WHERE THE GRASS IS GREENER – MAPPING OF URBAN GREEN STRUCTURES ACCORDING TO RELATIVE IMPORTANCE IN THE EYES OF THE CITIZENS

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ABSTRACT

Conservation and development of urban green meets today's challenges of sustainable urban planning in fast growing urban environments. In our highly transformed urban settings, green spaces play a significant role for the comfort of the citizens. The loss of both public and private green not only threatens urban climate and ecosystems, but may also influence a city's image and the residential satisfaction in general. Quantifiable information about green structures and the amount and distribution of green spaces is essential for sustainable planning. However, this information is to reflect the citizen's perspective, since in general the acceptance of planning decisions can be credited to the participation of local stakeholders in the decision making process. In the study presented a weighted green index (GI_w) has been elaborated, which both integrates the classification of relevant green structure types on the basis of a QuickBird image and the results of an interview-based survey revealing the relative importance of these types. The inclusion of aggregated perception of urban green structure types within the framework of monitoring is aimed at 1) supporting arguments of experts and at 2) enhance public acceptance of planning decisions through integration of public evaluations.

INTRODUCTION

Green spaces and corridors in urban areas not only have ecological and climatologic importance for residents but also affect the local recreational quality. The attractiveness of an urban area is significantly influenced by the amount of green which can be directly used and perambulated or visually and aesthetically enjoyed. Particularly the pleasure of even little green areas in various places at certain moments ("*Minutengrün*", i) may increase the satisfaction of the citizen and residential environment quality. Along the guideline of sustainability, city planners look for tradeoffs between expansion and densification: filling gaps may prevent uncontrolled sprawling, but at the same time may erase remnant green spaces within anyway congested areas and threaten ecological networks potentially existing among these (ii). The planning authority of the city council of Salzburg is establishing a monitoring concept for observing spatio-temporal changes of urban green. This should be done on the basis of a quantifiable indicator being included into of a set of indicators for residential satisfactory as being developed the research studio iSPACE (iii). The envisaged monitoring system should be built upon a transferable, yet cost-effective methodology, being fully repeatable in regular intervals, but at the same time transparent and flexible in terms of conceptualisation. It should be adaptable to different systems of spatial disaggregation, since reporting the results on different scales and reference units is important for urban and regional planning.

Considering the political dimension, the applied method is expected to reflect a broad public opinion, since in many cities 'urban green' has to some extent become a sensitive issue. Repeatability, transferability and cost-efficiency are rather technical aspects, which today are mostly fulfilled by the advancements made in remote sensing technology and data. Transparency and flexibility instead are more attributed to the way of analysing and processing. Here, again, we can meanwhile rely on proposed frameworks for image processing and intelligent knowledge representation (iv). Essential methodological and technical considerations of the approach followed in this paper have been discussed before (v, vi). But still, acceptance among and 'publicity' of the undertaken approach is more difficult to operationalise, since qualitative judgements and subjective impressions are to be converted into quantifiable information and to be integrated with quantitative remote sensing data. Monitoring and conservation activities of urban green should thus not simply be based on objective measurements from e.g. satellite sensors, but also on subjectively perceived attributes of the residential environment (vii). The inclusion of subjective attributes into a GI-based planning support may be seen as a form of participation that reciprocally validates the results of remotely sensed data. It may also lead to higher identification and residential satisfaction with the area concerned. "If everyone (...) can participate in the production of an urban image through their production of social space, then all can at least feel some belonging to that place" (viii, p 14).

METHODS

Study area and project design

The study site spatially coincides with the city limits of Salzburg, Austria (see figure 1), and comprises an area of 120.6 sqkm. The city of Salzburg is dominated by the ancient core ("Altstadt") and the adjacent densely built-up inner city, interspersed with wood-covered hills. Surrounding city quarters are built up to a lesser extent mostly characterised by single-family houses, stand-alone ones or in rows, as well as some blocks of multi-storey buildings. To some extent, agricultural fields and forest are inside the limits of the city, mainly towards east and south. A remarkable urban element is the rectified Salzach river crossing the city from south to north.

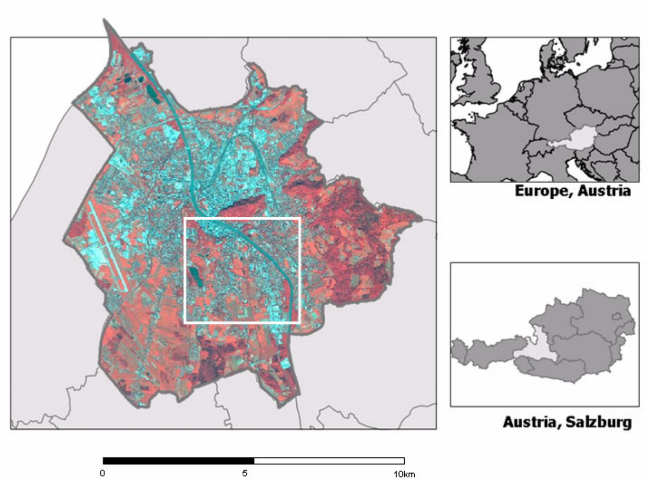

Figure 1: Study site

The study conducted so far has been threefold: in a first and experimental stage (*stage I*, vii) we used a 500 ha orthophoto mosaic from July 2002 representing a limited area of the inner city. Infrared information has been obtained by integrating VNIR information from an ASTER scene captured two months before (vii). Advantages of using an object-based image analysis approach has been reported there as reaching from scaled representation over data fusion up to spatial explicit characterisation of the resulting green structure units. In the second, operational stage, the study was extended to the entire city (*stage II*). We used QuickBird data from June 21, 2005, cloud-free and covering the full polygonal extent of the city limits. In the third, integrated stage, we now seek to integrate the results of an interview-based survey regarding the relevant importance of green structure types directly in the classification process and related analyses. The result of the first part of *stage III* is reported in this paper. For this, a subset of approximately 11 km² (3360 *

3360 m, 5601 * 5601 pixels) in the southern central part of the city has been selected from the QuickBird scene (figure 1).

Data pre-processing

QuickBird collects four multispectral (MS) bands (VIS and VNIR) at 2.44 m spatial resolution and a 0.61 m panchromatic (PAN) band, each band coded in 11-bit radiometric resolution. The scene was pan-sharpened and co-registered to a digital cadastral map (BMN-31). Pan-sharpening has been performed according to Liu (ix) using an image fusion model implemented Erdas Imagine 8.7. Nearest neighbour interpolation was used for resampling the MS bands into the PAN resolution. A 5 * 5 matrix determines the implemented low pass filter, which merges the values of MS and PAN. In the absence of an appropriate digital elevation model, the rubber sheeting method has been used instead of rationale polynomial orthorectification for geometric correction.

A strictly hierarchical, multi-resolution segmentation approach has been chosen for generating spatial units. Image segmentation was done using eCognition 4 throughout all stages of the study. Table 1 summarizes the parameters of a six-step hierarchical segmentation as performed in *stage III* next to the number of generated image segments in each level.

Table 1: (L = Level, SP = scale parameter, SF = shape factor, CW = color weighting, CPW = compactness weighting, SD = spectral difference)

Level	Parameters used	# of segments	∅ size of segments (m²)
L 6 / 7	SP 300; SF: 0.1; CW: 0.9; CPW: 0.9 / merge	4,403 / 3,907	2,564.07
L 4	SP 65; SF: 0.1; CW: 0.9; CPW: 0.8 / SD 65	66,560 / 49,848	169.62
L 1	SP 10; SF: 0.1; CW: 0.9; CPW: 0.5	1,699,408	6.64

Classification, green index and spatial aggregation

A multispectral classification has been used as data basis for *stage II*. Based on the normalised differenced vegetation index (NDVI) a rule-based classification resulted in three spectrally defined classes, namely *Green*, *Not-Green* and *Water*. The class water only comprises water bodies, such as larger ponds and rivers. Out of the first two classes a binary mask of green and not-green was created. The class *Water* was used as a temporary class for flexible assignment (green or not-green). This was done, because the survey that has been started by then already revealed that water plays a significant role in subjective green impression (see below for more details).

The classification result was used to calculate an overall green index GI (vi). This index corresponds to the percentage of classified green in the respective spatial unit. Depending on which category the class *Water* has been assigned to, slightly different values for the green index resulted. We therefore differentiated between GI-I (excluding water) and GI-II(including water). The green index was reported on a set of different reference units. Starting from any arbitrary image segment, which was assigned a certain percentage of greenness, the index was aggregated on administrative units of relevant planning levels and also the entire city. Finally, a non-administrative regular grid was generated (50*50m in size), by which we ensured compatibility of the green index with other indicator-based planning tools being established in the city (iii).

Interview-based survey

Since the binary mask of *stage II* was derived by considering spectral characteristics of the classes only (besides *Water*, see above) the result may not sufficiently reflect individual impressions of respective green structures. Within *stage III* we therefore differentiated the classification scheme into various types of urban green by considering the results of an interview-based survey. This survey, conducted among 128 people throughout the city, revealed a ranked evaluation of twenty-nine different green structure types ("*Grünstrukturtypen*"). These were judged by their relative relevance for an overall green impression in a range of 0 to 5. To assist respondents with assigning values to the respective types that were sometimes scientifically named, exemplary images (photos) were provided along with a questionnaire. In addition to that, the interviews contained questions pertaining to the general perception of urban green in the city. The interviews were done between June and July, 2005, and coincide with the date of the QuickBird scene.

Advanced classification

Thirteen out of twenty-nine green structure types were transformed into a cognition network and classified using object-based image analysis. To set up the rule base in a flexible way, we established a cognition network (x). The network provides the ability to interact flexibly with the classification scheme (figure 2). It not only controls the classification process as such, but also serves as a graphical means for communication and interaction with users or stakeholders. Those can decide about the very semantic content of aggregated target classes like 'green' or 'not-green'. In our case, the class hierarchy contains eleven green structure types plus two classes not considered as green (i.e. sealed surface and shadow on non-vegetation). Depending on the threshold applied to the ranking among the respondents or any other decision rule, the classes are assigned to the target classes Green or Not-Green.

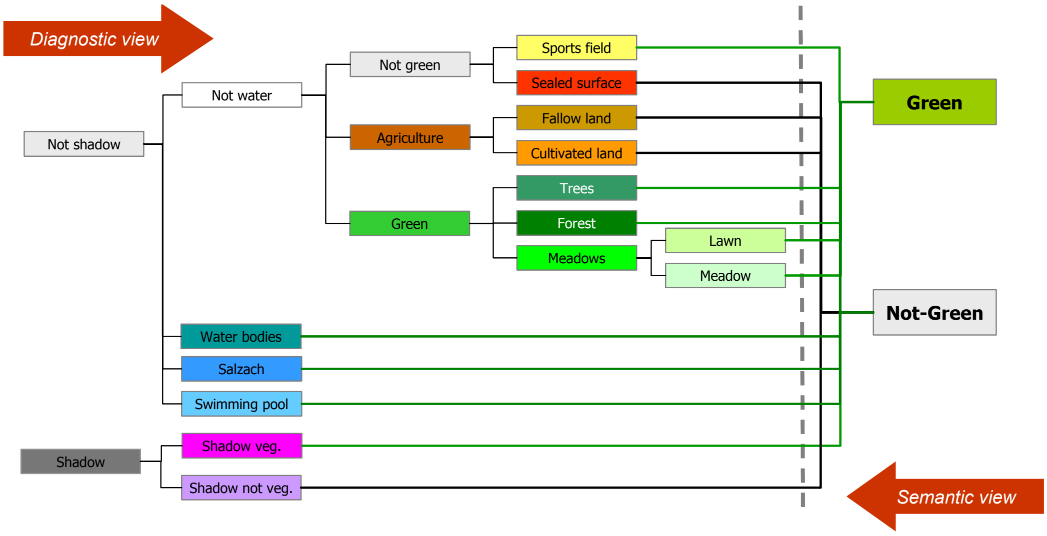

Figure 2: Cognition network for stage III

Most of the classes were classified on the fourth segmentation level. For larger sized objects like water bodies and forest we referred to level 6. Classification-based segmentation was used to merge forest objects even in a higher level. The weights for the segmentation process mainly emphasize the spectral attributes and not the form of the objects. Like in *stage II*, the NDVI was used arithmetic customized feature. Classes were defined by one or more different rule-based membership functions. For example for class *Water Bodies* we used the following functions: (1) *Mean value* of green band, (2) *Mean value* of the IR band, (3) *Standard deviation* of blue band and (4) *NDVI*. Since working in an object-based environment, point-based accuracy assessment will not reflect the spatial appropriateness of the classified image segments. This has been tested in *stage I* (xi) though not considered being operational as yet.

Weighted green index

To represent an averaged green impression per cell, a single value has been elaborated. The weighted green index, GI_w, can be calculated for any spatial reference unit, since being based on the percentages of green structure types and their respective importance. For the resulting weighted rank GI_w of a given unit (e.g. a 50m * 50m raster cell) the following metric has been used: First weights were established by determining area percentages of each structure type occurring in the respective unit, with respect to the entire area of green within there. Then ranks of the structure types were linearly stretched to an interval of [0/1]. The ranks occurring in the unit were then multiplied by the assigned weight. These products we called GI_{w0}. Finally, to derive GI_w, the sums of these products were re-transformed into the original range of the rankings.

RESULTS

Classification results and accuracy assessment

Rule-based multispectral classification of the entire city area (*stage II*) revealed an overall percentage of green areas of 60.1% (GI-II, i.e. including water) and 58.4% (GI-I), respectively. Percentages of green within the 50 m * 50 m raster cells values ranged from 0 to 100 %. Within administrative units (e.g. enumeration blocks) percentages ranged from 0.5% up to 93.3%. Table 2 shows the result of the classification in *stage III*, performed at a subset of ca. 11 km². The last two classes were classified, yet not considered as green structure types. Concerning the percentages of green, again cells occurred were there was full cover of green or no green at all.

Performing point-based accuracy assessment (stratified random, 200 points) in *stage II*, we obtained very high values > 95 % for all classes. User's accuracy for class green was reported with even 99.4 %. For *stage III*, point-based accuracy assessment (stratified random) was used again, this time choosing 300 points and 20 points per class as minimum. It revealed an overall accuracy of 81.7 % (K^ = 0.8005). This value increases to 87.2 %, when summarizing classes *Lawn* and *Meadow*. *Lawn* has been classified by form features, which cannot be fully reflected by point-based accuracy assessment. See table 2 for details.

Table 2: Classes, codes and accuracies for stage III classification (codes: 1 = group of trees, 4 = fallow, 5 = sport fields, 9/13 = water bodies/river, 17/18 = shadow veg/non-veg [not shown], 21= forest, 29 = swimming pool, 29/30 = lawn/meadow, 20 = sealed [not shown])

Code	1	4	5	9	13	17	19	21	28	29	30
Rank	4.3	2.1	2.9	4	4.3	3	2.3	4.1	3.5	3.4	3.6
Area (ha)	4.5	0.7	9.4	33.2	11.1	31.5	31.5	64.3	0.6	46.6	181.1
Prod./ user's acc. (%)	64.8/ 75.0	93.7/ 100.0	100.0/ 100.0	95.2/ 100.0	95.4/ 100.0	80.0/ 80.0	62.9/ 80.9	95.6 / 100.0	100.0 / 80.0	57.1/ 36.3	67.7/ 77.7

Result of the survey

Concerning individual relevance of urban green within the local population the survey results showed a very high (80 %) or high importance (18 %) attributed to the conservation of urban green. Some 56 % of respondents stressed the importance of urban green to be either seen from or directly adjacent to their residence. A further 42 % opted for urban green within five minutes walking distance from their home. General satisfaction with urban green within the city limits ranges at close to 80 % respondents. Estimates of the overall green of the city area however show no conclusive results. Estimates are almost evenly distributed between 30 % and 70 % of the city area, while the actual area as extracted from Quickbird Imagery has been calculated as about 60 % (see above). Detailed results concerning specific green structure types vary markedly. They range from values of 2.0 to 4.5 on a scale from 0 to 5 (see table 2).

Weighted green index

The weighted green index GI_w ('green impression') has been calculated for altogether 4,692 raster cells, each of them 0.25 hectares in size. Cells were $GI_w > 3.9$ sum up to 3,400 or 8.5 sqkm and 245 cells or 0.6 sqkm have values $GI_w < 3.0$. The distribution of the results can be characterized by the following: Values for GI_w range from 2.1 to 4.3. This covers a major part of the entire span of the subjective evaluation ranging from 2.0 to 4.5. Note that zero (0) is excluded, because this value represents raster cells being entirely covered by non-green. The median value (4.1) indicates a rather slant distribution towards higher values; this observation is supported by the negative value for skewness (-4.3). Curtosis of 21.3 refers to a sharp peak.

By extruding the raster cells in a 3D software environment according to their values of GI_w, analytical surfaces were generated. These reflect each type's relative importance and represented as plateaus of different levels. Figure 3 shows a portion of such a surface, where 'holes' are representing cells, where $GI_w = 0$. The right part of the figure shows the inner portion of a 120 m *

120 m subset of the QuickBird image, overlain by four raster cells, and showing the calculated values of GI-II and GI_w.

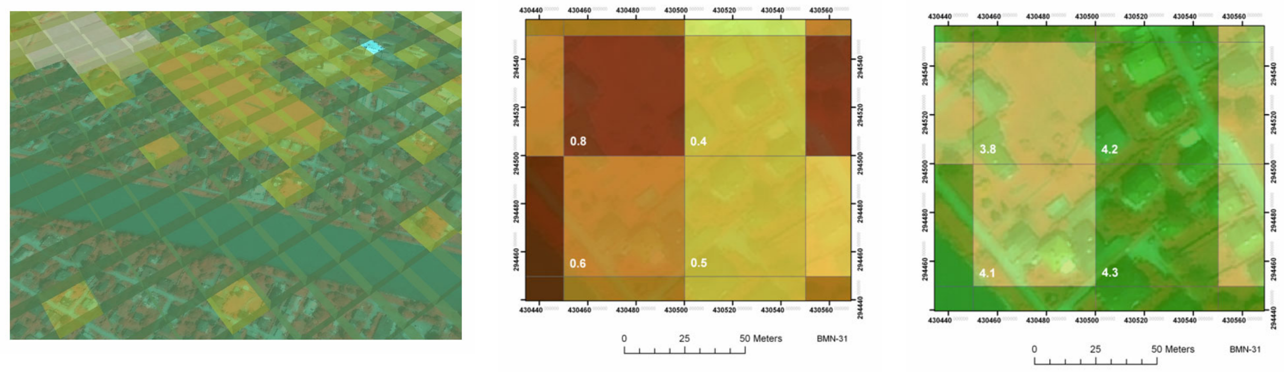

Figure 3: Analytical surfaces generated from GI_w (left). Comparison between GI-II and GI_w (centre and right).

For comparison reasons, green index GI-II (including water) has been contrasted with GI_w by using the initial weight product GI_{w0}. A set of 10 neighbouring cells (cell-IDs 18974-18983) was selected for illustration purposes (see graph in figure 4). Here the 'greenness' of a cell is evaluated much more specifically, reflected by the undulated curve representing GI_{w0}. Of special interest those cells may be considered, where, according to the given weights, GI_{w0} exceeds GI (see cell-ID 18983). This applies to nearly 44% of the cells (2,095), taking only those cells into consideration, where (1) there is at least 10% percentage of green and (2) there is at least 10% difference between GI-II and GI_{w0}, The range of the lowest and the highest value as well as the median, is indicated by a stock chart (figure 4, right part).

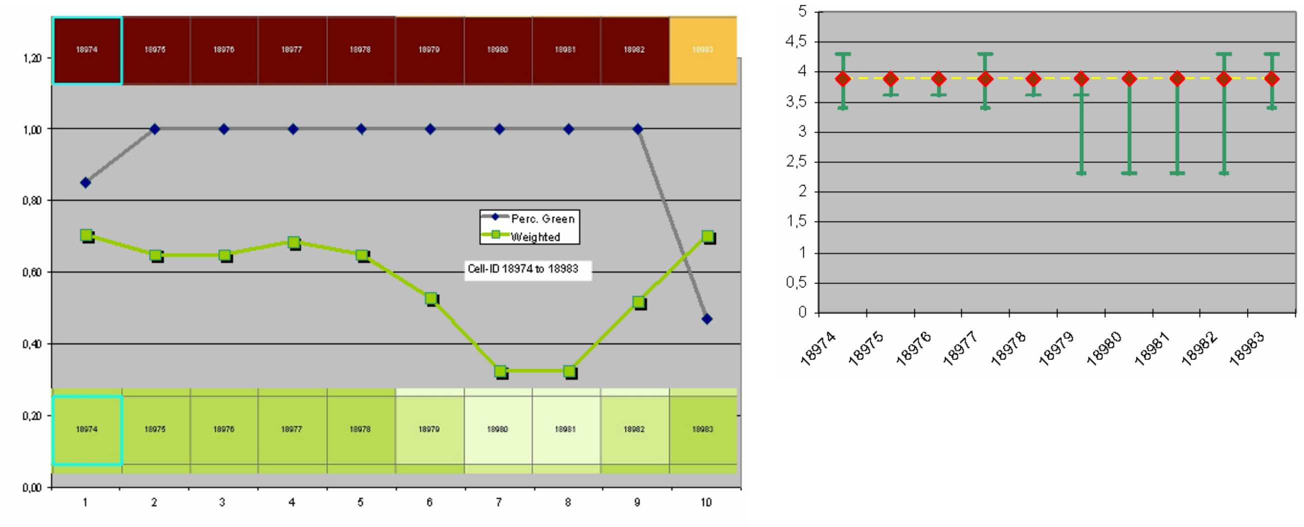

Figure 4: GI –II and GI_{w0} for 10 neighbouring cells (left). Ranges for GI_w (right)

CONCLUSION

A transferable and transparent, yet flexible method for quantifying green structures has been elaborated by using an integrated approach: results from image classification and spatial disaggregation were combined with qualitative data obtained from a socio-geographic survey. In a co-operative study, three institutions dealing with spatial issues yet from different viewpoints (Z_GIS, IISR, iSPACE) have undergone the challenge of integration. Still, from the perspective of the participating researches, the study is at its beginning. Areas have been identified, which are perceived 'greener' than others – based on their respective relevance in the eyes of the residents. Data suggests that this relevance is linked to landscape aesthetics (openness, varied patterns), but also to accessibility and usability of urban green. No direct link could yet be established between individual relevance and biodiversity that is supported by specific green structure types. This coincides with suggestions offered by Hard (xii) that are aimed at the opening of available green spaces to the public.

The high median value (4.1) indicates fairly high appreciation of the existing green structures. This result though only applies for those areas of the city which are generally considered as belonging to urban green. These areas on the other hand, as the study has demonstrated, are not necessarily congruent with the green mask which is derived from the QuickBird image based on the NDVI. It also needs is to be mentioned, that ordinal scaled data (ranks) have been used for weighting the green index, and thus the result should not be interpreted by means of ratios. That means, a cell with GI_w equals 4.2 is not to be considered 'twice as green' as a cell having 2.1. The variation of specific green structure types may be attributed to landscape aesthetics (e.g., openness, varied scenery, water bodies, xiii). The results of the survey further lets assume that higher values are assigned to types that are generally open to use for the public, while private green or green not otherwise to be used easily features lower on the scale of relevance. While these assumptions need better verification through qualitative research, they may be one of the openings for GI-based decision support.

Problems of integration arise from different spatiality of remotely sensed data and socially constructed values placed on specific spatial entities, e.g. green structure types. In this study, this has been bypassed by only asking for values to green structure types as such, without reference to specific locations. Further research should try to properly integrate 'objective' (i.e., remotely sensed) and socially constructed 'distorted' spatial data. Shareholder maps ("argumaps", cf. xiv) that respect individual values may provide an opening. GIS operations for explicitly taking into account the spatial context of a given spatial unit do exist, whereas respecting the entirety of relevant aspects that make up the impression of a specific setting, is of course still limited. Approximating that and utilizing the toolbox of landscape metrics (xv), one could analyse the contrast of two neighbouring cells, i.e. the difference of the respective GI_w values. Moreover the specific shapes and the spatial configuration of the green structure types inside the cells could be investigated further, and again their relevance could be explored. Taking the entire set of grid cells as a surface, regions of similar GI_w could be identified as peaks and valleys. These could form the base for appealing models serving planning needs. Depending on the task, the analytical and cartographic communication by a flexible and variable resolution is important for an innovative decision support. In general, the inclusion of survey-based data so far helped staff of the planning department in arguing planning decisions. If these decisions also find better acceptance in the eyes of the general public remains to be seen.

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