Monitoring the urban development with integrated system from RS observation and GIS information

Ellen Banzhaf
Katrin Hannemann
Mike Martini
Department Urban Ecology, Environmental Planning and Transport
Helmholtz – Centre for Environmental Research UFZ
Leipzig, Germany
ellen.banzhaf@ufz.de

Volker Grescho
OLANIS GmbH
Leipzig, Germany
grescho@olanis.de

Maik Netzband
F&u confirm
Leipzig, Germany
maik.netzband@ufz.de

***Abstract*— Urban remote sensing predominantly focuses on positive growth patterns. Urban planning mainly concentrates on the investigation of cities as an administrative unit. In this paper the phenomenon of a negative urban growth is investigated within an urban region for two selected areas: one selected test area is the gradient from inner urban districts to peri-urban communes, the other selected area is composed of four local districts within the first selected region. The urban region is the City of Leipzig, Germany, with its surrounding communes. Selected patterns of spatial processes are analysed for the gradient on a smaller scale using Spot XS data, and additionally, Landsat TM data where Spot data were missing. For the four local districts in Leipzig Color Infrared Aerial photographs (CIR) were taken for the analysis on a much larger scale. The focus of the analysis is the development of open spaces and densification. It will be shown how suburban communes and local districts within the city have developed disregarding sustainable planning. Several communes in the Leipzig region have started a planning cooperation, called "Grüner Ring Leipzig" (Green Belt Leipzig) in which remote sensing activities of the UFZ spatially support a better coordinated regional planning.**

I. INTRODUCTION

Tremendously high dynamics of urban development where growth and shrinkage processes occur at the same time can recently be observed in cities of many Northern American and European countries undergoing the process of de-industrialization. In this particular situation suburbanization going along with an expansion of residential and commercial areas at the urban fringe is simultaneously observed and interacts with a declining population and a stagnating economy. At present 114 ha of open spaces per day are taken for new settlements and infrastructure in Germany [1]. In many other European urban regions a similar picture is displayed. A temporal and a spatial side-by-side of suburbanised areas with built-up activities for commercial sites and housing and a diverging development in inner cities with their compact urban form suffer from declining population density and residential vacancy as well as industrial derelict land has been observed [2]. As a result, such shrinking cities with expanding spatial land consumption have developed an urban form that is far from being sustainable. The Federal Government of Germany aims at reducing this land consumption to 30 ha per day in the year 2020 in order to stop this trend of new built-up areas going along with a strong negative impact for soils, and the habitat of human beings, flora and fauna [3]. This goal is supposed to be reached by minimizing new built-up areas in the peri-urban belt and by sanitising inner urban areas. Especially in urban regions such as Leipzig with urban brownfields and vacant houses new potentials for densification and a redevelopment of open spaces can be identified. So, most recently the inner development has become a more significant field of action for communes to reduce land consumption and to protect open spaces. As a high densification of the urban fabric could also lead to a decrease in quality of life the strategy is to follow a double track: reactivating settlement use and development

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open spaces in the core area of cities [4]. In a balanced proportion the strategies of densification and protection of open spaces can be an important contribution to improve the urban quality of life [5].

II. Research Objectives

These processes need to be followed-up upon in terms of their spatial fingerprint, and a more detailed information on suburban and inner urban differentiation to support sustainable management decisions. As the strategies and political motivation are a rather recent term of action it first needs to be monitored and analysed if this development of high land consumption and densification problems is apparent in the region. So the last decade needs to be monitored to find recent stages of spatial development. To compare the test site to the more general trend of Germany and other European countries it will be analysed in the urban to suburban gradient how much land has been converted on the more detailed scale of each commune. The methodological approach is to develop monitoring systems in which land use information on increase and decrease of land consumption can be assigned to an administrative unit (i.e. *local district* being part of a city and *commune* being part of the region or part of the federal state) and demolition of houses can be assigned to the classification system of urban morphology, in this case the urban structure type.

Set against this background, this paper analyses the chances and limits of urban monitoring with different remote sensing methods and approaches to develop a concept explaining and assessing these contrasting processes in their quantitative and qualitative dimension. First, land use classes are identified that characterise land consumption choosing a ranking of three categories for imperviousness (low, intermediate, high) [6]. Second, the urban structure is characterised by identifying different types of buildings (different types of housing, industrial buildings, infrastructure) and open spaces (woodland, allotments, parks), then analysing type and area of demolished buildings. When the basic mapping for land consumption and lack of urban density is calculated, then the response from urban planning will be integrated expanding the system by socio-demographic information. It will then be discussed to what extend social science knowledge can be brought together with quantitatively based remote sensing methods and analytical concepts. Methodologically it will be focused on the way shrinkage processes challenge existing monitoring approaches: why this land consumption in the suburban region and densification demands in the inner urban parts needs both, updated prognostic and observation instruments as well as procedures. Last but not least it is important to know, what kind of methodological implications for the development of an urban monitoring concept is required that includes this multi-scale approach and is accepted in urban development strategies.

To allow for a more detailed picture, the paper draws on empirical evidence from East Germany where dramatic suburbanisation processes pre-dominate the urban presence and future alike.

III. Case Study: The Urban Region of Leipzig, East Germany

The urban region of Leipzig is the focus of our investigation as it is one example for cities with negative demographic figures and a decrease in population going along with numerous economic impacts. More than a century ago the city experienced a period of vibrant growth from the 1870s to the 1930s, making it the country's fourth city when it reached its population peak with more than 700000 inhabitants. An artificial economic push was launched right after the German reunification. It had taken place in the early 1990's by institutional subsidies aiming at an attraction of capital and investments into East German regions and cities. According to unemployment and out-migration these financial incentives led to high mis-investments and negative spatial consequences of uncontrolled sprawl. This negative demographic development is due to numerous facts: a dramatic decrease in birth rates after the reunification of Germany in 1990, an extreme loss of inhabitants because of economic contractions going along with a job-driven out-migration to other parts of the country, and a decline for inner urban population density due to suburbanisation processes. As a concomitant of expired promotions of investments further suburbanization in terms of new family housing constructions now are about to decline.

Therefore the spatial – temporal analysis of the inner urban to suburban gradient is chosen for points in time during the 1990's (1994, 1998) and up to now (2005). In this paper only the time span from 1994 to 2005 will be presented.

Due to these suburbanisation processes with a high land consumption and the negative demographic development apartments and houses fall vacant in the inner urban area. Vacancy is no longer restricted to uninhabitable housing but also to completely renovated buildings and building complexes. The supply outweighs the demand even if, at present, household numbers still continue to rise. The drops in density account for about 17 % of the city's housing stock, some residential districts exhibit vacancy rates higher than 30 % [7].

This severely negative und unsustainable development brought up the discussion of demolition. As a new strategy, a federal program of urban restructuring was launched [8]. It operates in terms of a guideline to organise and finance the demolition of overhang of housing stock and revaluation of the remaining residential areas. Furthermore, it represents a scientific approach to deal with urban development under the conditions of non-growth or stagnation, and shrinkage [9].
Therefore the second part of the analysis comprises the structural analysis of four local districts in Leipzig which underwent a high loss in population. As demolition of houses was undertaken more rapidly from 2003 onwards (rejection of

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Leipzig's application for the Olympic Games) it is most appropriate to investigate spatial land use dynamics in the most recent time.

IV. METHODOLOGICAL APPROACH

A. The urban-suburban gradient

In order to analyse the settlement development spatially with respect to densification and open spaces Spot XS imageries were taken for the years 1994, 1998 and 2005. But as these images do not cover the most eastern part of the area under investigation Landsat TM has to be taken to fill the gap. Landsat TM imageries were transformed to fit the 20 m ground resolution of Spot XS. All imageries were georeferenced and atmospherically corrected. The atmospheric correction was necessary to compare the imageries especially when calculating the Normalised Difference Vegetation Index (NDVI) being very useful for classifying open spaces.

For the classification procedure a knowledge based expert classification concept was elaborated. This pixel oriented hierarchical approach combined the unsupervised classification of vegetation being extracted by means of the NDVI with the supervised classification of potentially impervious surface. A decision tree was configured for the knowledge based classification to subdivide impervious surface into subclasses of different degrees, and vegetation into woodland, meadow/ grassland / floodplain.

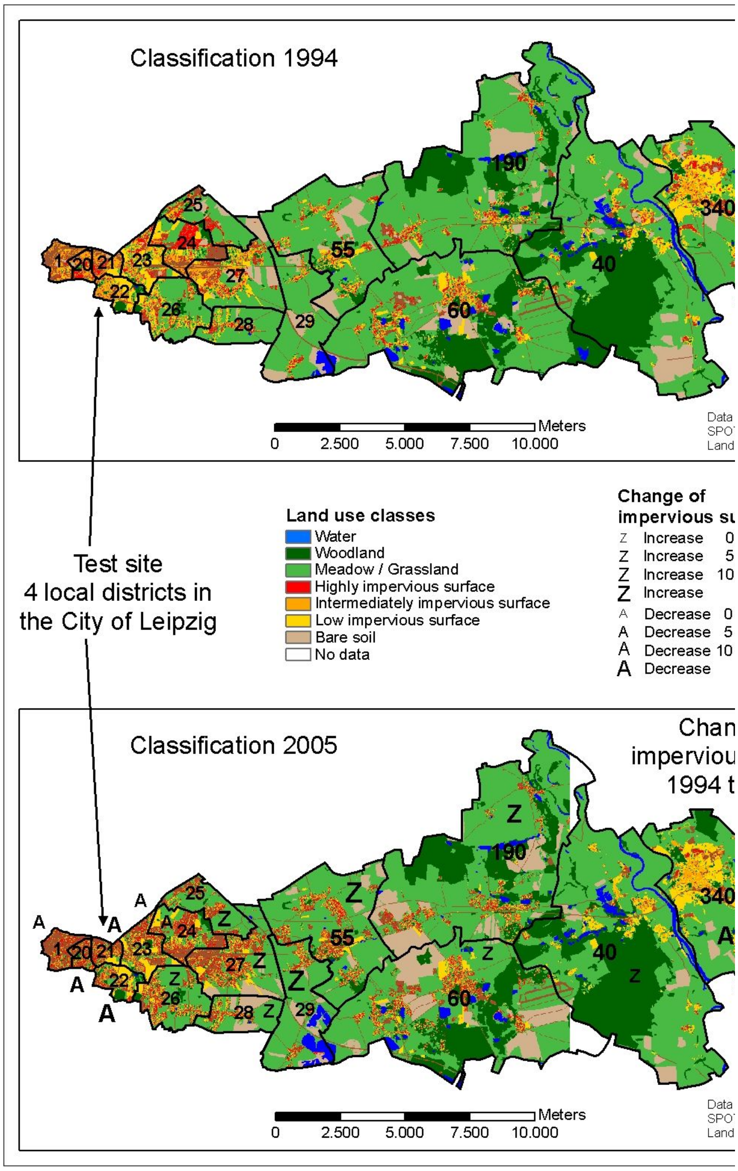

Figure 1. Classification of the urban – rural gradient for two points in time using Spot XS data and Landsat TM for the communes No. 40 and 340.
Changes in land use, especially impervious surface, is assigned to each local district (City of Leipzig) and to the suburban communes.

Bare soil was chosen as a class of its own so that increase or decrease in urbanization could be assigned to more than only to existing classes of vegetation and imperviousness. The training areas for bare soil were open pit mining near man made lakes and agricultural land without cultivation, for highly impervious surface the training areas were e.g. industrial and commercial sites and railroad tracks.

Intermediately impervious surface was trained with e.g. dense settlements with Wilhelmeanian style row houses being built between 1870 and 1918, and to prefabricated housing estates (1970's to 80's). Training areas for low impervious surface were mainly residential areas with detached and semi-detached houses, allotments / community gardens.

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The accuracy assessment shows 89 % for Spot data in 1994 and 86 % in 2005. The overall accuracy for Landsat TM only reached 82 % in 1994, but 90 % in 2005.

Before the change of impervious surface was calculated as shown in figure 1, a change detection procedure was carried out. This change detection procedure is an additive approach in which the younger thematic layer is added to the older. The older thematic layer gets class numbers 10 times higher so that it consists of two figures (class 1 being changed into class 10, etc.). When adding up the second classified image the new class 11 means "no change", whereas class 12 would explain a change from class 1 to class 2 over this calculated period of time. Once the change detection has been performed the portion of increase or decrease in imperviousness can be calculated and is presented with the letters A and Z. The size of the letter refers to the amount of change. Presented in this paper are the time slots 1994 and 2005 in order to refer to the most up-to-date situation. So figure 1 and table I refer to this selection of time series. In addition, further information is given in table II to a more differentiated investigation for the changes from 1994 to 1998 and from 1998 to 2005 to understand the speed of land use changes better and to demonstrate that the fastest part of changes happened during the 1990's.

Table I shows the amount of land having been changed within the last decade. Class names such as meadows and grassland represent land under cultivation and parks which have decreased although woodland has been expanded. This is due to the fact that in commune 340 a military base was closed and reforested. Otherwise cultivated land has been converted into built-up areas, and bare soil largely remains uncultivated as land for building (see commune 60 and 190 – central part of the map). From the urban fringe to the suburban region the built-up area has increased, whereas in the inner eastern part of Leipzig built-up areas have decreased. As low impervious surface is a class name representing single family houses and semi-detached houses it characterises the suburbanisation processes in the area under investigation and thus proves that this test site is representative for the overall development contrasting inner urban decrease of dense building structure and suburban land consumption.

TABLE I. Portions of land use in 1994 and 2005

	1994		2005	
Land use classes	[ha]	[%]	[ha]	[%]
Water	473	2	532	3
Woodland	3458	17	3513	17
Meadow / Grassland	11442	56	10747	53
Highly impervious surface	963	5	1368	7
Intermediately impervious surface	1466	7	1112	6
Low impervious surface	1195	6	1248	6
Bare soil	1427	7	1655	8

Apart from these changes towards a higher imperviousness the creation of new open spaces could be made out as well, but at a much lower rate. At this point it must be stated that Spot data with 20 m ground resolution are not sufficient to detect inner urban open spaces, especially once they cover smaller contiguous areas.

TABLE II. Changes in imperviousness for each commune and local district based on the classifications and change detection

No. of commune / local district	Amount of imperviousness [%]		
	94-98	98-05	**94-05**
1	-1,2	-0,6	**-1,7**
20	-4,0	-4,8	**-8,6**
21	-2,7	-4,9	**-7,5**
22	-2,1	-10,3	**-12,2**
23	-2,9	-1,5	**-4,3**
24	4,0	-8,1	**-4,3**
25	5,6	2,1	**7,8**
26	12,6	-9,1	**2,3**
27	7,4	0,2	**7,6**
28	-0,7	5,6	**4,9**
29	33,5	0,3	**33,9**
40	1,0	0,1	**1,1**
55	37,4	2,9	**41,4**
60	3,5	-0,4	**3,0**
190	27,4	-5,7	**20,1**
340	-2,4	-11,2	**-13,3**

In table II more information is given than presented in figure 1. The number of communes and local districts as well as the changes in land use between 1994 and 2005 have been presented in figure 1 and table I. Just to illustrate the single steps in changes per administrative units the other change detection slots – not presented in this paper - are displayed in grey colour. As stated before in commune no. 340 a military base was given up and the area has been reforested. All other suburban communes from no. 190 to no. 40 show a positive value in terms of building activities. The local districts no. 25 to no. 29 have undergone an administrative changes as they were incorporated into the City of Leipzig due to the land reform in the 1990's. So they changed their status from individual communes in the 90's to local districts in this century. All of them have a positive value in terms of building activities and the rise in the amount of imperviousness. This development undermines the fact that the more remote from the centre and the closer to the urban fringe the higher are the activities in building constructions. The other numbers representing the inner urban differentiation are 1 to 24 and mainly show a decrease in the built-up areas. In the context of sustainable urban planning with the overall concept of a rather dense and compact city and less suburbanisation being produced this development is far from being sustainable.

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B. Four inner urban local districts

After having identified spatial suburbanization processes, a new focus in urban land use monitoring activities is set on deriving urban structure types from remote sensing data. When monitoring and analyzing the land use information of the city on the scale of the urban structure a very high ground resolution is needed. The inner urban differentiation of four local districts of the City of Leipzig has been investigated with a different data set and a different classification approach: Digital Color Infrared photographs (CIR) were taken with a ground resolution of 40 cm and the acquisition date on July 2002 followed by the quantification of built-up areas and natural environment by means of an object-based classification approach. The classification shows that single buildings could be extracted and the type of the building could be assigned to most of these segments. The object identification could also be applied for water bodies, vegetation, and impervious surfaces that are not connected to buildings once a very high resolution (VHR) data set is taken. Depending on the districts that were classified the overall accuracy was between 82 % and 89 %.

With respect to the main demolition process having started in 2003 this acquisition date in 2002 states a point in time of rather slow demolition taking place. In this methodological approach a change detection is performed to capture the process of the demolition of houses and, what is more, to assign the area of demolished houses to specific urban structure types. Therefore the classified thematic information is compared with ATKIS data from 2005 (authorized topographic-cartographic information system of Germany), and, as a ground truth and mapping of demolished buildings and industrial sites was carried out by the UFZ in summer 2005 these pieces of information have been included in the GIS layer as well.

In this part of the study, the remote sensing data are only used for classification purpose and the change detecting is produced performing a composed GIS overlay over the classified thematic layer.

The most important step in the object-based classification approach is the prerequisite step of image segmentation [10]. The advantage of this methodological approach is that rather complex semantic objects that need to include local context information can be processed very well. The most difficult part in segmentation was that elements had to be defined comprising the most surface area of the rooftops. But these rooftops could be homogeneous or heterogeneous which made it rather difficult and demanded for several segmentation levels.

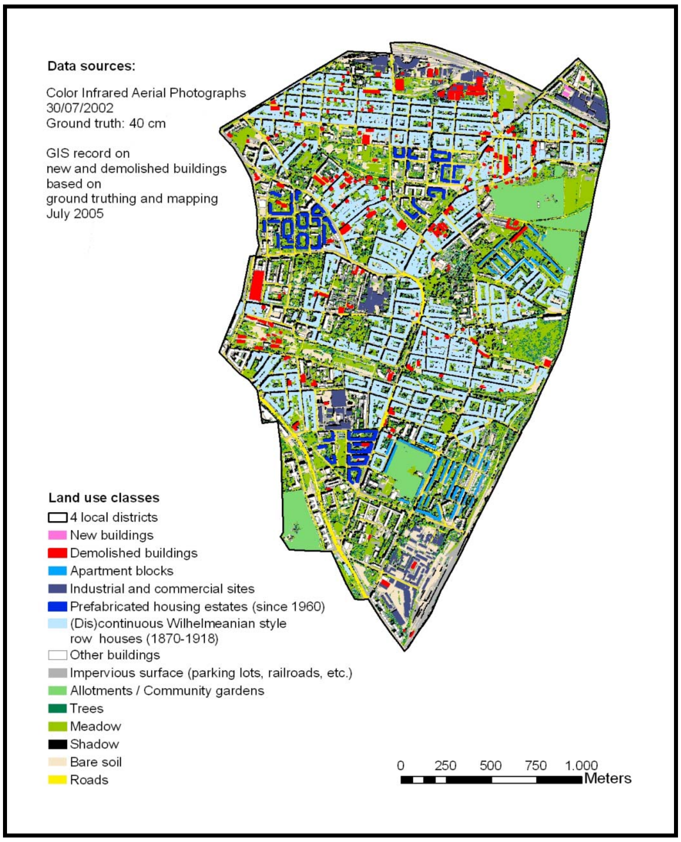

Figure 2. Classification of four local districts in the eastern part of Leipzig using digital CIR photos. Changes in the existence of buildings such as "demolished buildings" and "new buildings" are taken from GIS data sets

After the segmentation levels were performed, and three of them finally taken, the classes could be generated. The basis for this classification scheme was the legend of urban structure types derived for Leipzig in the 1990's without a quantitative approach [11]. This legend was adapted to the automatic and object-based classification approach keeping the characteristics of the structure types. Depending on the defining class the classification method *nearest neighbour* or *membership function* was taken. So the coexistence of both algorithms forms the basis for the classification.

The most dominant structure type in Leipzig as well as in the presented test site is the Wilhelmeanian style row houses. This type can be subdivided in continuous and discontinuous blocks of houses referring to the open spaces left in the row of buildings (=discontinuous) or no open spaces (= continuous) along the row-to-row houses. The Wilhelmeanian style row houses are so dominant because they belong to an intensive époque of building activities in the city when Leipzig was growing very fast (see III. Case study). But during communist times these houses were not looked after so they are either renovated nowadays or left to decay. The second dominant structure type are the prefabricated housing estates being mainly built in the 1970's and 80's followed by apartment blocks from the early 1960's. With respect to the natural environment parks (trees and meadows) and allotments are

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most characteristic in the presented local districts with a high portion of green vegetation and of open spaces but showing some lack of connectivity and patchiness in their form and location. As the latter was not of major interest but the demolition of houses the following statistics refers to the built-up environment only.

Regarding the challenges of urban planning and the seek for urban sustainability the focus of the statistics is laid on the quantity and characterization of demolished houses. The total area of buildings cover approximately 112 hectare and make up for about 20 % of the total area of the four local districts. The largest part of demolished houses is taken by the Wilhelmeanian style row-to-row houses with more than 60 %. This is due to the fact that especially in the eastern part of Leipzig the renovation of this type happened rather delayed in comparison to other parts of the city. This structure type is followed by industrial and commercial sites forming ugly areas of derelict land und representing about 28 % of all demolished buildings. It is hard to make these sites attractive for redevelopment as infrastructure has offered better access for commercial sites in suburbia that in the more central parts of the city. The overall result of about 8 hectare of demolished houses makes a high amount of rapidly created open spaces through demolition especially as hardly any demand on new buildings and new development of these open spaces have taken place. So there is a plentiful of open spaces for renaturalisation and a chance for a difficult area under demolition to change its face.

TABLE III. Portion of built-up land use in 2002 and its changes between 2002 and 2005

Type of demolished building	[ha]	[%]
Other buildings	0,42	5,15
(Dis)continuous Wilhelmeanian style row houses (1870-1918)	5,06	62,49
Prefabricated housing estates (since 1960)	0,06	0,71
Industrial and commercial sites	2,27	28,06
Apartment blocks	0,29	3,59
Total of demolished buildings	**8,10**	**100,00**
Total area of 4 local districts	544,27	100,00
Total area of buildings	112,02	20,59

IV. RESULTS AND OUTLOOK

Urban densification areas and open spaces were monitored on a multi-scale approach. To investigate upon suburbanization processes contrasting an inner urban loss of compactness the Spot XS and Landsat TM sensors were applied as high resolution instruments. In the second part of the study it must be stated that in terms of inner urban differentiation, and especially the demolition of houses, Spot data reach their limit. With very high resolution imageries such as CIR, or IKONOS and Quickbird, to name some spaceborne sensors in this context, inner urban differentiations can well be monitored and analysed.

Besides economic variables, urban land use changes counteract the planning demands for an urban density towards a new development of open spaces with derelict land and an urban perforation. Thus urban structure types contain a whole set of physical indicators such as rate of imperviousness, of green spaces, of derelict land, of biotopes, etc. to characterize state and dynamics of the urban physics in space and time and to foster planning strategies for a sustainable urban development.

It is a new challenge for remote sensing applications to investigate upon the urban structure and to typify the urban morphology automatically with an object-oriented methodology. There is a vast field of applications for the model of urban structure types beyond this approach such as their exposure to natural hazards or to fast uncontrolled growth, and especially to an overlap of several factors occurring at the same time.

In this context the urban structure types are analysed with respect to their vulnerability to demolition. This physical vulnerability results in a multitude of economical, ecological, and social changes in the urban quality of life. After all, the imbalance of such dynamic processes of suburbanization and inner urban demolition makes an urban region vulnerable to an acceleration of these impacts. So an urban sustainable development must face these processes, accept a lower density of the urban fabric and develop and a concept highly adapted to reurbanisation and to stabilize stagnating cities towards a higher resilience.

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