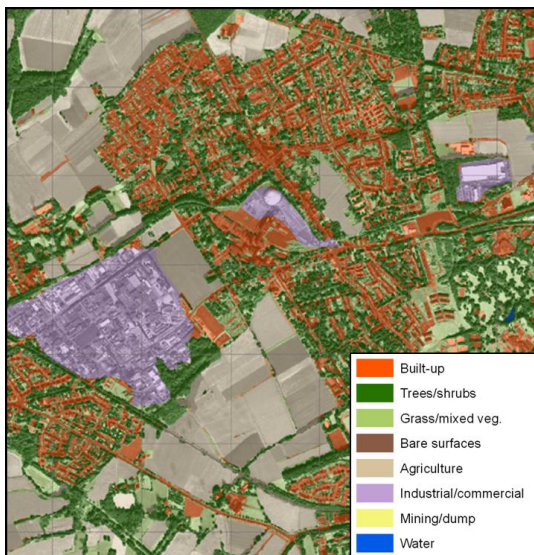Figure 6 shows a prioritized overlay of the three classification outputs (see table 4).

Figure 6: Results of the semi-automated classification

The outputs of the land cover extraction have been evaluated by a statistical accuracy assessment using an error matrix and the error of commission/omission (see table 6). The overall accurracy is 87.25 %.

The reference is based on manually labeled image objects, which have been chosen by a automated procedure to ensure objectivity and randomness. Though the assessment can be regarded as a pixel-based method as the referencing has been conducted pixel per pixel.

The outputs of the land use extraction have been evaluated by visual examination and assessed as valuable information for a MDSS in the context of urban planning.

Ref. \ User	Built-up	Trees\ Shrubs	Grass\ Mixed	Open Space	Water
Built-up	19634	0	0	1540	143
Trees \shrubs	456	14013	1639	0	67
Grass \mixed	109	1215	10099	1382	0
Open Surf.	1660	44	0	9054	0
Water	89	0	0	0	4278
Sum	21948	15272	11738	11976	4488
Algorithm	0.89	0.92	0.86	0.76	0.95
User	0.92	0.87	0.79	0.84	0.98
Accuracy	87.25				

Table 6: Errormatrix of the retrieved results

4 CONCLUSIONS AND FUTURE WORK

In this study, the thematic data could extracted by automated processes for feeding a MDSS. **Following classification outputs and relevant planning issues can be linked:**

- urban footprint → measure spatial compactness

- land cover as function of land use → quantification of impervious surface or green infrastructure

- land cover as function of land use → detection of open and underdeveloped urban areas

- land use → evaluation of surrounding area of potential sites (scenario for reuse and consolidation)

Future work comprises the development of a Multi-criteria Decision Support System (MDSS), which is dedicated to the detection and qualitative valuation of building potentials regarding the principles of urban consolidation and the prevention of sprawl. The basic data sets feeding the MDSS are derived from satellite imagery, as described in the previous sections. Complementary, optional inputs to make use of available local data sets, such as transportation infrastructure, lithology or topography will be implemented.

Urban sprawl is a complex phenomenon, which requires a multi-layered treatment of different aspects. Measured in scales of population density, spatial compactness, imperviousness or functional structure and segregation, VHR satellite imagery emerged as feasible data source for the (semi-)automated extraction of thematic data, which represents those aspects.

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ACKNOWLEDGEMENTS