From Earth Observation to Urban Planning in Cities

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Abstract — **Can earth observation data, methods and products substantially support the complex process of urban planning? Today urban planners confirm that remotely sensed data and derived products are only used rudimentarily in their daily routine. The rapid development of technologies and applications in the field of remote sensing open up new capabilities: From multi-temporal monitoring of urbanization to 3-D city models, from analysing spatial structures to cross-city comparisons, from indirect assessments of population distribution to socio-economic analysis, from applications in the fields of urban climate, vulnerability analysis, traffic detection to energy-relevant questions. Thus, a critical discussion is needed beyond long-established remote sensing or planning communities to transform the new capabilities into practical value.**

I. Introduction

Urban planning can achieve many gains through closer connection to the remote sensing community and use of modern remote sensing technologies. Some projects, such as the European Urban Atlas (Seifert, 2009; Steinborn, 2010) or REFINA (Esch et al., 2010) already use remotely sensed data with precisely defined applications and coordinated user needs focusing on cities. It shows that the gradual commercialization of satellite or airborne earth observation since the 1970s and its prospects on performance and effectiveness have greatly expanded.

Earlier predictions on uptake and use of earth observation data were probably far too optimistic. This led to some disappoints where projects were not realised. In consequence, remote sensing data and products often played, at least in Germany, a secondary role. Today urban planners confirm that remotely sensed data and derived products are only used rudimentarily in their daily routine (Reiß-Schmidt, 2010). For this reason it is important to demonstrate the value of today's earth observation technologies for urban planning to open up a critical inter- and transdisciplinary discussion on expectancies, requirements, and capabilities.

Planning is a highly complex process aiming at a conceptual anticipation of future situations. Urban planning is an elusive subject of study (Seto & Fragkias, 2005). It draws on a variety of disciplines and has no widely accepted canon. The higher-ranking goal of regional- and urban planning is to effectively direct settlement development to qualitatively high-value, livable and sustainable structures. The difficulty is to reconcile national and regional planning guidelines with the large variety of political, economic, ecologic and social issues of town planning as well as private interests at local level (Streich, 2005).

Thus urban planning needs a responsible balancing of advantages and disadvantages from a holistic perspective. The most important condition for the balancing of pro's and con's and a subsequent development of strategic orientation for future planning activities is knowledge: e.g. knowledge on the inhabitants of the city, the physical urban environment, as well as change over time.

These changes can impact urban climate, traffic, social and economic considerations, which are inherently spatial in nature. In the best case manifold spatial and quantitative information are available to form opinions and support subsequent strategic decision-making. But relevant data sets are often limited at hand or even inaccessible, because they are too expensive, outdated, generalized or restricted due to data security, among other reasons.

Earth observation is an independent data source. Since the launch of the internet platform "Google Earth", earth observation data became more or less common knowledge. On the one hand the theoretical possibility to obtain spatial information on objects, structures or patterns of the land surface all over the globe allows unimagined information and possibilities.

Meanwhile, the development of sensors with a spatial resolution of one meter and better allows the specific requirements of small-scale and complex city landscapes to be met. On the other hand timeliness of the data on these platforms and their volume, often leave users with an amorphous ocean of buildings in a mega city, when their needs are more direct and dependent upon quantified and objective information needed for the planning process.

Therefore this paper addresses several specific questions on the value of remote sensing to urban planning:

1) Which remotely sensed data sets are useful for urban areas?
2) What are the capabilities and limitations of remote sensing regarding mapping, subsequent analysis and indirect assessments for relevant products to urban planning?
3) Remote Sensing and Urban Planning – a common future?

II. THE VALUE OF REMOTE SENSING TO URBAN PLANNING

1. Remotely sensed data sets

The capabilities of various sensors reach far beyond the obvious benefits available at platforms like Google Earth or Bing. They provide reflective responses all along the electromagnetic spectrum which enables detection of objects or patterns of the earth's surface and their condition (Mather, 2004): The sensors cover many spatio-temporal dimensions, with a flexible repetition rate and in various scales ranging from spatially detailed analysis on single buildings or building block level to global studies on continental scale.

In combination with widely automated methods of data processing and image analysis, urban remote sensing provides multiple options to support decision makers such as resource managers, planners, environmentalists, economists, ecologists and politicians with accurate and up-to-date geo-information. Thus, information may be tailored for individual and organisational use.

Available space-borne systems provide data sets with low spatial resolution (in the range of > 500m) and a broad swath (spatial coverage of one image) of 3000 km and more. Thus, sensors like DMSP-OLS (night-time lights), MODIS or NOAA enable mapping on continental or national basis. On medium spatial resolution (>5m) sensors like Landsat, SPOT, IRS or RapidEye featuring a field of view of 60-185 km enable to separate urbanized from non-urbanized areas on a regional scale.

Highest geometric resolution (<5m) provide sensors like Ikonos, Quickbird, Cartosat-2 or WorldView I & II allowing the classification of the small-scale individual objects typical for cities. The restriction here is that the swath of around 15 km often does not cover the full extent of urban-suburban areas.

Also, radar sensors such as TerraSAR-X, CosmoSkyMed, RADARSAT or ALOS are operating from space. These active systems are weather-independent (all-time) systems, while the optical systems are restricted to cloud free skies. With spatial resolutions up to 1 meter these data sets are capable of detecting the small-scale structures of cities as well, with swaths from 10 to 100 km.

In addition, interferometric SAR has been applied widely to derive digital elevation models (DEMs). In particular, the Shuttle Radar Topography Mission (SRTM) of the year 2000 supports urban analysis with area-wide DEMs with a spatial resolution of up to 30m. The German TanDEM-X will provide from 2012 on a global DEM with a spatial resolution of 10-12m.

Next to satellite based sensors, airborne remote sensing provides complementary data sets especially suitable for cities: Hyperspectral sensors such as HyMap enable the mapping of surface materials or the condition of vegetation, aerial imagery provides spatial resolutions up to few centimetres and laserscanning as well as stereo cameras enable producing digital surface models at geometric resolutions of 1 meter or even higher, for example.

2. Mapping

The various remotely sensed data sets presented above are *data* not *information*. The strength of remote sensing with its synoptic overview allows independent, fast, up-to-date, area-wide and relatively cost-effective transformation of data (or images) into information. Making use of a vast amount of methodologies – e.g. statistical-, neural-, fuzzy classifiers – for automatic information extraction for particular data sets this transformation leads to application-driven products.

With the land cover classification the basic question on "what" is "where" within the urban environment can be answered: The main field of application is mapping the urban environment providing an inventory of the urban morphology. Depending on available data sets, products vary from urban footprint level (Fig. 3) to a spatial level where individual objects are identified (Fig. 1).

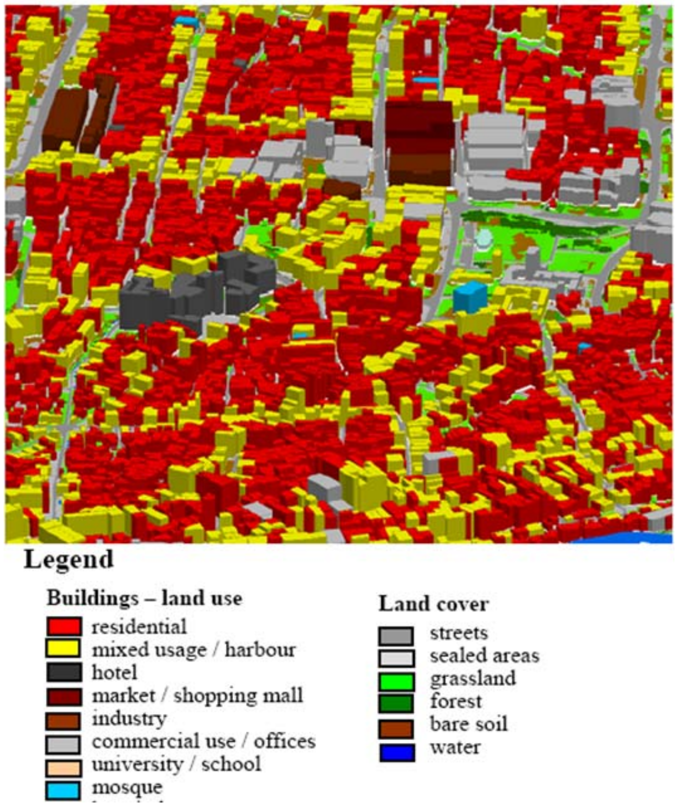

Fig. 1: 3D City Model of Padang in Indonesia from a southern view

As one example, multi-sensoral data processing of high resolution optical satellite data in combination with a high resolution airborne digital surface model allows the derivation of a 3D city model (Fig. 1). This is e.g. relevant for identification, localization and quantification of the building stock, building types, vegetation fraction, infrastructure, or undeveloped areas.

Also at building level, hyperspectral remotely sensed data allows the retrieval of information on the materials of the surfaces (Heiden & Heldens, 2010). Thus, roof materials, asphalt types, vegetation types and condition, etc. can be identified and quantified. Typical applications include the detection and quantification of existing solar panels, green roofs or the identification of roofs suitable for this usage.

A city is not only a conglomeration of buildings and streets. The people living there, their mobility turn the physical urban scenery into a lively system. Beyond mapping the fixed physical appearance of a city remote sensing allows also to capture mobility. Especially airborne remote sensing systems enable the necessary short time intervals for data acquisitions to monitor traffic flows.

Thus, it becomes possible to detect traffic situations or to monitor parking areas in near real time (Kurz et al., 2010). Using these algorithms it even becomes possible to detect people or crowds and their trajectories and movements, which is a crucial application in the field of risk management and emergency coordination (Hinz, 2010).

Next to the use of optical remotely sensed data, thermal infrared bands of e.g. NOAA-AVHRR or Landsat data in combination with the NDVI, which is an indicator for emissivity, allow to retrieve land surface temperature (LST) (Van De Griend & Owe 1993). Figure 2 shows the derived LST for the suburbia of Munich in Germany measured on the 26th of August in 2007 on regional scale using Landsat TM data. It becomes obvious that the LST in the urbanized area of Munich and its suburbs is significantly higher than its rural surroundings (Heldens et al., 2010).

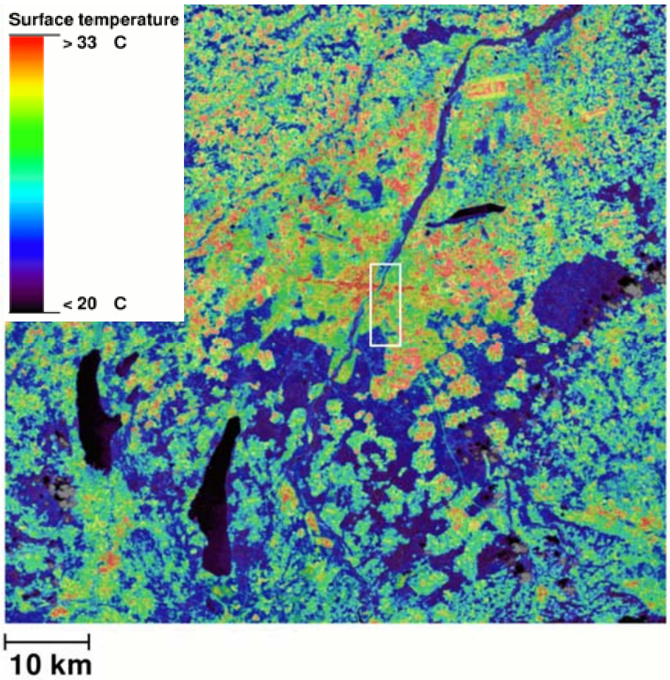

Fig. 2: Land Surface Temperature for Munich and its surroundings (Heldens et al., 2010)

3. Analysis

Beyond the various capabilities of mapping the city, remotely sensed data sets can be used for analysis: Multi-temporal remote sensing facilitates the monitoring of spatial urbanization over long as well as short time periods. Using satellite systems like Landsat, available since 1972, monitoring spatial urban growth becomes possible for almost 40 years. Change detection from 1977 until 2010 in 4 time intervals shows spatial urbanization for the city of Puebla in Mexico and its surroundings (Fig. 3) – based on Landsat MSS, TM, ETM+ and TerraSAR-X stripmap data.

Using methods like gradient analysis (Taubenböck et al., 2010) or landscape metrics (McGarigal et al., 2002), the spatial extent, its landscape configuration, direction of growth, etc. can be quantified and used to compare cities to each other (Herold, Scepan, & Clarke, 2002). Here, zonal statistics are applied: A ring-buffer analysis employs six artificial concentric rings with 5km-intervals around the urban center of Puebla creating comparable zones from the urban core to the fringes. The built-up density is a measure to characterise spatial urban pattern and structure. Densities vary substantially from city to city and from urban centers to peripheral areas (Taubenböck et al., 2009). Built-up density is calculated as ratio between the areas of the particular ring with water areas omitted and the urbanized areas.

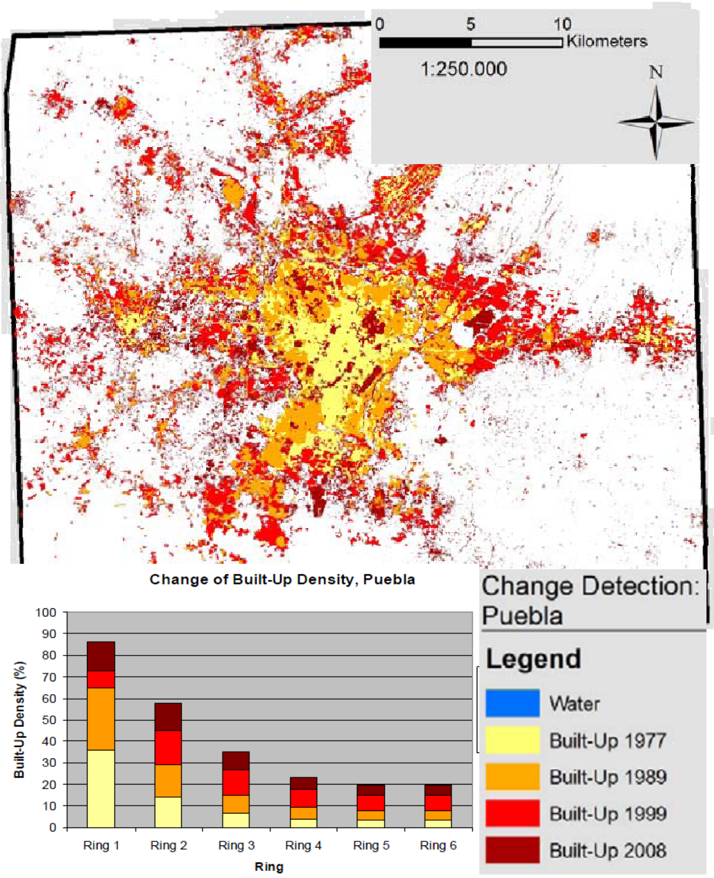

Fig. 3. Multi-sensoral spatio-temporal growth mapping of the sprawling city of Puebla in Mexico since the 1970s

Regarding shorter time intervals detection or monitoring of changes, like e. g. at construction areas or building collapses after an earthquake impact (www.zki.dlr.de) are valuable applications (Schmitt, 2010).

Using the 3D city model spatial analysis on a higher geometric resolution is possible. Different spatial references, e.g. administrative units, blocks, the street network or artificial units like rings or sectors enable the calculation of physical parameters describing and quantifying the urban structure or pattern: examples are building density, floor-space index and percentage of impervious surfaces, vegetation fraction or dominant roof materials. Figure 4 shows two exemplary parameters calculated for the reference unit “block” defined by the street network for the city of Munich. In addition, the physical knowledge on block level in combination with physical parameters on building level, like building size, height, alignment, etc. allows the derivation of urban structure types, e. g. perimeter block development, detached houses or high-rise buildings. These spatial parameters support regional and urban planning with objective and quantitative information on the urban morphology.

The availability of these products on urban morphology is of crucial importance in the field of risk and vulnerability assessment and management. Current mapping e.g. of flooding events allows localisation and quantification affected areas, buildings or infrastructure as basis for rescue measures or risk prevention (BBK, 2010).

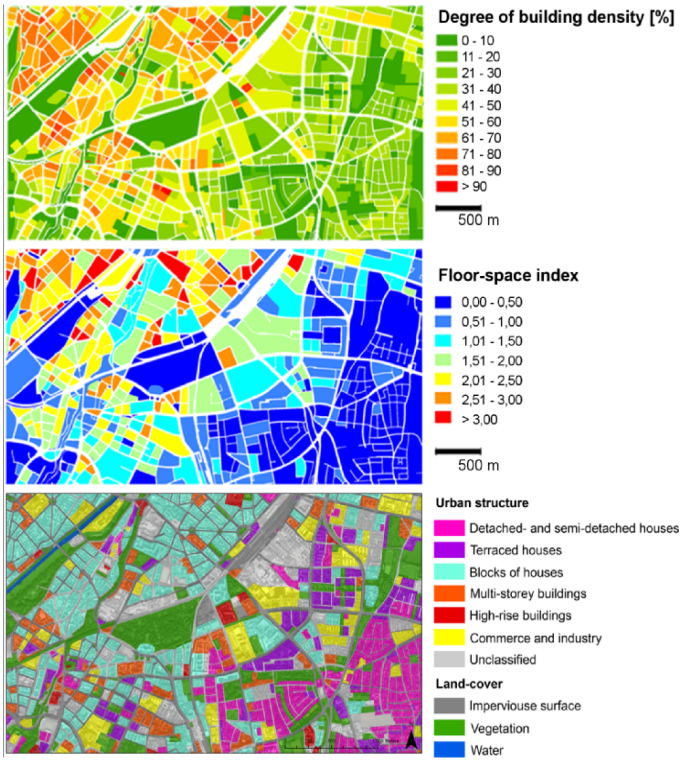

Fig. 4: Physical parameters and urban structure types on block level derived from multi-sensoral remotely sensed data (Wurm & Taubenböck, 2010)

4. Indirect assessment

The city, seen as a human product, is the physical and architectonic reflection of the society that created it (Gonzalez & Medina, 2004). Thus, the remotely sensed data and derived products indirectly contain additional information. The products presented above refer to land cover, which is defined as the physical material on the surface, while land use refers to the human activity that takes place on, or makes use of that land.

The fundamental problem for remote sensing is that while there is often a relatively simple and direct relationship between land cover type and detected spectral reflectance, the same is seldom true for land use (Barnsley, Möller-Jensen & Barr, 2000). Nevertheless, physical parameters like building sizes and heights, roof types, etc. as well as their structural alignment often correlate to the usage of the buildings. In combination with field work information the indirect relationship of urban structures and land use has been applied to the 3-D city model as displayed in figure 1.

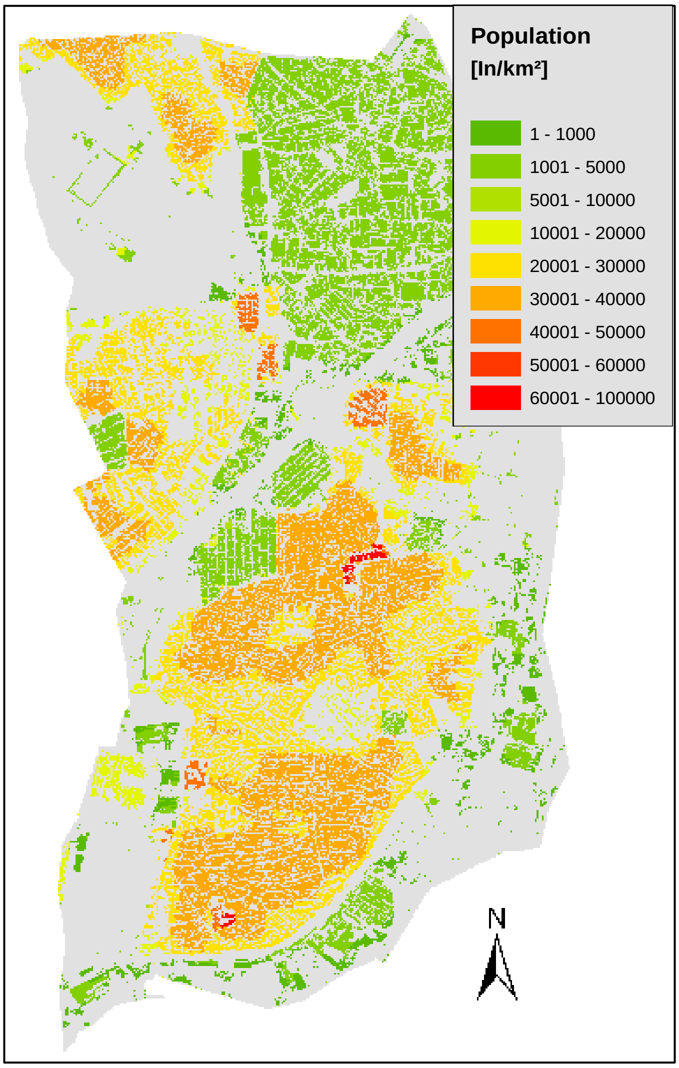

Fig. 5: Population assessment on building level using a top-down distribution methodology – example of the district Zeytinburnu at megacity Istanbul

Furthermore it is obvious, that the knowledge on these parameters allows conclusions about the population distribution, even on its spatiotemporal shift within the course of a day. Figure 5 shows a top-down distribution of generalized population data on city level onto the spatial unit of buildings.

In addition, in depth analysis aims at correlation of space-oriented information and socio-scientific survey data. Thus, interrelationships between subjective indicators, like "perceived and measured distance to the urban center" as well as objective indicators, like "measured vegetation fraction and the felt lack of green space of residents" in dependence of location and urban morphology can be analysed to assess life quality.

Further inter-disciplinary cooperation allows indirect value-adding to remotely sensed products: Examples are the usage of local time-dependent population information for traffic simulation (Nagel et al, 2008); the spatial analysis of the structural alignment of the urban morphology to prioritize areas appropriate for investment in local heating systems (Geiß et al, 2010); the correlation of building parameters to punctual stability analysis of civil engineers for area-wide building vulnerability extrapolation and assessment respectively; the transfer of potential building and infrastructure damage due to natural hazards into economic losses (Kreibich et al., 2008); the usage of change detection information and urban morphology parameters as input data for climate simulations or urban growth modelling; the support of epidemiologic or medical questions like localizing areas for malaria infection, typically highly dense built-up areas, close to water areas (Dhiman, 2000).

III. Pros and cons of applying remote sensing to planning practice

The constantly increasing availability and accessibility of modern remote sensing technologies provides new opportunities for a wide range of urban applications such as mapping and monitoring of the urban environment (land cover, land use, morphology, urban structural types), socio-economic estimations (population density, life quality), characterization of urban climate (microclimate, human health conditions), analysis of regional and global impacts (climate modelling, urban heat islands) or urban security and emergency preparedness (sustainability, vulnerability).

Thus, the high potential of earth observation data, methods and products to support urban and regional planning is beyond controversy. But why did these applications using remotely sensed data to date only rudimentarily expand into the field of urban planning?

In general the authors experienced, at least with German city administrations, a knowledge gap between the stakeholder's data requirements or operational procedures and the progress applying remote sensing to urban planning. But closing this knowledge gap does not seem to be the single path to a common future.

Still today, one major constraint is costs: the data costs are often too high for local authorities as well as for developing countries. While satellite data are relatively low priced, some applications need high temporal repetition rates, where airborne and thus cost-intensive remote sensing is required.

Furthermore the investment in processing is still comparatively high due to mostly not fully automation of classification procedures. During processing, adjustments are needed due to different atmospheric conditions, land cover types or different user's requirements or the algorithms are still in experimental status, for example. Missing data standards or compatibility of software add to it.

Another constraint is the difference between requirements and capabilities regarding accuracy of the products: the synoptic overview of remote sensing in the previous chapter shows area-wide and spatially highly detailed information extraction, but the accuracy of cadastral data sets is not achieved. On the one hand accuracies of 80-90 % and sometimes even higher provide an objective basis for decisions. On the other hand these earth observation products are not established at the current legal foundation and now need to find juristic acceptance.

So does remote sensing have essential value to urban planning? In general the data and products are independent, up-to-date, basically available from anywhere around the globe – underlined by the presented examples in this paper from Germany, Indonesia, Mexico and Turkey – and the products are reproducible, objective and thus comparable. Especially in developing countries, remote sensing data often are the only data source.

The various examples of mapping products shown in this paper show the value of remote sensing: With multi-sensoral earth observation a multidimensional view on the city can be produced independently from location. These quantitative and thus objective information products form the basis for the strategy development and informed decision-making.

But how about countries where spatial data sets in high quality already exist? The strength of remote sensing is the multidimensional perspective allowing for spatial and quantitative statements – from a physical, demographic, social, economic and environmental view. And the analysis is not restricted to administrative artificial boundaries, thus theoretically enabling the analysis on a regional, national or continental scale.

Beyond that, products can be produced on cross-community level. Thus, an advantage arises from objective comparisons between cities as basis to learn from other examples and to develop solutions not solely on the knowledge of a single city. In interdisciplinary projects the strength arises through correlation of often punctual knowledge with the area-wide availability of remote sensing products, enabling the extrapolation of information.

IV. Remote sensing and urban planning: A common future?

What defines our city? How is the city arranged spatially? How dynamic is the urban environment changing over time? Where are traffic hot spots? Where are climatologically and socially the best neighbourhoods? How many people live there? Urban planers need answers on these space-oriented questions and many more. Remote sensing has the unique capability to support decision-making with spatial, quantitative data and information products on various topics, from the extraction of urban morphology to the detection of urban growth, surface temperatures, to monitoring of traffic or assessment of population.

As the concluding question arises: do remote sensing and urban planning have a common future? In fact, both disciplines can learn and profit from each other. Thus it is up to all involved parties – politicians, stakeholders, industry, science and even the residents themselves – to overcome the problem of isolated approaches and to initiate an inter- and trans-disciplinary discussion and cooperation.

The willingness for an open dialogue about expectations, requirements, capabilities and limitations beyond established communities could serve as a ground-breaking step to transfer remote sensing products into value for urban planning. On these premises we have a good chance to transfer innovative ideas into sustainable solution for liveable cities of tomorrow.

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