CORVINUS UNIVERSITY OF BUDAPEST
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THESES OF PhD DISSERTATION

PASSIVE REMOTE SENSING IN LANDSCAPE CHARACTER ASSESSEMENT

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CONTENT

1. BACKGROUND AND OBJECTIVES

Landscape character assessment is a preparatory assessment supporting landscape planning activities. The Anglo-Saxon method is internationally accepted and some of its elements are applied at regional, national and European scale too. The advantage is that it is compatible with the national landscape planning process in practice. Landscape character assessment can facilitate for development, planning, protection and rehabilitation specialists the perception and understanding of peculiar landscape characteristics. It can help to present the values of the landscape and can provide guidelines or proposals in landscape management.

Likewise landscape planning process, the method of landscape character assessment is supported by **images, maps and other visual materials**. These can **appear** definitely **as tools** in the assessment as base data or as illustration. Nowadays remote sensing and image processing has emerging role in landscape character assessment. Use of photos, aerial photographs, satellite images and data derived from them is getting widespread among landscape architects, too. It is important to know and be able to use this “passive remote sensing toolset” for the description and management of landscape character.

Digital remote sensing solutions provide new framework for everyday life in the field of spatial information acquisition and management. Several fields, from medicine to business, experience this phenomenon. Remote sensing and related GIS solutions speed up, simplify, and broaden the professional presentation and analysis options, they further deepen understanding of landscapes in time and space.

The combination of remote sensing and GIS can facilitate planning support in any scale. It can become an important tool in analysing landscape characteristics, but these tools can neither recognise nor solve landscape management tasks. Nevertheless, these tools carry a real chance for us to spare some time-consuming, exhausting tasks and provide clear and spectacular results about landscape characteristics.

The necessary overview of the landscape character assessment toolset is justified by the **European Landscape Convention**, signed by several European countries. According to the convention Hungary has enacted a law (Act CXI. 2007), that ensures the identification, description, monitoring and evaluation of landscapes. The law, while providing a list of major tasks, similar to the steps of landscape character assessment, gives no reference on any digital technical toolset supporting them.

The **main goal of the PhD dissertation** is to determine the **role of passive remote sensing in landscape character assessment**. Accordingly, the literature review has concentrated on the following questions:

1. What **landscape elements, group of elements** can be detected and analysed with passive remote sensing data?
2. What kind of **images and derived databases** are applicable for use in various scales of landscape character assessment?
3. Which **image processing** and **GIS analysis solutions** can be used in landscape character assessment?

The **goal** is to give an overview about the role of aerial photographs, satellite images, derived databases and related image processing procedures in landscape character assessment. My main objective is to prove with new scientific results that some elements of passive remote sensing toolset and image processing are applicable in landscape character assessment. In my opinion, certain applications will be capable to detect new aspects of landscape elements. The dissertation aims to give specifications of images and data processing techniques that can be used to describe distinct characteristic elements of the landscape, and to prepare for an effective landscape management in the frames of landscape character assessment.

2. MATERIAL, PILOT AREA AND METHOD

In my research many different materials and methods have been used related to various landscape topics in pilot areas. Among the **materials of passive remote sensing toolset**, aerial photographs, satellite images, field photographs and derived maps or databases have been used. I completed my research with statistics and other maps if appropriate.

I carried out my research in **four pilot areas of different scope and nature**: in EU28 plus three states, throughout the territory of Hungary, in the Nagyberek region and in the Southwest Budaside region. The areas were chosen depending on the kind of landscape analysis the toolset was meant to complete and the expediency of applications.

My work was based on several research methods. The **literature review** supported information collection about existing practice. During **field trips and surveys** I have collected impressions and images about pilot landscape characteristics. I have determined the usability of images, and surveyed the opinions about landscape character and its changes with the help of **interviews and questionnaires**. Digital landscape analysis has been carried out on images and databases by means of **image processing and GIS analysis**.

3. THESES (NEW SCIENTIFIC RESULTS)

My results, based on the literature review related to the landscape character assessment practice and based on new applications of passive remote sensing images and data, are summarized in 9 theses. These theses are related to the result topics in the dissertation:

- Literature review (1st thesis)
- Surface analysis (2nd thesis)
- Spatial indices (3rd and 4th thesis)
- Change analysis (5th thesis)
- Visibility analysis (6th and 7th thesis)
- Visualisation (8th thesis)
- Landscape borders (9th thesis)

1st thesis
Determination of basic role of land cover and vegetation in characterisation

I have determined, based on literature research, that passive remote sensing images and derived databases have fundamental role in landscape character assessment in the interpretation and analysis of such potential characteristics as land cover and vegetation.

With the analysis of Hungarian and international landscape character assessment studies, guidelines, and other **sources** written in the topic of landscape character I have concluded, which landscape elements and groups of elements are taken into consideration during landscape characterisation. I have sorted the elements in the order of frequency in use, and I have analysed the data used to characterise the landscape. I have found that remote sensing tools play an important role in the examination and comparison of several groups of landscape elements. The interpretation and processing methods are various.

My results show that most of the character assessments deal with two of the important elements in the priority list; **land cover and vegetation**, and with few exceptions they use images of **passive remote sensing**, like aerial photographs, satellite images, or data derived from them. The use of photos and images is very frequent in the assessment of visual elements, landscape structure and pattern too.

2nd thesis

Determination of suitability of elevation models in landscape characterisation

With the comparative analysis of elevation models, that are used to examine terrain in assessments, I have proved that ASTER GDEMv2 model is suitable for the determination of relief character in mountainous landscapes.

Topography is characterized by digital elevation models in many landscape character assessments. I have determined the accuracy of ASTER GDEMv2 elevation data, derived from passive remote sensing, relative to the most detailed digital elevation model available in Hungary (DDM5) and compared to the model of active remote sensing SRTM.

As a result of the comparison in study areas I have found that **in mountainous regions** the **ASTER GDEMv2** model average is **4,4 m higher** while SRTM average is 8,4 m higher than DDM5. In spite of lower resolution in lowland the SRTM model is not significantly worse than ASTER GDEMv2. In hilly areas the difference between the active and passive remote sensing models is not significant.

3rd thesis

Development of green space intensity index to characterize vegetation cover

As a result of my research I have determined and proved that the green space intensity index, derived from NDVI, is able to characterise, the average intensity of green coverage of any bounded area by a single number. Thus the index is able to describe the green coverage of landscape character areas and landscape character types.

During several years of research I have developed the **Green Space Intensity** (GSI) index and continuously refined the method of calculation. The green space intensity index is based on the NDVI index using red and near infrared bands of Landsat satellite images, but it describes and maps green coverage of landscape character areas or landscape character types more clearly and consistently as it makes temporal and spatial average easier to be calculated. The green space intensity (GSI) expresses the ratio and vitality of **green space in an area** with a number from 0 to 100. This scale of positive digits makes GSI indicator more suitable for spatial and temporal aggregation and analysis than the spectral NDVI index.

The 2010 green space intensity data was compared with infrared orthophoto from year 2010 in sample areas, and the accuracy of the GSI data was determined for Budapest and its agglomeration. I have proved in various study areas that with the GIS-analysis of GSI data it is possible to **describe green coverage of areas** and the results are suitable for **spatial comparison**. The GSI dataset has been used in the preparation of the Development Concept and Program of Green Space System in Budapest, and in the Budapest 2030 long term urban development concept.

4th thesis

Defining green space intensity of regularly changing surfaces

Analysing Landsat images of the 1986-2011 period in study area I have determined what green space intensity values are reasonable to use to characterise landscape character areas or types with dominant agriculture, where regularly changing vegetation coverage is significant.

In case of landscapes it is inappropriate to characterise surfaces with constant changes in green space intensity (arable land, intensively managed grasslands etc.) with a single value reflecting a certain moment. I have realized that for **agricultural areas**, with regular cultivation (ploughing, sowing, harvesting, mowing, etc.) resulting a change in green surface vitality from one month to the other, it is reasonable to use an **average value of green space intensity** for each specific land cover type.

I have determined the **average green space intensity (GSI) values** for a 15 thousand km^2 large region with the centre of Southwest Budaside by summarising the monthly mean GSI values of 31 Landsat TM or ETM + satellite images of 25 years. GSI values of agricultural areas with frequent changes in **intensity vary between 45 and 66% for a vegetation period of 6 to 7 months**. These values are more suitable for the description of landscapes permanent characteristics than a GSI value of a single moment derived from a satellite image.

5th thesis

The renewal of the "change of openness" indicator

Based on the spatial index "openness of landscape", I have defined and described the "change in landscape openness" indicator, that can be used at landscape level for the description of landscape character change. The indicator presents the change in the openness of landscape with a numeric value, that can be aggregated for any area. The indicator has been tested and its usability has been proved for characterisation of landscape changes in European and Hungarian pilot areas.

In the literature, the openness of the landscape is defined, for each land cover category, by **the height and density of landscape elements** (e.g.: forests are closed, vineyards are semi-open, grasslands are open). Based on “Openness/closeness” analysis and change analysis examples in literature, I have defined the “change of landscape openness” indicator, that is capable to indicate **distinct changes relevant for landscape character** (e.g.: forestation resulting decrease in openness or clear cut of orchards resulting increase in openness). As a result of my research, I have created a change indicator formula, which **can determine the change of openness with one single numeric value**. It shows clearly the ratio and the direction of change in openness.

I have tested the index on different study areas for the period of 1990-2000 and 2000-2006 with CORINE Land Cover Change data. I assessed the change in openness in the landscapes and settlements of Hungary and the regions of EU28+3 states. The direction and ratio of **change in openness** of the landscapes is very diverse in the different countries and regions. In **Hungary decreasing openness** used to be the trend in the period of 1990-2006 due to the built-up land growth and forestation.

6th thesis

Determination of visible landscape units with "theoretic visibility index"

As a result of my visibility assessment research I have introduced the "theoretic visibility index" which describes the visibility of landscape units with a numeric value, using surface models. With the help of the index I have determined the most visible landscape units and landscapes of Hungary.

I have introduced the **"theoretic visibility index"**, which shows the percent of visibility of a specific area from the surrounding viewpoints. This index shows the percentage of the "seeing viewpoints" within the total number of viewpoints in case of all analysed landscape units. The index is capable for spatial aggregation thus makes possible to **describe landscape character areas and landscape character types by an average visibility value**.

I have prepared theoretic visibility assessment for Hungary, with additional analysis of distance and vertical angle of view, using the ASTER GDEMv2 surface model derived from passive remote sensing images. The results show that **the most visible landscape units** are the monadnocks rising from lowlands (e.g.: Ság, Somló, Badacsony) while the most visible **landscapes** are the contiguous hills and volcanic rocks as the Villányi Hills or the Tokaj Hill.

7th thesis

Determining the definition and the mapping method of "facing slope"

As a result of visibility assessment research I have created the definition of "facing slope", and determined its significance in case of visible areas from observation points. I developed a semi-automatic process, suitable for any viewpoint of the country, to delineate and map the slopes facing to the analysed lookout point.

Steep slopes are important factors in visibility assessment, because they can increase the significance of landscape elements visible from an lookout point. Visibility mapping in case of viewpoints can reasonably involve steep slopes in the analysis as weighting factors, but only in case where the slopes are facing to the observer point. I have defined the slope, that faces towards the observer point and is predominant for the landscape a **"facing slope"**.

Using ASTER GDEMv2 data in my research, I have developed a process, suitable for delineation and mapping of facing slopes, the results of which can be integrated in the visibility assessment. My **pilot area research** has proved the usefulness of mapping facing slope in order to determinate elements clearly visible **from observer points** and significant for landscape character. This application can be particularly useful in visual impact study that can also play an important role in landscape character assessments.

8th thesis

Determination of applicability conditions for landscape models in visualisation

I have determined that 2.5 dimensional landscape models, created with the combination of ASTER GDEMv2 surface model and orthophoto, are adequate for visualisations presenting landscape character, when no bird's eye view aerial photos are available. To provide an authentic illustration of landscape character in case of low viewing angle and proximity of ground, it is necessary to use 3D models of vertical landscape elements (trees, buildings).

Based on interviews with 40 persons and questionnaire with 215 students I have concluded that 62% of people would be satisfied with the details of **2.5D landscape models** based on ASTER GDEMv2, and do not feel characteristic difference between those and DDM5 based landscape models. On the other hand, 38% of persons involved in the research **prefer to use the most detailed DDM5 model** in case of hilly landscape units, smaller than 5 km^2, even if the municipality has to pay an extra cost of 10 thousand HUF per location.

As a result of questionnaires and interviews I have concluded, that in case of buildings closer than 1 km to the viewpoint, at least two third of respondents perceived characteristic difference between 2.5D landscape models and bird's eye view aerial photographs. This ratio in case of different kind of 2.5D landscape models with additional photo-realistic 3D building models was only between 25-45%. In order to make unique or typical landscape characteristics perceivable, it is reasonable to visualise buildings and vegetation with 3D models in case focus area is closer than **1 km, and viewing angle is lower than 30 degrees**.

9th thesis

Determination of hill-boundary method

I have determined the scope of passive remote sensing data in delineation of landscapes and their potential use in the boundary selection method. I have named the "hill-boundary" process as a new element of this method and tested it in pilot areas.

As a result of literature research the experts have a major role in **the delineation of landscape character areas**. The essence of **boundary selection method** is that the potential boundaries, prepared from passive remote sensing data, are visualised and offered in GIS for selection, and the expert chooses the right line to form landscape boundaries. This **semi-automatic** method provides opportunity to combine objective and subjective elements of the assessment.

I have defined hill-boundaries as part of potential landscape boundaries. **Hill-boundary** is the closed border line that separates neighbouring emersions, and connects the lowest elevation points in the surrounding of any height (e.g.: mountains, hills). I have **developed and documented the delineation process** of **hill-boundaries** combining existing functions in GIS, using the watershed analysis in the inverted and lifted elevation model. I have tested the applicability of the procedure with success in the hill-land area of Southwest Budaside region.

4. CONCLUSIONS AND PRACTICAL APPLICATIONS

My research has proved that passive remote sensing images and image processing methods can be **used diversely in landscape character assessment**. Based on literature review I have determined how to integrate images and procedures in the steps of landscape character assessment at different scales. I have proved that the scope of the existing applications can be extended in the area of surface analysis, spatial indices, change analysis, visibility analysis, visualisation and in the field of creating landscape boundaries.

The use of passive remote sensing, and the **use of my research results is justified** by the mass of regularly updated images and datasets, available in some cases free of charge. The differentiation and spreading of image processing methods or GIS procedures as well as the increasing needs of the stakeholders do also reinforce the intensive use of these applications.

The results can be applied in practice **during the implementation of European Landscape Convention obligations**. The results of landscape boundary-selection method could be well used during the task of landscape identification, prescribed by the Convention. Spatial and temporal indices, based on passive remote sensing, can be used in **describing landscapes and their changes**. The applicability of land cover ratio indicators, forest edge indicator, and change of openness indicator has been tested in various pilot areas.

The results of my research can be used during the **preparation and supporting process of regional and settlement planning**. The elevation analysis and the layers of visibility assessment, showing visually characteristic elements of landscape, can have a role in the support of **municipal building regulations**, in regional planning of landscape protection zones at county or country level, or in **visibility impact assessments**.

Based on the results of **green space intensity analysis**, following decades of practical application in pilot areas, I suggest the **introduction of a monitoring system**, in order to preserve the green space ratio of settlements with additional legislation if necessary. To support green space conservation purposes, I recommend monitoring based on aerial and satellite images and fostering green space preservation or development activities.

The research results can be used to raise awareness about the importance of landscape character in education. To this end, together with my colleagues, I have been emphasizing more and more on the application of free software, data and 3D visualisation in **landscape architect education** during the past years. Passive remote sensing data figure in high proportion among these applications.

The successful management of landscape character needs **open-minded experts, conscious, demanding, active society**. Passive remote sensing images, processing and visualisation procedures are suitable tools of raising awareness, and providing objective, spectacular assessments. These can be utilised convincingly according to the visualisation results I presented. Illustration of character assessment results with bird's eye view aerial photos and **visualisation on 2.5D or 3D landscape models** provide key benefits when involving stakeholders. The method of landscape character assessment of Anglo-Saxon origin builds on **self-conscious, thinking, active, local citizen**s, who are key elements in landscape management. In case they are missing from the system the management of landscape character is going to be one-sided, therefore according to my results passive remote sensing data should be used right from the communication process of landscape character assessment in order to reach the maximum number of potential stakeholders.

5. LIST OF PUBLICATIONS

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