A "GREEN INDEX" INCORPORATING REMOTE SENSING AND CITIZEN'S PERCEPTION OF GREEN SPACE

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ABSTRACT:

Remote sensing is widely regarded to be useful to get a spatial overview. Typical results are maps showing the spatial extent, changes and intensities of phenomena of the Earth's surface. Qualitative information is usually only indirectly related to measurable parameters such as vegetation indices. This paper describes a research project carried out together with the city council of Salzburg, Austria. Planners defined the needs for a series of maps which reflect the citizen's 'well-being' and living situation. Among other factors, the 'greenness' of the direct neighborhood is an important factor for satisfactorily living conditions. Together with planners, a green index was developed which uses remote sensing information to derive a basic 2-D map of vegetation classes. It reflects the relative proportion of multi-story houses in the direct surrounding and the distances between them. So methodologically, the research aims at linking human viewpoints with ecological aspects of urban green. Such linkages offer the promise of new insights for understanding the perception of urban green space.

1. INTRODUCTION

1.1 Importance of urban green

The importance of preserving and maintaining green spaces in urban environments is widely acknowledged. Green space in cities is considered a crucial factor for realizing environmental quality goals and fostering sustainable local development in the framework of Local Agenda 21 guiding environmental politics (Tschense, 1998). The ecological dimension ranges between effectiveness of population density and consumption of free space. The concept of the Berlin Agenda[1] for example codifies target values for percentages of green areas per inhabitant. An increase of 10% green proportion is aimed at in areas where this value is not achieved at the current situation. Policies of nature conservation within cities include the restoration of green space deficits in the densely built-up inner cities and an improvement of the connectivity between green spaces (Pauleit, 2004). Quantitative measures like percentage of surface sealing within blocks or cells or green area per inhabitant (Wickop, 1998) provide a means to identify and localize areas of re-planning and restructuring parts of a city. On the other hand percentages and arrangements of green spaces may also be used for characterizing 'city image', life quality and attractiveness of city quarters or planning units. Urban morphology and its evolution have long been studied in geography, landscape planning and architecture, and sociology. Building structure and the specific arrangement of green areas can strongly influence aesthetical values. In order to evaluate the socio-residential conditions, a simple quantitative analysis of the amount of green areas is not sufficient.

[1] Arbeitsentwurf für die Berliner Agenda 21, 2004. Mit Zukunft gestalten – Zukunft mitgestalten. Online available: http://www.stadtentwicklung.berlin.de/agenda21/de/service/download/Agendaentwurf21April04.pdf

1.2 Mapping urban green structures

Urban green is mapped in different scale domains. On a fine-scaled level relevant for detailed planning purposes, urban biotope mapping (Ries et al., 2002) is usually done by manual air-photo interpretation. Mapping urban green on a coarser scale it is tried to map relevant urban structures on medium-resolution satellite data. A typology of detectable green structures has been proposed by Duhme and Pauleit (1994). This comprises streams, canals and lakes; wetland habitats; woodlands; heathlands and wastelands; parks and public green spaces; low density housing; farmlands; railways. Though addressing and accurate mapping of these classes using Landsat data seems to be limited, the percentage of green values for an entire city can be easily derived from these classes. The 'bird's eye view' generally allows a horizontal representation and a good overview. Resulting 2-D maps are routinely used in planning but 2-D maps may not directly reflect the 'green feeling' of the citizen living there. It is challenging to explicitly consider the direct impression of greenness 'on the ground'. For instance, a green area coverage of 40% may be perceived much more intensive if the green areas mainly consist of higher vegetation and the buildings are predominantly small family houses. The same percentage of green area may be perceived much less positive if it is mainly lawns and the buildings are high.

With a focus on densification and a consequent closure of existing gaps within the built-up areas the city of Salzburg, Austria, follows a strategy of sustainable city development. The planning department of the Salzburg city council has been financing a study to establish a comprehensive set of indicators for the assessment of residential living qualities. The green index described in this paper is considered to be one important component of this indicator set. We present an approach that uses remote sensing data sets and GIS layers to provide spatially disaggregated information of green space. Our approach is to combine image processing, GIS and spatial analysis tools to quantify urban structures in terms of greenness. This strives to

integrate to a certain degree the individual perception of the residents by additionally reflecting the spatial arrangement of houses.

2. METHODS

2.1 Study area and data sets used

The study area (figure 1) comprises an area of approximately 500 ha (covered by a mosaic of 16 orthophotos) in the southern central part of the city of Salzburg. The methodology has been developed and tested using two scanned color orthophotos (No. 433-48/2 and No. 4330-48/3) taken on July 05, 2002, with 0.1m ground resolution. The orthophotos were provided by the city council in jpg format. By adding the coordinates of the corner of the images we created world files to co-register the aerial photographs (Austrian reference system). A digital cadastre has been used for obtaining additional information on boundaries of buildings. The cadastre was converted to a raster data layer with 0.8m resolution.

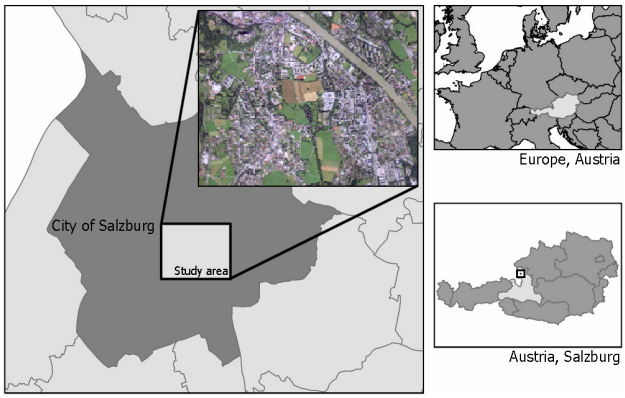

Figure 1. Location of the city of Salzburg and the study area.

For utilizing additional infrared information we integrated Aster data (VNIR bands) from May 18, 2002. The Aster data have been co-registered with the software Erdas Imagine 8.7 to the orthophotos using a second-order polynomial transformation with nearest neighbor resampling. The normalized difference vegetation index (NDVI) was calculated of NIR channels 2 and 3 for later data fusion.

2.2 Cognition Network

Over the last five years or so remote sensing applications increasingly use image segmentations as a first step to derive image objects and subsequently process these relatively homogeneous objects rather than single pixel. The evolution of this object-based image processing coincides with the advent of commonly accessibly high resolution satellite data (Ikonos, Quickbird, etc.) and the increasing number of airborne scanner systems including LiDAR systems and very high resolution digital cameras such as the HRSC-A. Image segmentation (see Haralick and Shapiro, 1985) was seldom used operationally in image processing of remotely sensed data until recently. Especially within the last three years, many new segmentation algorithms and applications have been tested in geoscience applications, but few of them lead to qualitatively convincing results while still being robust and operational (Benz et al., 2004).

For urban applications based on high resolution data it seems to be intuitive that the basic processing units are relatively homogenous segments, so-called image objects, and not single pixels. These objects exhibit characteristics beyond spectral values: objects can be parameterized in terms of shape (e.g. length, area/perimeter ratio, number of edges, etc.) and topological features (e.g. neighbor, super-object, etc.). Such relations may improve the classification results and can hardly be fulfilled by common, pixel-based approaches. Therefore, the object-oriented approach can contribute to automatic and semiautomatic analysis for most remote sensing applications. In the application, we demonstrate that classification systems based on objects are readily transferable between different scenes. In the literature it is claimed that this may be the case (Blaschke and Strobl, 2001; Hay et al., 2003) and it has been proofed for single situations (Flanders et al., 2003; Benz et al., 2004).

In the context of urban environments synergetic use to pixel-based or statistical signal processing methods may unravel rich information contents. Benz et al. (2004) explain principal strategies of object-oriented analysis, discuss how the combination with fuzzy methods allows implementing expert knowledge and describe a workflow from remote sensing imagery to GIS. Burnett and Blaschke (2003) developed a methodology for multi-scale segmentation. Most of these studies utilize the object-oriented image analysis software eCognition, but the general workflow is software-independent.

For the study of the city of Salzburg, a simple cognition network (Binnig et al., 2002) has been established to build up the class hierarchy (see figure 2). The network controls the number of segmentation levels and the definition of classes. In this case we only used one layer for classification, i.e. we did not incorporate hierarchical class definitions.

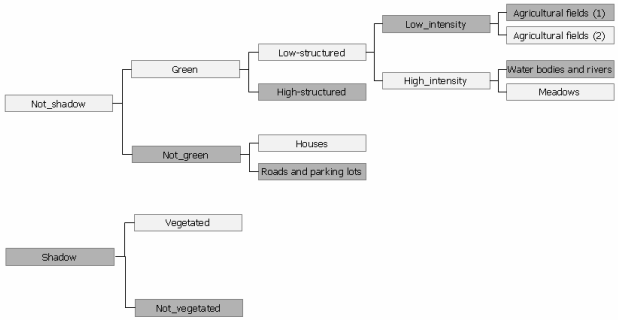

Figure 2. Cognition network being used for segmentation and classification.

2.3 Hierarchical image segmentation

The segmentation techniques developed over the past decades can broadly be divided into the main categories *edge-finding* and *region-growing* although there are many derivates and also map or knowledge-based segmentations (for a recent overview see Blaschke et al., 2004). The method used here is an advanced region-growing and knowledge-based segmentation approach built on the algorithm of Baatz and Schäpe (2000). The algorithms are based on the conceptual idea that important semantic information required to interpret an image is not represented in single pixels but in meaningful image objects and their mutual relations, i.e. the context.

Image segmentation was performed in three steps in order to obtain optimized image segments. We created a fine level with a scale parameter of 10, followed by the second level with a higher weight on the compactness of the objects. Finally spectral difference segmentation was used for the classification level (level 3, see table 1).

Level 1	SP: 10; Color: 0.9; Compactness: 0.5; Smoothness: 0.5
Level 2	SP 80; Color: 0.9; Compactness 0.8; Smoothness: 0.2
Level 3	Spectral difference; SP 10

Table 1. Segmentation parameters.

2.4 Classification

The orthophoto 4430-48/2 was used to develop a classification hierarchy being transferable to other scenes covering the whole study area. The classification relies on spectral information rather than on structural features. Semantic information was obtained from cadastral data to distinguish between houses and streets, which otherwise would have the same spectral behavior. In a first step the *shadowed* (13.5 %) and *not-shadowed* areas (86.5 %) were separated using the overall brightness. Subsequently, for the not-shadowed areas the *green* areas were detected by the information derived from the ratio between the green band and the overall brightness. In several steps the green areas were further subdivided into child classes. Structural information derived from standard deviation in the green band was used to distinguish between *highly-structured* vegetation like trees and hedgerows on the one hand and *low-structured* (relatively homogenous) vegetation such as lawns and gardens. Figure 3 illustrates that not only trees and hedgerows were classified as highly structured vegetation but also complex land use systems such as football grounds and playgrounds.

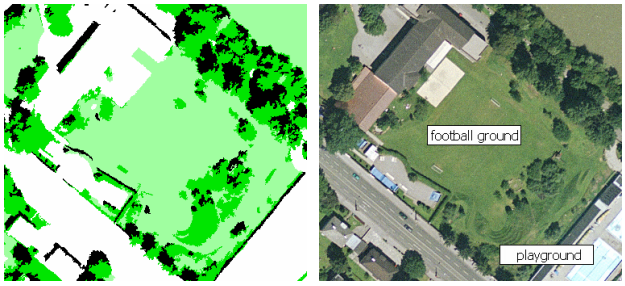

Figure 3. Classification of high-structured vegetation (green) and low-structured vegetation (light green) (*left*) on a subset of the orthophoto 4330-48/2 (*right*).

In the following step the *low-structured* areas were split up to areas with *low (vegetation) intensity* and *high (vegetation) intensity*. We used the ratio between the blue band and the overall brightness. Within the class *low_intensity* the mean values of the green band were used to classify different *agricultural fields*. Likewise, using the deviation of the red band the class *high_intensity* could be further subdivided into *water bodies* with a low standard deviation and *meadows*, respectively.

As described in section 2.1 the NDVI was calculated from Aster data and has been imported to be used as an additional image layer. A threshold of 0.3 was defined to distinguish between *vegetated* and *not-vegetated* shadowed areas. After classifying the single green classes the results have been aggregated to a binary classification scheme (i.e. green and non-green areas, figure 4).

Figure 4. Orthotophoto 4330-48/2 on the left, the final binary classification (green and non-green areas) on the right.

2.5 Transferability

In order to test the transferability of the developed classification schema to another orthophoto (4330-48/3) the established class hierarchy was exported. The second orthophoto was segmented using the same parameter as described before. For the resulting segmentation levels the classification process could be done automatically by simply importing the classification scheme and starting the classification procedure. The values for defining the membership functions of the classes have not been adjusted in order to test the ability for an automated transferability to other scenes.

2.6 Mapping spatial distribution of green and additional weighting

The binary classification result (classes green and not-green) has been spatially aggregated to a regular 100*100 m (=1 ha) cell raster. However, we assume that green space may be perceived differently according to the point of view of the observer and the specific building neighborhood he or she lives in (see figure 5). As mentioned before we want to encounter this relative amount of the green with which we want to reflect the personal situation. For the sake of simplicity we used average measurements for the 1 ha raster instead of modeling any possible constellation in regard to individual citizen's perceptions.

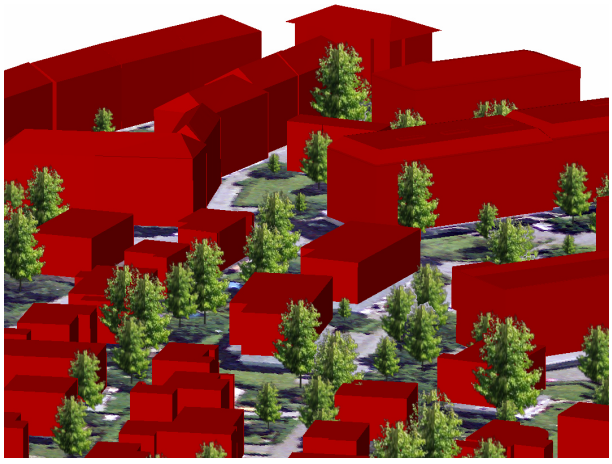

Figure 5. 3D-view illustrating different constellations of neighboring buildings.

The following factors have been used to weigh and further qualify the percentage of green within each raster cell (Lang and Schöpfer, in press): (1) the percentage of multi-story buildings, (2) mean distance of buildings within the cell. Both factors used have been stretched into a range of 0 (zero) and 1 (see table 2). This has been done in a way so that values close to 0 indicate low 'green quality' (i.e. high percentage of multi-storey buildings or low distance, respectively). Conversely, high values indicate high 'green quality'. Finally all factors were combined by weighted averaging to an aggregated measure called 'weighted green quality' (see figure 6).

Factor	*Weighting*
Percentage of green	60
Percentage of multi-storey buildings	20
Distance between buildings	20
Green index	*Range of values*
Low green quality	< 0.25
Moderate green quality	0.25 – 0.5
High green quality	0.5 – 0.75
Very high green quality	0.75 – 1

Table 2. Factors for a 'weighted green quality'.

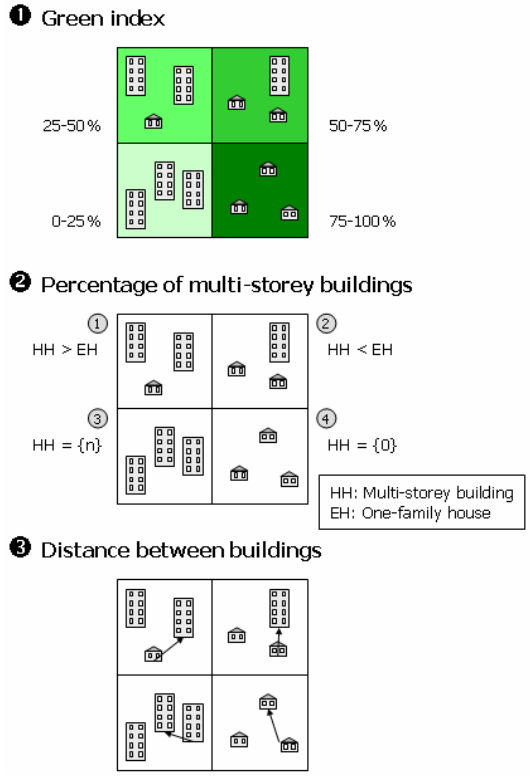

Figure 6. Graphical representation of the three factors used for deriving a 'weighted green quality'.

3. RESULTS

3.1 Classification accuracy

For the accuracy assessment we applied an automatically stratified random distribution of 100 points using the software Erdas Imagine 8.7. The reference values were based on ground truth data and visual interpretation of the orthophoto. The classification of the orthophoto 4430-48/2 achieved an overall accuracy rate of 92 % (K^ = 0.91). The accuracy of the transferred classification of the orthophoto 4330-48/3 result was 81 % (K^ = 0.78).

3.2 Green index

The distribution of green and non-green areas aggregated on 100*100 m raster cells is shown in figure 7.

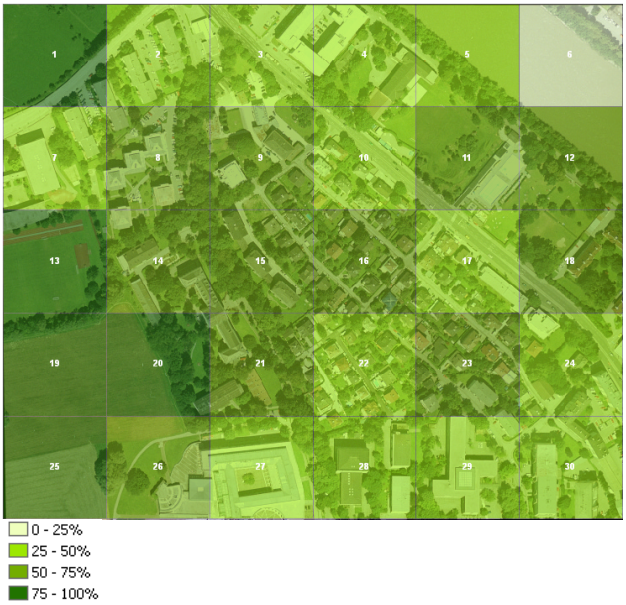

Figure 7. Green index categorized in four classes in 100*100 cell raster (orthophoto 4430-48/2).

The two factors 'percentage of multi-storey buildings' and 'mean distance of buildings within the cell' have been calculated for the orthophoto 4330-48/2 in three different categories (see figure 8). The result after the final weighting of all three factors is shown in figure 9.

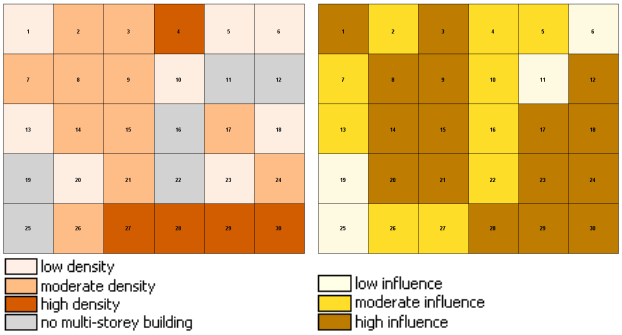

Figure 8. Distribution of the factors 'percentage of multi-storey buildings' (*left*) and 'mean distance between buildings' (*right*) for orthophoto 4330-48/2.

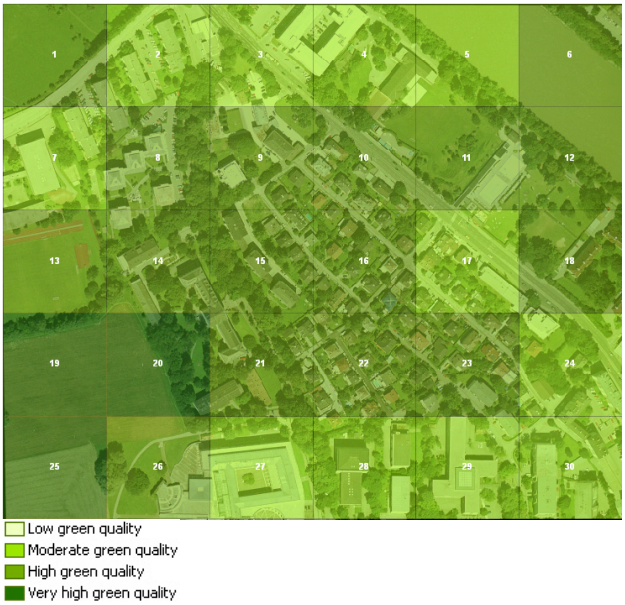

Figure 9. Aggregated measure 'weighted green quality' (for the weighting see table 2).

4. DISCUSSION

It has been demonstrated how a spatially disaggregated 'green index' could be derived from classified orthophotos with additional weighting factors. The combination of the factors and defining their weights is not an easy process. Secondly, we are leaving the remote sensing and image processing domain in two regards: firstly, the last part of the workflow consists mainly of GIS tasks. Secondly, and more relevant to the interpretation of the results, we are leaving hard science ground and add human centered indices to 'measurable' factors. But this coincides with the planners demand: they want data sets which reflect the well-being, the notion of place and the satisfaction with the place rather than typical remote sensing results such as NDVI values. How well the calculated values really reflect the perception of the citizens is at the moment somewhat tentative. A questionnaire-based survey is planned to verify the respective factor weighting. Still, the planners visually evaluate the resulting maps as very useful and look forward to further studies.

A more technical problem is caused by the sample design: the cells to be evaluated are considered to be isolated from their neighboring cells which could reveal quite different qualities. Therefore results could be further refined by considering e.g. a 3*3 kernel, or overlapping aggregations. Classification instability has been successfully overcome by using additional remote sensing data layers, in this case the NDVI calculated from Aster 15*15 meters pixels. For the data fusion the object-based image analysis methodology has some advantages. Problems arise only at the edges of the objects where the different resolutions may cause some problems.

Due to several limitations inherent in orthophotos, e.g. spectral, radiometric or problems caused by mosaicing, high resolution satellite images (Quickbird) will be used in a subsequent study. The preliminary cognition network will be extended using the improved spectral features by the satellite data. A 3D model may provide additional height information to more realistically model the influence of neighboring buildings to the individual perception. Still, it is believed that this methodology paves the road to combining remote sensing parameters with GIS for urban environments as a basis of spatial planning. It is well known that the geometric configuration of the spatial units used to represent spatial data can have a profound effect upon subsequent analysis and interpretation. The 1 ha raster used in this research is just one realization of an infinite number of approaches and was suggested by the city planners. The methodology serves various other aggregation systems. Since planners are less interested in the situation of an individual house this spatial system neutralizes the effect of any bias which is caused by convoluted or distorting house geometries. Grid-based systems turn variables which are spatially extensive into their density/intensity equivalents and this immediately means that comparisons can be made between different parts of the same system as well as between different systems.

Finally, this methodology may be used in the future as an input in urban systems modeling. There are many elaborated dynamic models based on intricate decision processes which simulate space-time properties. Many urban models and their dynamics are based on theories of development associated with cellular automata (CA), whose data is fine-grained, and whose simulation requires software which can handle an enormous array of spatial and temporal model outputs. Both remotely sensed (spectral, vegetation indices, spatial texture) and other geospatially explicit ancillary data (topography, soil type, etc.) may be used in such modeling or expert system to derive urban land-cover classifications.

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