GIS Ostrava 2013 -

Geoinformatics for City Transformations

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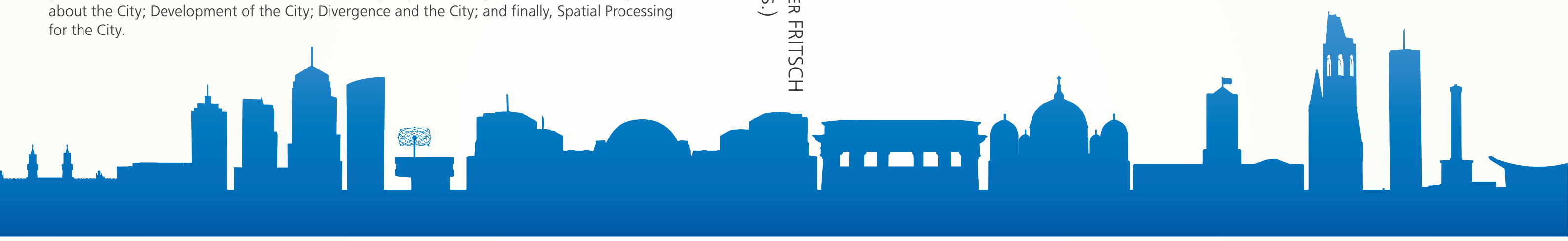

ISSN 1213-2454

ISBN 978-80-248-2974-6
ISSN 1213-2454

Igor IVAN, Paul LONGLEY, Jiří HORÁK, Dieter FRITSCH
James CHESHIRE and Tomáš INSPEKTOR (Eds.)

GIS Ostrava 2013

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Geoinformatics for City Transformations

Tenth International Symposium
Ostrava, Czech Republic, January 2013
Proceedings

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Auspices

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GIS Ostrava 2013 – Geoinformatics for City Transformations, Proceedings
January 21st – 23rd 2013, Ostrava, Czech Republic

Printed by: VŠB - Technical University of Ostrava, 2013
Bound by: OFTIS Ostrava, Chelčického 693/7, 702 00 Ostrava, Czech Republic
Edition: First edition, 2013
Number of pages: 298

ISBN 978-80-248-2974-6
ISSN 1213-2454

Preface

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Papers selection

Number of registered papers: 36

Number of papers published in the proceedings: 23

Home countries of the authors of the papers published in these proceedings are Canada, Czech Republic, Finland, Germany, India, Iran, Netherlands, Nigeria, Norway, Poland, Republic of Serbia, Slovakia, Spain, Turkey and United States of America.

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Content

BUILDING EXTRACTION USING SURFACE MODEL CLASSIFICATION

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Abstract

In many applications like urban planning and environmental simulation, the major solution is building extraction, which can be performed using different airborne or space-borne data or an appropriate fusion of them. This paper presents an automatic building recognition technique using fusion of LIDAR data and multispectral imagery. To this end, a rule-based classification method is considered in order to extract buildings from input data which are DSM, DTM extracted from DSM and an optical Image. To achieve better accuracy classification is performed in both pixel and object level. Accordingly, a user-friendly MATLAB toolbox is provided for both classification and evaluation procedures. It is experimentally shown that the proposed algorithm can successfully detect urban residential buildings, when assessed in terms of different quantitative criteria and visual inspection.

Keywords: Building Extraction, Digital Surface Model, Rule-based Classification

Recommended Citation: AREFI, H., ALIZADEH, A., GHAFOURI, A. (2013) Building extraction using surface model classification. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Building detection from remotely sensed data is important to the real estate industry, city planning, home-land security, disaster (flood or bush fire) management and many other applications. The Automated extraction of building boundaries towards generating city models is also an essential step [1]. As it can be observed, over the last few decades, a large number of building detection techniques have been reported [2]. However, a fully successful automatic building detection is still an ambitious goal. There are several reasons to explain the obstacles in this way including [2], [3]:

- *Sensor dependency:* the primary data to support the building detection is available from a variety of sources with different resolutions, each source having its own bright and dark points for building detection.

- *Scene complexity:* most of the scenes usually contain very rich information which provide a large number of prompts with geometric or chromatic co-similarity to buildings, but belong to non-building objects.
- *Incomplete cue extraction:* due to occlusions, poor contrast, shadows and disadvantageous image perspective, there is always a significant loss of relevant building cues.

According to literatures, three main categories can be considered for building detection approaches [4]. First of all, there are many algorithms that employ 2D or 3D information from photogrammetric imagery [5]. The complexity of separating buildings from other objects Increases with increasing image resolution. This is because high-resolution images contain more detailed information [1] and doubtlessly occlusions and shadows [6]. Furthermore by using stereo images or multiple images captured from the same scene it is possible to derive 3d information. It should be noted that 3D information is one of the most important feature in building detection [7]. Nonetheless, nearby trees of similar height also make the use of such derived range data difficult [4]. Certainly, the problem meaning trees next to building can be resolved by using some texture analyses or NDVI index [8]. Nevertheless, height information extracted from a stereo pair of images is much more weak particularly in urban areas because of mismatching in these areas [9].

As the second group, there have been several attempts to detect building regions from LIDAR (LIght Detection And Ranging) data. This task has been largely solved by classifying the LIDAR points according to whether they belong to bare-earth, buildings, or other object classes [4]. In fact, the introduction of LIDAR has offered a favourable option for improving the level of automation in building detection process when compared to image-based detection [10]. A number of problems with building detection have been discussed in the literature [11], and they have been shown that the use of raw or interpolated data can influence the detection performance [2]. Moreover, building detection with very good horizontal accuracy and appropriate discrimination between trees and buildings is almost impossible [12].

Each of LIDAR and photogrammetric imagery has particular advantages and disadvantages in horizontal and vertical positioning accuracy. in comparison with photogrammetric imagery, LIDAR generally provides more accurate height information but less accurate boundary lines. On the other side Photogrammetric imagery can provide extensive 2D information such as high-resolution texture, and different indices like NDVI index.

The third category of methods utilizes both LIDAR data and photogrammetric imagery. More explicitly, intensity and height information in LIDAR data can be used with texture and region boundary information in aerial imagery to improve accuracy and correctness [4].

It is necessary to mention that LIDAR data and aerial photography have the same quality as high-resolution DSM and satellite images such as orthorectified worldview respectively. Consequently, all algorithms aforementioned for the former group can be used for the latter group. This point has been mentioned because our data in this study are high-resolution DSM and orthorectified worldview.

Although there are a lot of works having been done about building detection, a few works have been done by integration of LIDAR and photogrammetric imagery.

Building detection techniques integrating LIDAR data and imagery can be separated into two groups. Firstly, there are techniques which use the LIDAR data as the primary cue for building detection and employ the imagery only to eliminate vegetation from the scene [10], [13]. As a result, they suffer from poor horizontal accuracy for the detected buildings. Since problem of horizontal accuracy can be somewhat resolved by different outline approximation [14], it can be ignored in building detection part. In another work, Dempster-Shafer theory as a data fusion framework was used to classify points as building, tree, grassland or bare soil. A method based on morphological scale space is proposed for extracting building foot prints from the elevation data and then removing vegetation pixels using the spectral data [10]. The proposed building detection technique falls into this group.

Secondly, there are integration techniques including [2], [3], [15] which use both the LIDAR data and the imagery as the primary cues to delineate building outlines. Consequently, they offer better horizontal accuracy for the detected buildings. Haala and Brenner [12] applied a pixel-based classification where the normalized DSM (nDSM) was used as additional channel to the three spectral bands of the aerial imagery [12]. Chen et. al. followed a region based segmentation of nDSM and ortho-images and then used a knowledge-based classification to detect building [15]. Sohn and Dowman proposed a data-driven approach on the optical imagery and a model-driven approach on the point cloud to extract rectilinear lines around buildings [3]. In another work, a similar technique was proposed with precise geometric position. Lee et. al. [4] extracted the initial building boundaries from the LIDAR data and then enhanced the initial boundaries using colour information, after which edge matching and perceptual grouping techniques were applied to yield the final building boundaries [4]. Demir et. al. applied four different methods to achieve an improvement by combining the advantages and disadvantages of these approaches and used the edge information from images for quality improvement of the detected buildings [16].

This paper aims at following two goals: a successful integration of the LIDAR data and photogrammetric imagery for building detection so that LIDAR performance in tree removal is improved ,and development of a rule-based classification performed in both pixel and object level. In other words, the goal of this study is building extraction based on a rule-based classification in pixel and object level using fusion of multi-source data.

RULE BASED CLASSIFICATION

As mentioned above, a rule-based classification method is used for building extraction. The first stage of this classification is feature selection. After feature extraction, classification is done based on a set of rules written by selected features. An outlook of rule-based classification is depicted in Fig. 1.

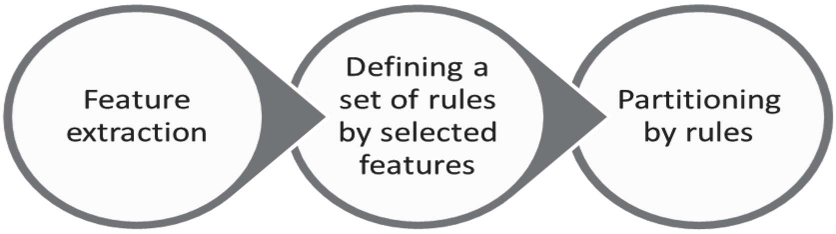

Fig. 1. General procedure of rule-based classification

In the following, at first different features used in this study is explained. After that rule-based classification process is discussed.

FEATURES

In this study, two kinds of features named pixel-based and feature-based are used. In the following each of them has been explained in more detail.

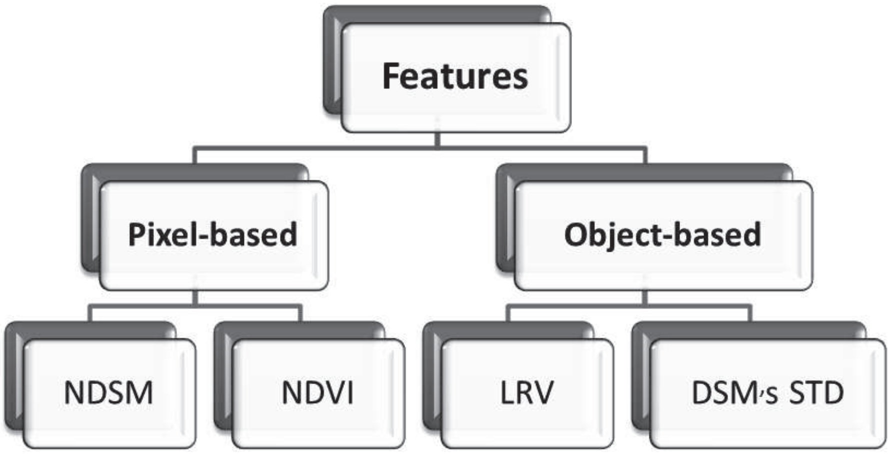

Fig. 2. An outlook of used features

Pixel-based features

NDSM. This feature, so-called normalized digital surface model (nDSM), is computed by measuring the difference between the DSM and the digital terrain model (DTM). Since the nDSM excludes the influence of topography, it represents the height of all overlying objects, such as buildings and trees on the terrain. Therefore, expert knowledge about the appearance of certain objects can be directly used. In many studies, the nDSM was used as an important clue for building detection. That is noticeable that DTM is extracted from DSM by morphological reconstruction algorithm [17].

NDVI. As it is indicated in equation 1, this feature can be computed by near-infrared and red bands. Since in this project the world-view 2 images with eight spectral bands are experimented, this feature can be easily extracted [18].

$$NDVI = (NIR - Red) / (NIR + Red), \quad (1)$$

Using this feature, vegetation and non-vegetation can be separated from each other.

Object-based features

For these kinds of features, first of all regions or objects have to be extracted. In this regard, there are two different approaches. One of them is segmentation and the other is using regions extracted from a processing. In this project, we used the latter.

Local Range Variation (LRV): As early mentioned, for this feature, regions have to be extracted. For each object on the DSM, borders are extracted. Every border consists of a number of points. Around each point on the border, a 3×3 window has been considered. Then for every window difference between max and min value are computed. This work is done for every point on the border. Consequently, for each border a set of LRV values are computed. In this study the mean of these LR values belonging to each region has been considered as a feature value. The objects such as small hills and buildings can be distinguished from each other using this feature descriptor [19].

STD: As early mentioned, for this feature, regions have to be extracted. This feature is the standard deviation of height values for each region. By this feature, leaf-off trees can be distinguished.

CLASSIFICATION PROCESS

After selecting appropriate features, classification is triggered. Usually in rule-based classification at first based on the most important feature (completely depends on application) an initial classification is done. After that, using other features this classification is improved. In this case since the aim is building extraction, nDSM is the most important feature. Consequently, initial classification is done in terms of nDSM (level0). Then, this initialization will be improved by the other features. This initial classification is includes in leaf-on and off trees, mounts and buildings. Since our goal is building extraction, non-building features should be eliminated in the improvement levels (we considered 3 levels in this study). At first, leaf-on trees and height vegetation are excluded from nDSM (level 1). By this work leaf-on trees are removed. After that, mount and other objects like that are excluded from improved nDSM in the first level. By this work mounts and hills are removed (level 2). Finally leaf-off trees and other objects like that are excluded from the improved nDSM in the second level.

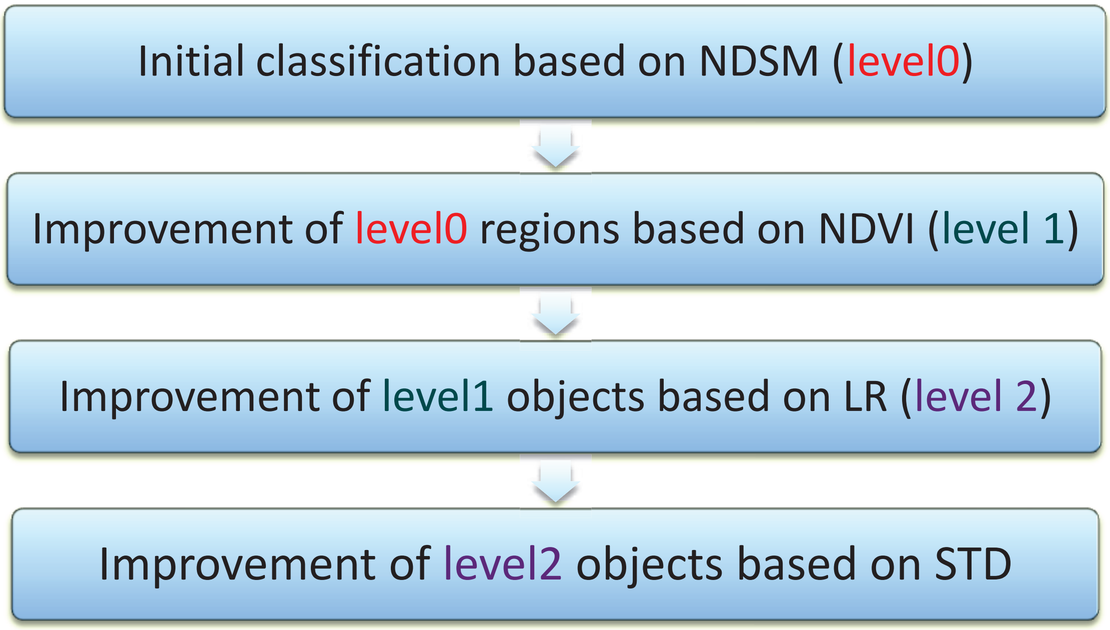

Fig. 3. An outlook of classification process

IMPLEMENTATION

In order to building detection a program is developed in MATLAB which can provide rule based classification of DSM considering DTM and Satellite image as well. Generally nDSM is produced by subtraction of DTM from DSM in order to remove natural topographic.

PROGRAMMING AND DEVELOPMENT

Fig. 4 depicts the interface of the developed program. After selection of the type of input data which could be MAT or Image file, by clicking on "Open Image", the input Imagery data would be selectable. In the next step "Digital Terrain Model" is added like an input to the program [1]. "DSM" as the second input is considered as the third step. After this data import, normalized DSM can be calculated by subtracting DSM from DTM.

By clicking on the forth button of data input process, Ground Truth map which has been prepared by digitizing the Imagery Data is imported and would be ready to use. Ground Truth preparation is fulfilled in the ArcGIS software as a vectorized output. The vector ground truth had been converted into raster with the same resolution as the optical image and Digital Models (DSM/DTM and nDSM).

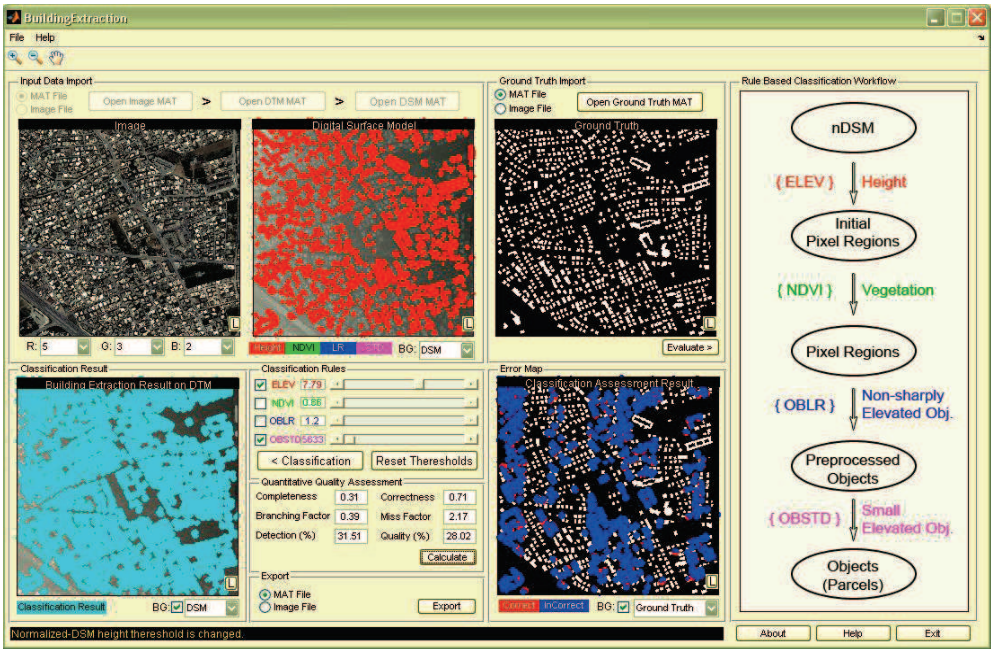

Fig. 4. Program Interface

In the program, three rules are selected to affect the process of building height classification. At the beginning based on heights of the nDSM, it is possible to classify it by moving a slider. Moving the slide changes the height threshold, and finally a logical and acceptable threshold would be considered. Two other rules are also imposed to filter and have a better classification. The "Standard Deviation" and also the "NDVI" are two limits for this goal. Standard Deviation is calculated via the obvious formula as expected value of each pixel value and its average difference. NDVI (Normalized Difference Vegetation Index) roughly is the index of vegetation and is calculated by division of difference and summation of NIR and Red bands of the satellite imagery.

SIMPLE PROCESS OF RULE-BASED CLASSIFICATION

After the data input, some default values for Elevation, STD and NDVI thresholds are considered which could be changed gradually to achieve an efficient threshold. Finally, the user must click on the button of "Classification" to see the result of imposing the rules as described above.

As discussed above, Fig. 4 obviously demonstrates how aforementioned data are loaded and after affecting the rules of Rule-based Classification, the results, assessment and evaluation parameters are calculated and presentable.

For “visual inspection”, an error map is shown as well in the right down of the window and the four categories discussed in future sections are shown. The correctly classified results are shown in red and the incorrect ones are shown in blue. The best inspection can be done by viewing this error map with “Ground Truth” as background; but other backgrounds as DTM, DSM and also nDSM are available to view as base.

Six criteria as will be discussed in the aforesaid section are revealed in the special frame for it. This frame is placed below the threshold sliders in the program interface (Fig. 4).

Users can have a sort of export from the program output in the special frame in the middle bottom of the program. It is made possible to export in form of MAT file or an image.

OUTPUT EXPORT

Result of the classification could be saved for further post-processing via the module of export close to Exit button of the program.

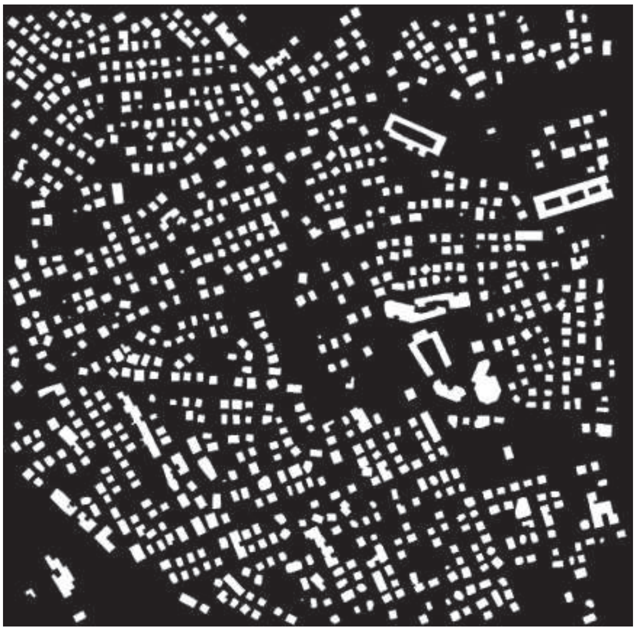

Fig. 5. Ground Truth Map

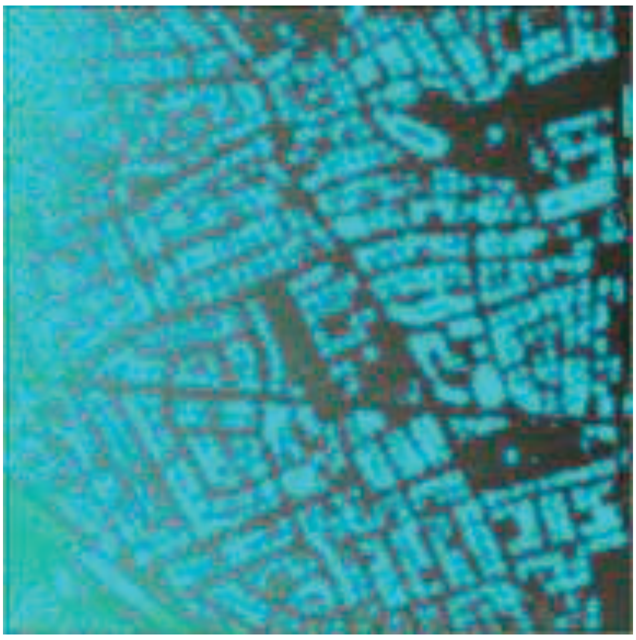

Fig. 6. Classification results

PROGRAM OUTLINE

Fig. 5 and Fig. 6 obviously demonstrate the ground truth map and the classification result. The ground truth can be used for quality assessment of results. Assessment report will be available after determination of assessment method and clicking the related button.

Fig. 4 (program interface) shows the effect of a fair threshold result for Elevation and Vegetation Index (NDVI) as pixel-based thresholding and also Object-based Local Ranging and Object-based Standard Deviation. After excluding the low height areas from the nDSM and vegetated heights like trees by the index of these features as NDVI from Elevation based selected areas, the process of object analysis is started and in two procedure of object classification Local Range of the pixel regions (which are considered as objects in this situation) are undertaken to process. By a 7x7 window the minimum and maximum values of nDSM on the border of each object is analyzed and can be thresholded. In the process of Object-based Standard Deviation calculation it must be described that the objects (parcels) with STD<Th4 which Th4 is an acceptable threshold, final results are achievable.

RESULTS ASSESSMENT

In this study, two kinds of assessment methods have been considered. The former is visual inspection, and the latter is the quantitative criteria.

QUALITATIVE CRITERIA

In visual-inspection state blue objects indicate regions which have wrongly been detected as building by our method. On the other side red objects indicate regions which have correctly been detected as building (Fig.7).

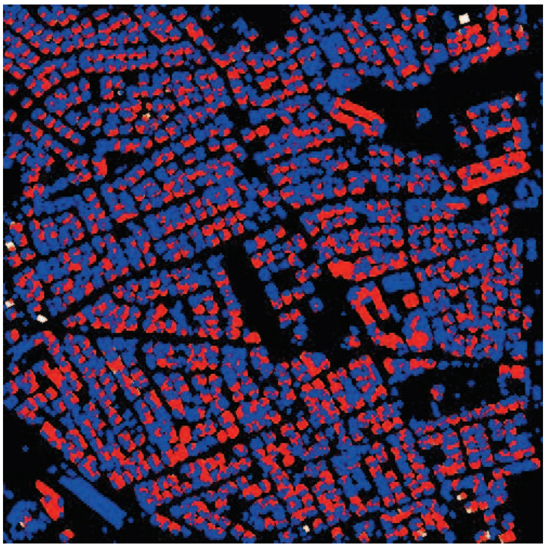

Fig. 7. Classification Result Evaluation based on Qualitative Criteria. In this figure Red pixels demonstrate the true classification and blue pixels depict the incorrect classification based on the ground truth data.

QUANTITATIVE CRITERIA

For evaluation of the raster building extraction quality, the results of the automatic procedure and also the reference building data base were rasterized. The extracted buildings were compared pixel by pixel to the buildings in reference data (ground truth). The standard statistical parameters are defined and measured as follows [12]:

1. **True positive (TP)** – both the automated method and the rasterized reference building database label a pixel as a building; in other words, The pixels which are building on the ground truth and classification classified them as building.
2. **True negative (TN)** –both the automated method and the rasterized reference building database label a pixel as background (non-building); in other words, The pixels which are not building on the ground truth also, they are classified as non-building.
3. **False positive (FP)** –only the automated method labels a pixel as a building; in other words, The pixels which are not building on the ground truth but they are incorrectly assumed as building.
4. **False negative (FN)** –only the rasterized reference building database labels a pixel as a building; in other words, The pixels which are building on the ground truth and classification classified them as non-building.

Using these four categories, the following statistical measures were computed to evaluate the performance of the automated building extraction process.

$Branching\ Factor = \frac{FP}{TP}$ $\qquad$ $Detection\ Ration = \frac{TP}{TP+FN}$

$Correctness = \frac{TP}{TP+FP}$ $\qquad$ $Completeness = \frac{TP}{TP+FN}$

$Miss\ Factor = \frac{FN}{TP}$ $\qquad$ $Quality\ Ration = \frac{TP}{TP+FP+FN}$

Interpretation of the above calculation is as follows. The **branching factor** indicates the rate of incorrectly labeled building pixels. The **miss factor** gives the rate of missed building pixels (the automated method incorrectly labels pixels as background). The **detection percentage** denotes the percentage of building pixels correctly labeled by the automated process. The **quality percentage** measures the absolute quality of the extraction and is the most stringent measure. It describes how likely a building pixel produced by an automatic approach is correct. The **completeness** is the percentage of the reference data which is explained by the extracted data, i.e., the percentage of the reference network which lies within the buffer around the extracted data. The optimum value for the completeness is 1. The **correctness** represents the percentage of correctly extracted building data, i.e., the percentage of the extracted data which lie within the buffer around the reference networks [20].

ASSESSMENT RESULTS

Based on the qualitative evaluation, Fig. 7 illustrates the graphical output of the program. As the quantitative assessment results based on the evaluation parameters given in previous section, in MATLAB are:

$Branching\ Factor = 0.4$ $Detection\ Ration = 84.44\%$

$Correctness = 0.71$ $Completeness = 0.84$

$Miss\ Factor = 0.18$ $Quality\ Ration = 63.06$

DISCUSSION

An algorithm is presented to hierarchically refine the classification results of high resolution worldview DSM and orthorectified images using different feature criteria. A MATLAb tools is produced for this implementation which helps to interactively monitor the effects of including to excluding each feature descriptor to the classification procedure. The refinement of segments is employed in both pixel- and region-based classification steps. The final result is compared statistically to the ground truth which is manually digitized. Final assessment results which are described in the last section obviously figure the effectiveness of the method.

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ASSESING SIMILARITIES BETWEEN PLANNED AND OBSERVED LAND USE MAPS: THE BELGRADE'S MUNICIPALITIES CASE STUDY

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Abstract

Techniques for evaluating similarities between categorical maps obtained by different spatial modeling techniques or representing similar space in different time instances are still developing. This paper reviews a current approach for assessing the similarity in land use maps that are used in city planning processes. The performance of recently designed *kappa location* and *kappa histo* measures as well as *fuzzy* set map comparison approach were tested on a case study area that comprises three cities of Belgrade's municipalities with different urban characteristics. By assessing similarities between the land use map of the Master plan designed for the year 2021 and the map representing the currently observed land use conditions, the level of realized planned activities as well as the level of discrepancy from the Master plan could be evaluated.

Keywords: Kappa statistics, land use map, fuzzy, urban planning

Recommended Citation: SAMARDŽIĆ-PETROVIĆ, M., BAJAT, B., KOVAČEVIĆ, M. (2013) Assesing similarities between planned and observed land use maps: the Belgrade´s municipalities case study. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Categorical thematic maps are produced for different purposes: land cover, land use, forest inventory, soil types or properties, etc. The development of high-resolution spatial modeling techniques, geographical information systems and more accessible remote sensing data has increased the need for map-comparison methods. There are several motivations for developing proper map-comparison methods and measures [1] that include: 1) detection of temporal/spatial changes or hot-spots; 2) the comparison of different spatial/temporal models, methodologies or scenarios; 3) the calibration and validation of land use models, 4) the model uncertainty and sensitivity analysis, and 5) the evaluation of map accuracy.

The objective of this paper is to provide insight into the appropriate analysis techniques and the discussion of the factors that must be considered when performing any similarity assessment. In addition, a detailed description of proposed comparison techniques is given in order to fully realize the importance of similarity assessment discussed in this paper.

METHODS

The *kappa* statistic measures the differences between the observed agreement among two maps and the agreement that might be achieved solely by chance due to the alignment of those two maps [2]. It is quite convenient for the map comparison if an equal number of classes are applied [3].

The *kappa* index that was introduced by Cohen [4] presents a measure of agreement adjusted for chance and it is calculated as:

$$\kappa = \frac{P(O) - P(E)}{1 - P(E)} \qquad (1)$$

where *P(O)* presents observed agreement and and *P(E)* is the proportion of agreement that may be expected to arise by chance.

$$P(O) = \sum_{i=1}^{n} p_{ii}; \quad P(E) = \sum_{i=1}^{n} p_{iT} \cdot p_{Ti}; \quad P(\max) = \sum_{i=1}^{n} \min(p_{iT}, P_{Ti}) \qquad (2)$$

The calculation of the *kappa* index is based on the main diagonal of the contingency table (table 1) together with its row and column marginals. Each element p_{ij} in contogency table is the fraction of cells in category *i* in Map A and in categoty *j* in Map B.

Table 1. Generic form of a contingency table.

Map B categories						
		1	2	…	N	total map
Map A Categories	1	p_{11}	p_{12}	…	p_{1n}	p_{1T}
	2	p_{21}	p_{22}	…	p_{2n}	p_{2T}
	…	…	…	…	…	…
	n	p_{n1}	p_{n2}	…	p_{nn}	p_{nT}
	total map	p_{T1}	p_{T2}	…	p_{Tn}	1

The *kappa* index values falling in the ranges of 0.41-0.60 are categorized as moderate, values between 0.61-0.81 are substantial and values higher than 0.81 are consider as almost perfect as was outlined in similar studies [5].

The standard *kappa* index has been used in different fields, from medical applications and biostatistics [6] to a great variety of geoscientific applications. In the field of geosciences, the *kappa* index was subsequently adopted by the remote sensing community as a useful measure of classification accuracy [7]. There is also a wide number of applications that are related to the validation of machine learning techniques in spatial modeling [8], [9].

Pontius [10] was one of the first, who criticized the use of simple *kappa* statistics in comparison to digital raster maps. He introduced two new statistics indices in order to examine separately the similarity of location κ_{loc} and quantity κ_{quant}. The *kappa location* corresponds to the measurement of similarities in the spatial allocation of categories in the two compared maps. Unlike *kappa quantity* statistics that have been proved as unstable and incomprehensible [11], *kappa location* statistics are sustained as a comprehensive measure because it gives the similarity scaled as the maximum similarity that can be reached with the given quantities:

$$\kappa_{loc} = \frac{P(O) - P(E)}{P(\max) - P(E)} \tag{3}$$

In order to overcome the drawbacks of the *kappa quantity* statistics, Hagen [12] introduced a new statistical index called *kappa histogram* κ_{histo}:

$$\kappa_{histo} = \frac{P(\max) - P(E)}{1 - P(E)} \tag{4}$$

Both statistics κ_{loc} and κ_{histo} are sensitive to particular differences in locations and in the histogram shapes for all the categories [1].

The mutual relation between κ_{loc} , κ_{histo} and standard κ could be expressed as:

$$\kappa = \kappa_{histo} \cdot \kappa_{loc} \tag{5}$$

The latest approach in assessing similarities of raster maps is based on fuzzy set theory [13]. Geoscientists and GIS professionals adopted this theory [14], [15] with the purpose of characterizing inexactly defined spatial classes or entities that deal with ambiguity, vagueness and ambivalence in mathematical or conceptual models of spatial phenomena. Based on fuzzy set theory, Hagen [16] proposed the new approach in assessing spatial similarities and changes between raster maps. The fuzzy-based map-comparison method was primarily developed for the calibration and validation of the cellular automata models for land-use dynamics.

Considering two sources of fuzziness; *a*) locational based on the concept that the fuzzy representation of a raster cell depends on the cell itself and, to a lesser extent, also the cells in its neighbourhood, and *b*) categorical which originate from vague distinctions between categories.

The extent of the neighbouring cells or locational fuzziness could be expressed by a distance decay function. The categorical fuzziness can be introduced by setting off-diagonal elements in the Category Similarity Matrix to a number between 0 and 1 that corresponds to membership values of different categories. Since there are no straightforward rules for assigning membership values, choosing values in the matrix is subjective, and it could be selected on the basis of a priori experience.

The *kappa fuzzy* index is similar to the traditional *kappa* statistic in that the expected percentage of agreement between two maps is corrected for the fraction of agreement statistically expected from randomly relocating all cells in compared maps.

We used a freely available Map Comparison Kit (http://www.riks.nl/mck/) software tool in the research presented here for the comparison of raster maps based on standard cell by cell map comparisons (the standard and variants on *kappa statistics*) and fuzzy-set calculation rules.

CASE STUDY AREA

The study area includes part of the territory of city of Belgrade, which is the capital of Serbia. Three neighboring out of a total of seventeen Belgrade municipalities were tested including: Zemun, Novi Beograd and Surčin that represent the different urban types of municipalities (Fig. 1).

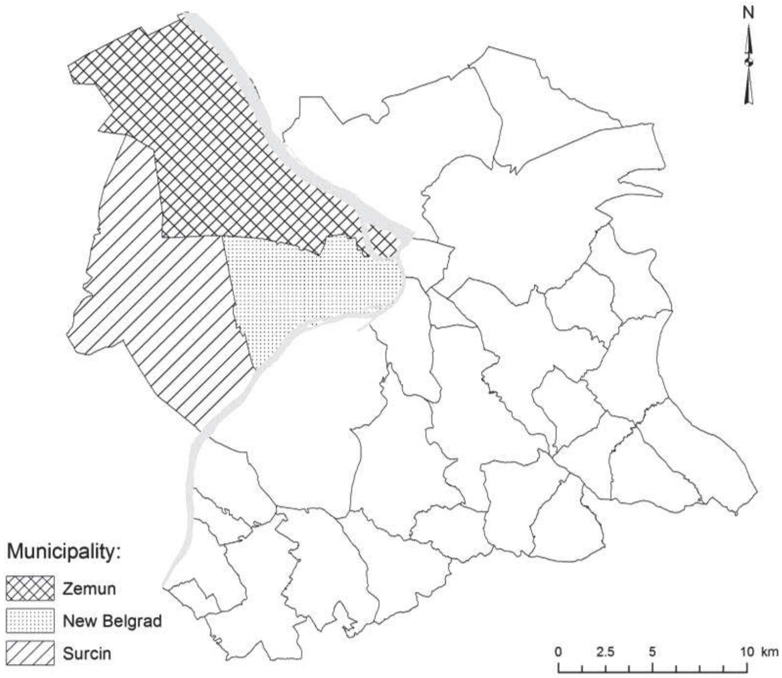

Fig. 1. Case study area within the city of Belgrade.

The municipality of Zemun has three suburban settlements: Zemun Polje, Batajnica and Ugrinovci, and one urban, Zemun, the old town. Zemun dates back to the Neolithic period and has developed as a separate town until 1934 when it merged with Belgrade. The Old town of Zemun was declared as the regional, cultural and historical site of great significance for the Republic of Serbia. The Master Plan of Belgrade includes all settlements except Ugrinovci, which makes a total area of 9,942 ha with a population of about 15000.

Novi Beograd (New Belgrade) is the municipality with the highest population density. The municipality covers an area of 4,096 ha, with a population of about 220 000 inhabitants. Its construction was planned and begun after World War II. The municipality of New Belgrade is divided into large residential blocks of a nearly rectangular shape that are separated by wide boulevards. New Belgrade has recently become the commercial center of Belgrade.

The municipality of Surčin was formed in 2004 from part of the municipality of Zemun. The Municipality consists of seven settlements, and some of them are situated within the boundary of the Master Plan. The airport complex "Nikola Tesla" is situated in the north-eastern part of the municipality and has a significant influence on its spatial development.

The assessment on Master plan realization is usually carried out for these three municipalities separately, but since these municipalities form one entity as well, the assessment is carried out for all three municipalities together. The total research area covers 22.236 ha, or about 30% of the total area of Master Plan.

The Master plan of Belgrade designed to 2021 was made by the Institute of Urbanism of Belgrade in the year 2003. The map of the Master Plan was used as the reference map with a raster size of 20x20 m and 908x1278 cells (Fig. 2a). Actual land use is defined based on ortophoto maps taken in 2010. The vector map, (polygons of land use) was rasterized at 20 m spatial resolution, with same dimensions as the primary map (Fig. 2b). The Master Plan of Belgrade for year 2021 was done in 2003, so based upon actual land use situation in 2010 we can do analysis of plan implementation over the past seven years. The aim is to determine whether the urban growth differ from planned in the period 2003-2010 and to evaluate the extent to which it was implemented. Based upon used statistics we can analyze implementation of Master Plan according to land use categories, based weather on location or quantity. *Kappa location* value can offer us information whether the certain land use category is developing on location that is planned for that category. Whilst *kappa histo* value can offer us information about the extent to which this category development is implemented.

Land use classification is carried out in nine categories on both maps: agriculture, wetlands, traffic areas, commercial, industry, residential, infrastructure, green areas and special use areas (sport, public services ...).

Fig. 2. a) Land use map of Master plan 2021, b) Observed land use map for 2010.

RESULTS AND DISCUSSION

All *kappa* indices were calculated for the total case study area as well as for each municipality separately in order to examine similarities between planned and observed land use maps

The fig. 3 below shows the spatial distribution of agreement, since *kappa* statistics are based on a straightforward cell-by-cell map comparison (Fig. 3).

Fig. 3. Cell by cell comparison

Table 2. *Kappa* statistic indexes

	Total area	Zemun	New Belgrade	Surčin
kappa	0.569	0.627	0.596	0.429
κ_{loc}	0.855	0.863	0.800	0.914
κ_{histo}	0.662	0.727	0.746	0.469

In all areas, except in Zemun (Table 2), the *kappa* index has a value between 0.41-0.60 which indicates moderate Strength of Agreement [5]. Zemun has value of 0.63, which indicates that Strength of Agreement is substantial. However, the absolute value of *kappa* has no intrinsic meaning in assessment of results of land use change models, since the amount of land use change is not considered [17]. Inconsistency of the two maps can be explained by analyzing the values of *kappa location*, *kappa histo*. The values of *kappa location* are high, which indicates that spatial distributions of different categories of land use over the maps are almost the same. Differences between planning and real states (conditions) of land use are more reflected in quantitative dissimilarities. The almost perfect matching in location depicts that the urban development is going as planned, i.e. land use persistence.

In order to get better insight in each category behavior, the *kappa* statistics per category can be calculated as an option. For a categorical *kappa* statistic, the two maps are transformed to a map consisting of only two categories, i.e. the considered category as first one and the second category as the combination of all other categories (one versus all).

Table 3. Total area *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
kappa	0.474	0.996	0.522	0.586	0.826	0.520	0.362	0.785	0.361
κ_{loc}	0.911	1.000	0.964	0.761	0.861	0.708	0.777	0.855	0.619
κ_{histo}	0.520	0.996	0.542	0.769	0.959	0.734	0.466	0.918	0.583

Looking at the *kappa* values per categories (Table 3), for total area, we can see that the largest dissimilarities are occurring in industrial and green areas.

Since the green and agriculture areas are unbuilt categories, they are the categories with the most discrepancies. Those discrepancies are caused by illegal construction of residential housing in planned green areas and by planning industrial category on agricultural areas.

Almost perfect location similarities in the category of traffic areas indicates that the existing traffic areas were constructed according to the plan, but only 50 precent have been realazed at the moment. It is planned to build new roads and to expand the airports mainly in locations that are currently in agricultural areas.

Table 4. Zemun *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
kappa	0.553	0.998	0.597	0.162	0.827	0.421	0.424	0.813	0.398
κ_{loc}	0.862	1.000	0.947	0.262	0.905	0.422	0.750	0.847	0.847
κ_{histo}	0.641	0.998	0.631	0.618	0.914	0.999	0.566	0.960	0.471

Spatial distribution of almost all categories is substantial, except infrastructure and commercial areas. Values of *kappa* indicate that the built infrastructure is in great disagreement with the planned (Table 4). This disagreement is mainly in the location and area of suburban settlements. Disagreement between commercial areas can be justified for several reasons: some of the existing industrial and residential areas had shifted to commercial land use and planned commercial areas were not built.

Table 5. New Belgrade *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
kappa	0.347	0.995	0.832	0.785	0.833	0.530	0.422	0.585	0.448
κ_{loc}	0.930	1.000	0.954	0.949	0.881	0.835	0.707	0.936	0.488
κ_{histo}	0.373	0.995	0.872	0.827	0.945	0.635	0.597	0.625	0.918

All unbuilt areas in the observed land use map are defined as green areas; on the other hand, part of the areas which are used as agriculture areas were planned as green space (Table 5). That is the main reason why *kappa location* for green area is small, while *kappa histo* is high. But, in the category of agriculture, the value of *kappa location* and *kappa histo*, is opposite, for the same reasons. It is planned for New Belgrade to become a commercial center of Belgrade, but it is not yet realized to the end.

Table 6. Surčin *Kappa* statistic per category.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
kappa	0.350	0.989	0.396	0.750	0.800	0.055	0.248	0.877	0.154
κ_{loc}	0.964	1.000	0.979	0.960	0.859	0.073	0.927	0.923	0.471
κ_{histo}	0.363	0.989	0.405	0.781	0.931	0.754	0.268	0.950	0.328

Surčin is the municipality with the lowest *kappa* statistic within the studied area (Table 6). Discrepancies are mostly occurring in the commercial area. Spatial distributions of this category indicate that only 7 percent of cells are located on the planed space. Since a new ring road is planned to be built through the territory of the Surčin municipality and the airport is also placed there, the measure of the quantitative similarity of traffic is low (Table 6).

The total area planned for commercial use is about one percent of the whole area of the municipality, and it doesn't affect the value of the total *kappa* statistics. Lower values of *kappa histo* indicate the quantitative dissimilarities, which is logical since planned urban areas in the municipality account for 30 percent of the total area while in 2010 the urban area extends to 17 percent.

Besides the *kappa* indexes calculation, the fuzzy set map comparison was also performed. There is some degree of similarity in land use considering the overlaping of the categories. Categories of green and agriculture areas are similar since they both belong to the unbuilt category whereas residential and commercial categories are often combined facilities.

The similarity between adjacent categories was realized with the following Category Similarity Matrix (Table 7):

Table 7. Category Similarity Matrix.

	Agricult.	Wetlands	Traffic areas	Infrastruct.	Resident.	Commerc.	Industry	Special use	Green areas
Agricult.	1	0	0	0	0	0	0	0	0.6
Wetlands	0	1	0	0	0	0	0	0	0
Traffic areas	0	0	1	0	0	0	0	0	0
Infrastruct.	0	0	0	1	0	0	0	0	0
Resident.	0	0	0	0	1	0.4	0	0	0
Commerc	0	0	0	0	0.4	1	0.2	0	0
Industry	0	0	0	0	0	0.2	1	0	0
Special use	0	0	0	0	0	0	0	1	0
Green areas	0.6	0	0	0	0	0	0	0	1

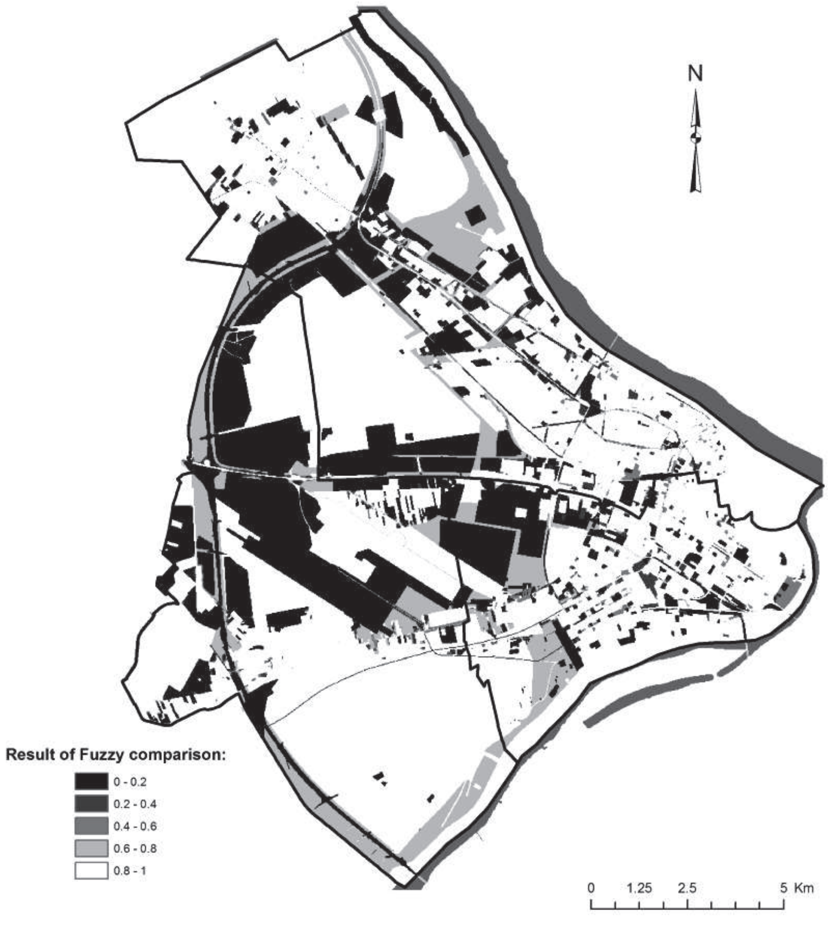

Fig. 4. Spatial assessment of similarity in the fuzzy set approach.

In Fig.4 each cell has a value between 1 (for identical cells) and 0 (for total disagreement). The darker areas indicate the more intensive disagreement. Unlike Fig.3 it is possible to obtain a gradual analysis of the similarity of two maps, by distinguishing total agreement (white areas), medium similarity and low similarity (the shades of gray) and total disagreement (black areas).

CONCLUSION

In this work the advantages of using the *kappa* statistics and its new variants to compare maps were demonstrated. It is interpretable, allows different results to be compared, and suggests a set of diagnostics in cases where the reliability results are not good enough for the decision making purposes. Moreover, map comparison methods are very useful to assess the similarity of a set of land use maps on a grid size level. In our case study area, we can conclude that in the period from year 2003 to 2010 urban growths has been carried out according to plan, with minor exceptions.

We suggest that this measure be adopted more widely within urban planning community. Further investigations should be conducted in order to come up with some standards that should used as a benchmarks in the land-use change assessment. Also, recently introduced metrics like *kappa simulation* [17], [18] have to be considered in the future work.

ACKNOWLEDGMENTS

The paper represents the result of research carried out on projects No. III 47014 „The role and implementation of the National spatial plan and regional development in renewal of strategic research, thinking and governance in Serbia“

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COMPARISON OF 3D CONSTRUCTION VISUALIZATION METHODS TO PROVIDE VISUAL SUPPORT IN GIS ENVIRONMENT FOR THE CONSTRUCTION PROJECTS

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Abstract

The development of 3 dimensional (3D) display technologies led to the widespread 3D designs and applications in construction industry. The major developments that offer visual presentation for the construction projects are 4D CAD, BIM and nD modeling. In addition, 3D GIS applications that use visualization features of GIS are also available. Unlike CAD tools, GIS software provide spatial data about construction for project participants. According to the previous studies, converting 2D CAD drawings into 3D data layers that refer to each construction activity is an efficient method. It is possible to transfer and edit them in GIS through data interoperability. Besides, 3D modeling and editing tools such as 3D Studio Max and SketchUp enables the realistic design with their material library and texture features. These modeling software can transfer data directly into GIS. In this study, two available 3D building visualization methods to provide visual support in GIS environment for the construction projects were compared. AutoCAD, SketchUp and ArcGIS were utilized for modeling, data transfer, editing and 3D visualization. 3D data transfer processes between these software were also discussed and multipatch geometry type that is supported by ArcGIS was emphasized. A reinforced concrete construction in Eskisehir, Turkey was determined as the study area for the case study. In consequence of the study, it was discovered that while the feature class objects that were transferred from CAD to GIS have 2D geometry, multipatch objects are in 3D geometrically thereby more realistic. Irregular 3D objects cannot be defined in feature class but they can be created in SketchUp and transferred into GIS as multipatch. On the other hand, each layers corresponding to the construction activities should be drawn individually in SketchUp.

Keywords: 3D Visualization, GIS, CAD, SketchUp, Multipatch

Recommended Citation: CENGIZ, A. E., GUNEY, Y. (2013) Comparison of 3D construction visualization methods to provide visual support in GIS environment for the construction projects. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

2D project drawings are utilized in phases of the construction projects on the purpose of the planning, design and network analysis. However these drawings do not have enough details about the construction applications in the site. Furthermore, manipulating and representing real world objects in 2D are no longer adequate [1]. Planners and engineers use 3D visualization in order to evaluate the efficiency of the construction project and develop various applications [2]. GIS that has a significant role in the advanced technology can also be utilized for 3D visualization. Using GIS for construction projects is important because of its spatial perspective with geographic reference system which CAD tools do not have.

Cheng and Yang [3] proposed to divide the project drawings into layers that are corresponding to each construction activity and transfer them into GIS environment. Bansal and Pal [4] stated that one-piece project drawings are not appropriate to generate 3D view in GIS. Thus they also divided the project drawings into the data layers. Bansal and Pal [5] calculated the quantity takeoff for a model construction using Avenue script language, integrated the calculations with 3D data layers and displayed in GIS environment. Zhong [6] developed a dynamic 3D simulation system for an arch dam construction. Bansal and Pal [7] utilized GIS for displaying direct sunlight gain of a model construction in 3D. Ekberg [8] studied on multipatch data structure for displaying and analysis of complex 3D objects in GIS environment. Multipatch is a type of geometry composed of planar 3D rings and triangles, used in combination to model objects that occupy discrete areas or volumes in 3D space. This geometry type may represent geometric objects, like spheres and cubes, or real-world objects, like buildings and trees [9]. Multipatch could be stored in geodatabase and used with standard tools of ArcGIS. It also has the same display feature with other geometry types. Although multipatch exists in ArcGIS as a data type but there is no possibility to create/edit multipatch features within ESRI products interactively [10]. This is possible only through programming with ArcObjects or through a standalone application such as SketchUp [2].

Advanced 3D applications allow the designers for the emphasis on virtual reality and this expanded the usage area of 3D design software such as AutoCAD, 3D Studio max, SketchUp, Microstation, ArchiCAD etc. SketchUp which is utilized for creating 3D design enables virtual reality. Data transfer between SketchUp and ArcGIS is also possible.

In this study, two available 3D construction visualization methods that are used to provide visual support in GIS environment for the construction projects were compared. Method that was developed by Cheng and Yang [3] and 3D multipatch methodology were discussed. A residential RC construction in Eskisehir, Turkey is determined as the study area for the case study. In conclusion of the case study, it was determined while multipatch objects are 3D, CAD objects that were transferred from CAD to GIS are 2D geometrically. Besides, CAD based inclined objects are not defined as 3D in GIS environment, but in SketchUp. However, each data layers corresponding to the construction activities have to be created one by one in SketchUp.

METHODOLOGY

GIS Based 3D Visualization

3D visualization methodology that was developed by Cheng and Yang [3] and used also by Bansal and Pal [4] includes converting project drawings that are in AutoCAD to data layers corresponding to each construction activity and transferring them to GIS. Data layers could be rendered in 3D by extrusion and base height functions in GIS software. Following parts provides detailed information about the steps of this methodology.

Converting drawings to data layers: Both architectural and technical drawings are utilized for 3D visualization. Interior and exterior details are created by using floor plans from the architectural drawings. Foundation phases and structural details of the construction are obtained from the basement and formwork plans in the technical drawings.

Transfer the data layers to GIS environment: Transfer the data layers to GIS is related to data interoperability between CAD and GIS. Files in AutoCAD could be transferred in ArcGIS by Import from CAD function. Dissolve is utilized to merge the objects and feature to polygon to create polygons during the editing in ArcGIS environment. Base height and extrusion are used to convert the data layers from 2D to 3D.

Merging the objects: Dissolve function that is under the Geoprocessing tools are utilized to merge the identical objects in ArcGIS. Objects that are created to define each structural member in architectural or technical drawing could be merged in one by this function.

Creating polygons from lines: CAD based drawings include line data type. These lines could be converted to polygons using feature to polygon function.

Creating 3D view: In order to create 3D view of the construction, base height and extrusion functions of ArcScene are utilized.

Multipatch 3D Visualization

It is not possible to define inclined objects in GIS based 3D visualization methodology. Thus, multipatch data structure that enables displaying 3D data layers in GIS environment could be utilized. This methodology used by Ekberg [8] and its efficiency was proven. In proposed methodology, 3D component are created in SketchUp. SketchUp can read .dwg/dxf files directly. Geometrically 3D components are created on 2D CAD drawings and saved as different .skp files. Then they are transferred to GIS environment as multipatch using Conversion tools of ArcGIS.

CASE STUDY

Study Area

A residential RC construction in Eskisehir, Turkey was determined as the study area. The construction has 242 square meter land area and five stories. Architectural and technical drawings of the construction were utilized as the visual data for the case study.

AutoCAD-ArcGIS Data Interoperability

Data transfer between AutoCAD and ArcGIS could be enabled by functions of Data Interoperability toolbox. dwg/dxf files were imported with .gdb (geodatabase) extension using Quick Import tool. Data layers were converted to feature class data structure. Base height and extrusion values were assigned each layers and 3D view were obtained. Fig.1 and Fig.2 represents 2D and 3D data layers respectively.

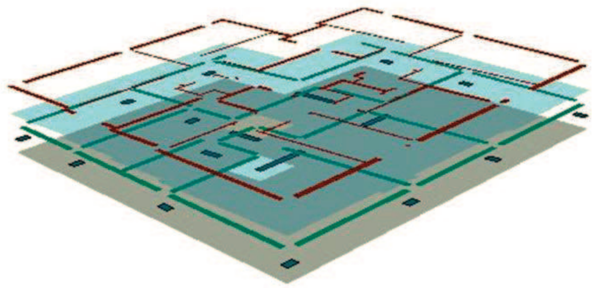
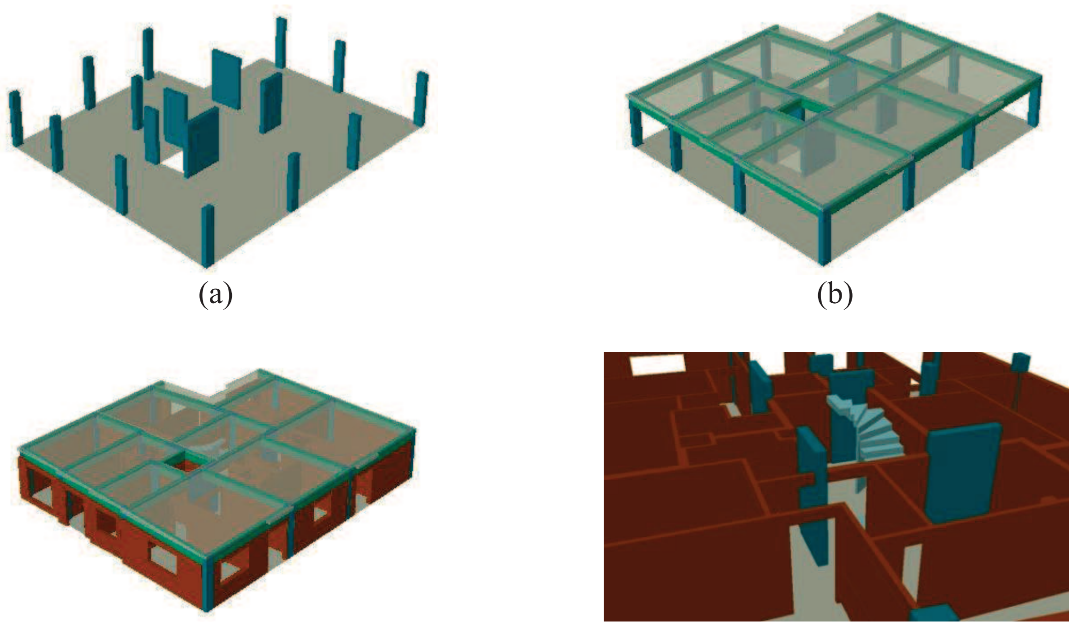


Fig. 1. 2D data layers that were transferred from AutoCAD to ArcGIS



(a) (b)

(c) (d)

Fig. 2. 3D view of data layers in ArcScene, (a) Columns, (b) Columns, beams and slabs, (c) General floor view, (d) Interior details.

AutoCAD-SketchUp-ArcGIS Data Interoperability

Project drawings of the model construction were transferred into SketchUp environment and drawn by means of corresponding to each activity. Visual components were saved as different .skp files. The reason of transferring the layers into GIS as different files is that drawings in a single piece are cumbersome for 3D construction visualization. Visual layers were imported as multipatch through Conversion tools of 3D Analyst. These layers were saved in a geodatabase and displayed on the user interface of ArcGIS. 3D model of the construction that was transferred into GIS environment can be seen from Fig.3

RESULTS AND DISCUSSION

Results

In feature class 3D visualization, visual data layers were created through CAD-GIS data interoperability. CAD based project drawings are geometrically 2D. ArcScene functions were utilized to create 3D view from these 2D data. However, this methodology is not sufficient to define irregular 3D objects such as roof. Thus, feature class 3D visualization does not include roof work of the model construction. In multipatch 3D visualization, .dwg files were imported to SketchUp and created in 3D. Then they were transferred into GIS as multipatch. As it is possible to define 3D inclined objects in SketchUp, multipatch 3D visualization included also the roof works. Visual data layers in each methodology were compared in visual reality aspect and it was discovered that multipatch 3D visualization has higher resolution because of being geometrically 3D thereby multipatch data layers are more realistic than the feature class data layers. Whilst visual data layers could be imported into ArcGIS directly and converted into feature class in the first visualization methodology, users have to create each component one by one in the second visualization technique. ArcGIS has geoprocessing tools to edit components. SketchUp does not have such a tool but it has toolboxes that are quite user friendly.

Discussion

Cheng and Yang [3] was developed a GIS based 3D visualization methodology considering converting the project drawings to data layers corresponding to the construction activities and also a cost estimation algorithm. Bansal and Pal [4], took these methodology and algorithm a step further and proposed to utilize ArcGIS editing tools instead of AutoCAD. However, it is not possible to define irregular 3D objects in that methodology. 3D multipatch data structure could remove this problem.

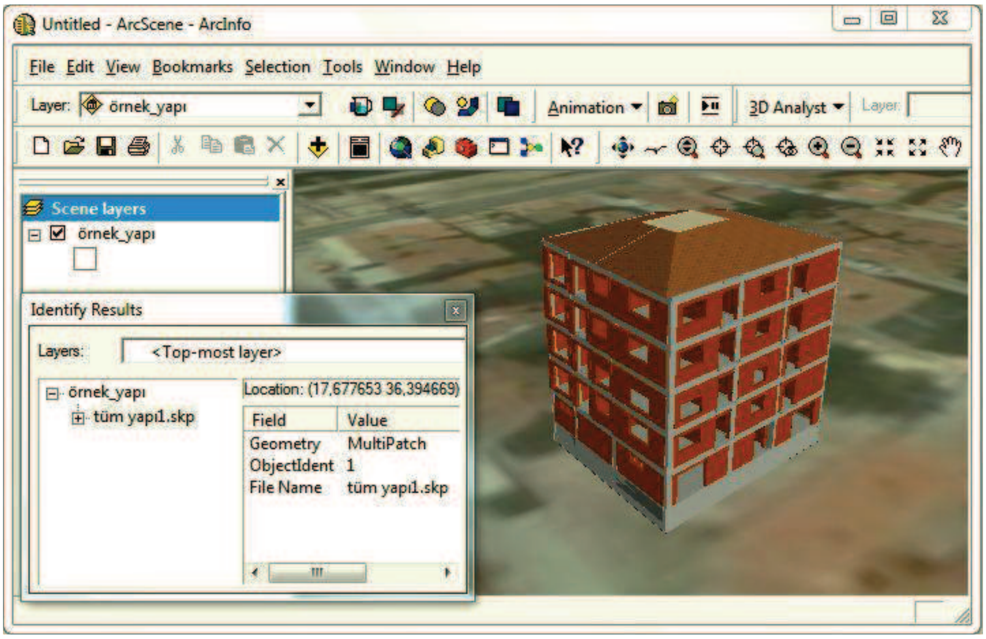


Fig. 3. Multipatch 3D construction model in GIS environment

CONCLUSION AND SUGGESTIONS

In this study, two available 3D construction visualization methods to provide visual support in GIS environment for the construction projects were compared. The case study of the methods was conducted for a residential construction in Eskisehir, Turkey. 3D visual layers were created in both ArcGIS and SketchUp environments utilizing the architectural and technical project drawings and displayed in GIS. GIS was utilized because of its spatial coordinator system which provides project participants to understand construction activities and their probable delays. ArcGIS which is mostly used and regarded as the most advanced GIS software on the market was preferred. Through CAD-GIS data interoperability, there's no need to draw the layers again. However, project drawings are created one by one in SketchUp. Despite that negative aspect, multipatch data are more realistic thanks to their true 3D geometry. Thus, inclined objects could be defined as multipatch. As a conclusion, it was determined that both methodologies have useful and adverse features.

In construction industry, 2D project drawings are utilized frequently. But lack of application details in the project drawings is one of the major problems of the construction projects for the project managers. Through integration between construction activities and 3D visual layers, it will be possible to track the project progressions and determine the probable delays. Furthermore, it is proposed to develop new methods for 3D construction visualization in GIS environment. Available methods that used for 3D visualization in GIS are not so efficient because of their requirement of time consuming drawing and editing processes. Thus the use of programming languages to create 3D layers from 2D project drawings is proposed for the further researches. 3D visualization through encode will reduce the total editing time and enable to save time.

ACKNOWLEDGMENT

This study was supported by Anadolu University Scientific Research Projects (SRP) Council as SRP with the number of 1103F044.

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‘LEAN’ PUBLIC PARTICIPATION GIS: TOWARDS A SUSTAINABLE TOOL FOR PARTICIPATORY URBAN PLANNING

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Abstract

The paper presents softGIS service, which is a currently developed, free and open source online Public Participation GIS (PPGIS) service, allowing for the collection of local knowledge from urban dwellers, and supporting participatory urban planning. The paper discusses recent enhancement of the service with functions facilitating multi-way communication between the actors involved in planning processes with the focus on the software development methods. Most of the PPGIS efforts to date have been rarely implemented in real decision-making situations and suffered from the low level of system sustainability. In an effort to overcome this, we propose a lean PPGIS approach, which aims at better supporting user and customer needs, improved cost efficiency, and easier adoption, leading to the increased sustainability.

Keywords: softGIS, urban planning, web-services, PPGIS, geoinformatics, lean software development

Recommended Citation: CZEPKIEWICZ, M., SNABB, K. (2013) ‘Lean’ public participation GIS: towards a sustainable tool for participatory urban planning. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

In 2007 urban population exceeded the half of the total human population [1]. Even though the most of the recent urbanization trend falls on the developing world, the share of urban population in western countries is even higher and exceeds 72% in Europe [2]. Cities have therefore become the primary living environment for humans. For this reason alone, providing a good quality of life for urban dwellers is essential. What is more, sustainable urban development is an important component of global sustainability [3], [4]. As the spatial organization of cities has an impact on the fulfillment of the above goals, urban planning has become an important tool for ensuring their realization. There is a growing need for tools and methods that would support planning with better knowledge of the internal functioning of cities, the factors affecting the urban quality of life, as well as social, environmental, and economic outcomes and conditions of planning decisions.

Sustainable development is based on three interdependent components: social development, economic development, and environmental protection. The social component is referred to by some sources as social acceptability. Decisions that are beneficial for the economy and for the environment will not be sustainable if they are not accepted by the public. Social development provided by the decisions is also a value on its own, and should lead to a more democratic and inclusive societies. Public participation in decision-making might therefore be one of the ways to provide more socially acceptable solutions. If sustainable urban development is the goal, there is a need for public participation in urban planning that shapes the spatial organization of cities. Such a need has been enshrined in numerous international documents, such as the Leipzig Charter or Agenda 21 [5].

In addition to addressing a general goal of urban sustainability, public participation in planning may serve specific goals and purposes. Innes and Booher [6, modified] list the rationales for public participation from the perspective of decision-makers:

- to know and take account of the preferences of the public in decision making,
- to improve decisions by incorporating local knowledge into existing knowledge base,
- to advance fairness and justice by recognizing the needs and preferences of the groups that would be otherwise not recognized,
- to get legitimacy for decisions,
- to meet legal requirements.

Drawing on the theory of communicative planning and the reflections on the planning practice in the United States, Innes and Booher [6] argue that the first four rationales are seldom met in real decision-making situations. Among other factors, they attribute this to the inadequacy of currently used methods, such as public meetings, and review surveys. It is not surprising then, that there have been numerous attempts to support public participation in planning with new techniques, adopting different paradigms and traditions. One such paradigm has called for the use of geospatial technologies in a way that supports public involvement in planning. Such efforts fall under the domain of Public Participation GIS (PPGIS), and their application domain is not limited to urban planning, but embraces such disciplines as environmental management, transportation planning and natural resource mapping.

PUBLIC PARTICIPATION GIS

The interest in PPGIS research and development comes from different sources. The groups traditionally interested in PPGIS have been the universities and non-governmental and grassroots organizations. In the academia, the interest initially stemmed from the criticism of GIS as a technology representing the knowledge of experts and institutions, not equally representing different groups of the society [7]. PPGIS has thus become an important part of a broader area of research called GIS and Society and has penetrated critical GIS agendas, in which the relationships between society and geospatial technologies are investigated [8], [9]. For NGOs and grassroots organizations, the practical reason for adopting and using PPGIS has been to become a partner for decision-makers, and to empower marginalized groups with access to data and information [10]. Such motivations have been therefore driven by social and political context in which they developed, with the empowerment and social change as desirable outcomes. In this perspective, the decision-makers are often seen as adversaries that represent the privileged groups, and PPGIS serves as a tool to create a counter-power for the existing structures.

In an overlapping yet different perspective, PPGIS aims at incorporating the local knowledge of residents into the existing knowledge base for planning. Local knowledge is a personal and subjective knowledge that has a spatial component and comes from the everyday experiences and interactions between people and the environment [11]. Talen [12] proposed a bottom-up GIS as a platform for synthesizing the knowledge of experts with the local knowledge of participants. In bottom-up GIS, resident perceptions and preferences are stored directly in a desktop GIS database, with the help of the facilitator. A vision to incorporate local knowledge into existing data sets was also behind the softGIS methodology, envisioned as a bridge builder between residents and planners [13]. In softGIS, however, local knowledge is collected through map-based online questionnaires. SoftGIS methodology is described in detail further in the article. What is important to note here is that in both bottom-up GIS and softGIS approaches, local knowledge is incorporated into existing data sets to help guide planners and decision-makers in arriving at more efficacious solutions. Thus planners and decision makers become the main recipients of the data and, by extension, beneficiaries of the PPGIS effort.

In the tradition of communicative planning, planning processes are understood as a process of constant interactions between the variety of involved actors [14]. With the advances in information and communication technologies (ICTs), the observation that the communication patterns in modern societies differ from those in planning processes has become increasingly obvious. In this perspective, the motivation for PPGIS comes from the inadequacy of the currently used participation methods with an increased availability of the enabling technologies [15]. Online PPGIS have become feasible with the raise of the mapping websites that opened the technology for the broader public (e.g. MapQuest, Google Maps) and the programming frameworks and APIs that allowed for easier software development (e.g. Google Maps API, MapServer, OpenLayers). The variety of enabling technologies have opened up the potential for a synergistic convergence of GIS and ICTs in a form of map-based online discussions [16], Web 2.0 features and social media integration [17], [18], and the content contribution mechanisms, such as volunteered geographic information (VGI) [19], [20]. From this perspective, PPGIS serves as a communication platform enabled by the new technologies, with the multiple practical purposes, such as sharing the ideas, consensus building or argumentation, as well as with various possible social outcomes.

In fact, it is difficult to discern between different motivations, and in most cases, there are many motivations behind each project. What is evident, however, is that most of PPGIS efforts have been initiated in academia, and have been driven by research goals, rather than by problems, which they aimed to solve. In the result, most of the PPGIS projects ended up one-off efforts supported by research grants and discontinued after the grant completion. PPGIS literature is replete with experimental or prototype applications that have never been implemented in a real decision-making situation, as there was no one to maintain the system or simply because the system was not intended for the real-life operation. A growing part of the literature focuses on the conditions and barriers for the adoption of the participatory tools in planning [21], [22]. Little is known, however, about the influence PPGIS would have on real participatory processes in planning or on the quality of decisions made with the use of the technology. There have been repeated calls for the evaluation of PPGIS efforts, but these efforts have been rare and far between.

PPGIS EVALUATION AND SUSTAINABILITY

Due to the diversity of approaches and contexts, the evaluation of PPGIS is a challenging task [23]. Another factor hindering the possibility to measure PPGIS effectiveness is the difficulty to establish a causal relationship between technology and the outcomes of its use [10]. Nevertheless, there have been efforts to provide general frameworks for PPGIS evaluation.

Jankowski and Nyerges [23] propose social outcomes and task outcomes as the main aspects of PPGIS evaluation. Instead of looking for “making better decisions”, they look for “better decision-making” as a task outcome, in which the use of technology leads to the effective participation and sustainability of its outcomes. Social outcomes include such aspects as learning, and changes in the social and institutional structures. Their framework provides an insightful perspective on PPGIS project as a dynamic process, but is mainly intended to structure PPGIS design, rather than to serve as an evaluation grid for existing PPGIS applications. In an earlier effort at formulating evaluation framework for PPGIS, Barndt [24] proposed the three main criteria: (1) the value of the results for decision-making, (2) the quality of process management, and (3) the support for the community development goals. From the perspective of process management, he highlights *sustainability*, defined as the ability of the system to support itself and to operate over a long term. The first and the third aspect of Barndt’s framework might be considered *task* and *social* dimensions, respectively. Consequently, the three dimensions of an evaluation framework that we propose here, and which draw on the two above frameworks, are:

- task outcomes,
- social outcomes,
- sustainability.

We consider sustainability as the core criterion to evaluate PPGIS software and its development process. If the goal of PPGIS efforts is to continuously improve the decision-making, as well as to provide a long lasting social value, system sustainability is crucial. The issue of sustainability is essential also from the perspective on urban planning as a continuous process which never ends [25].

The implementation, maintenance, and the use of the system requires the adopting organization to come up with resources. System sustainability might be thus achieved only when it provides valuable outcomes and serves the goals of the adopting organization. An organization is then considered a customer of the service and a party that is responsible for the system maintenance. With information and computation technologies becoming increasingly powerful and easy to use, the barriers to the adoption become less technological, and more organizational and institutional. In order to implement and maintain the participatory technology, the institution has to see the value of public participation in decision-making, and to set aside financial, technical and personnel resources [26].

In most countries, urban planning is a duty of public administration. Municipalities and their planning agencies prepare planning documents and convene the participation process. They seem thus to be the primary customers of PPGIS services. However, geospatial technologies have been seldom implemented by the public administration to support citizen participation in decision-making [26]. Public administration should be therefore seen as a customer of PPGIS. For a customer to pay for a product, the product has to provide value. The value does not have to be monetary, but must be important enough to convince the customer to spend resources. The reason for a potential failure of real-life PPGIS implementation might be therefore that the systems failed to provide enough value for the customers. In the remainder of the article we propose a *lean* approach to PPGIS software development, which aims at better supporting the needs of customers. Lean methods are expected to lead to the easier adoption of software, improved cost efficiency of the development process, and to the increased system sustainability. We also review the ongoing development cases as examples of lean approach and discuss challenges for the adoption of lean methods.

LEAN SOFTWARE DEVELOPMENT

The lean software development methods derive from various sources, including lean manufacturing and agile software development [27]. The agile software development is an iterative process that solves the problems of inflexibility of a waterfall process model [28]. The agile development follows short iterations over the elicitation of the requirements, software design, planning, implementation and testing, with the aim of fast delivery and flexibility to the changing requirements. The agile methods reduce the risk of huge investments on the features that have not been tested in practice and have not been proven to be necessary [29]. The agile methods bring flexibility and quality to the software itself, but they do not guarantee or take into consideration the economic perspectives of a long running project.

The lean method differs from the agile in that it focuses on overall economic sustainability of the product under development. It aims at producing understandable prototypes of services, testing them, and selling them to customers and users. The lean software development combines the agile methods with the lean manufacturing principles [30]. The term ‘lean’ was introduced as an improvement in manufacturing processes and refers to not spending a single resource on a product, before it has been sold or otherwise proven to be valuable for the user. In this way, the process can be seen as focused on creating the value for the user, eliminating waste, optimizing value streams, empowering people, and continuously improving (Fig. 1) [31], [32].

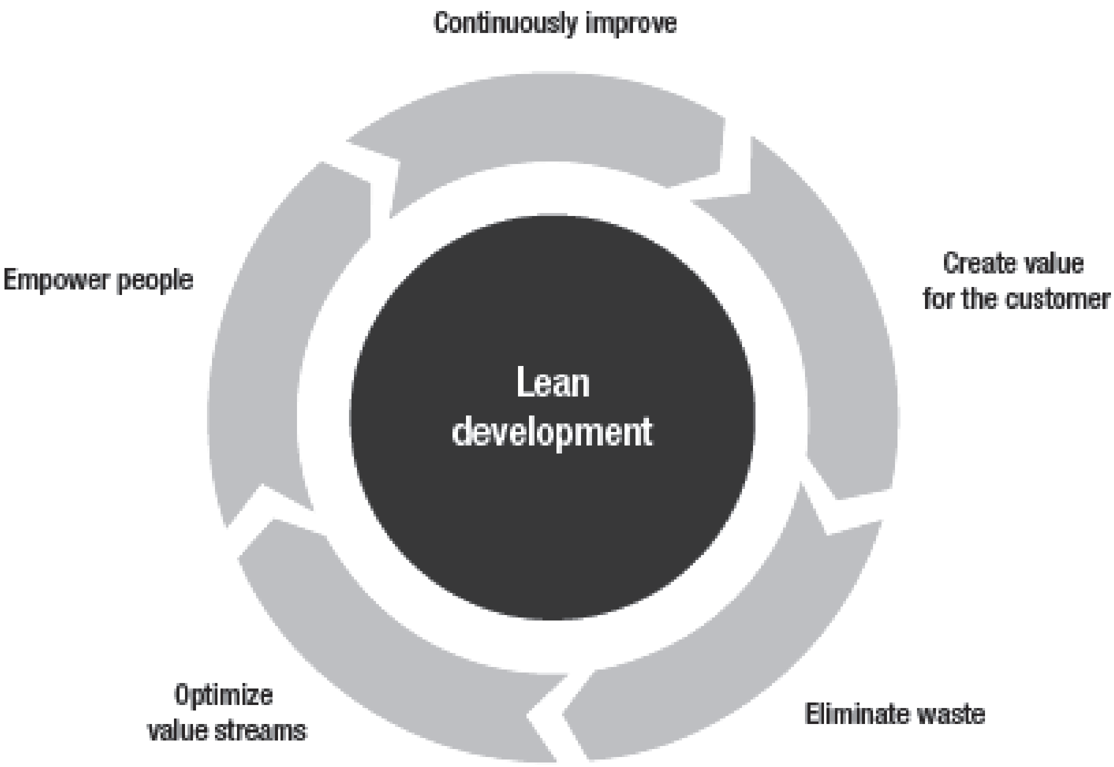

Fig. 1. Lean product development cycle [32].

The product and the concept can be sold before they have actually been developed. If selling the concept does not work, the product should never be developed. On the other hand, if the concept finds a lot of interested users and customers that are able to pay for the service, the product should be developed. Lean processes also emphasize a continuous learning process, in which the developers learn about their users and customers, through the attempts to solve their problems. Close collaboration of both users and customers makes the developers aware of the most critical issues regarding the success of the service under the development.

LEAN PPGIS FOR URBAN PLANNING

The technologies, that support the development of most PPGIS services, such as Google Maps API, OpenLayers or MapServer, are inexpensive or free of charge, and have become commodities. In a commodity market, it does not make sense to put efforts on technological development. The effort should be rather put on the design issues related to bringing value for the users. The resources should be spent on concept testing, user experience development and customer creation. Investing and focusing on the right development issues is expected to make the developed PPGIS services more sustainable. Funding long- term projects is in this way a fundamental issue, which also underlies technological changes requiring upgrades and maintenance of the service.

In the following paragraphs we evaluate from softGIS perspective the users and the current applications developed. The rate at which the current features support participative urban planning processes requires more research and a new set of metrics. But nevertheless the softGIS services are used in production and do fulfill a certain need for the current case studies.

Users and customers

The distinction between the users and the customers is crucial in the process software service design due to differing requirements and a different way of evaluating the quality of the service. In the urban planning context, we consider the customer as the person or organization making the decision to implement PPGIS and participatory processes. Without the initial decision to use PPGIS methods in a municipality, one cannot infer that PPGIS is what the municipality wants or needs. The concept of the service to be developed has to be presented in an understandable way that highlights the main benefits for the customer and the users. Presenting the service either leads to a decision of implementing the service or to modifying the concept to fit the specific requirements of the target customer. Only after a positive decision to buy or to use software that the concept presents, the development together with the users begins.

PPGIS users in urban planning

The proper definition of different user groups and the level of their skills allows to focus the design decisions on the right issues. The main user groups in PPGIS for urban planning can be considered to be:

- urban planners,
- citizens.

In the urban planning context the general skills of an urban planner who focuses on land use planning can be very different from other urban planners who, for example, focus on transportation planning. Urban planners may also differ in terms of general computer skills. In softGIS we have identified the main tasks that need to be done for creating a PPGIS service and using it in the urban planning context.

The identified high level tasks include:

- creating content for a PPGIS service,
- marketing the PPGIS service,
- analyzing the outcomes of the PPGIS service,
- presenting and/or using the outcomes for urban planning purposes.

Depending on how each municipality has organized their urban planning and what skills the individuals involved have, these tasks might be performed by different user groups.

PPGIS customers in urban planning

Identifying who is the person involved in making decisions of using PPGIS is important as this person or persons might be considered the customers of the service that provide the much needed funding. For participatory applications it would be controversial to consider the citizen to be the customer. Although as taxpayer to the government, municipalities and agencies, citizens support indirectly PPGIS services and the government is a purveyor of this support. The ethics behind this is to develop PPGIS services that produce customer value. The situation of PPGIS can also be considered as a two-sided market where government agencies provide the required monetary support by buying the PPGIS product and citizens are the ones who should gain the value. Producing value for only one side does not produce the same amount of value as providing products that both sides can use and value. In two sided markets only one side pays, and as clarified above in the urban planning case the funding would come from the government side.

SOFTGIS

SoftGIS is the term used for both the methodology and the software originally intended to collect the residents' perceptions of their living environment and to combine them with physical geographical information and other geospatial data layers. Based on the principles of the environmental psychology and participatory GIS, softGIS methodology allows for the micro-scales and individualized research on the spatial aspects of relationships between human and physical environments. Even though the methodology was first used in a place-based research, it has been intended from the beginning as a tool supporting public participation in urban planning [13].

To this date, softGIS data has been collected using web-based questionnaires allowing for the collection of both place-based and non-place-based information from respondents. Place-based questions allowed respondents to draw points, lines and polygons on map, which are then stored in a geospatial database. Other questions are facilitated by multiple-choice and radio buttons, slide-bars, open-ended questions, etc., which allow to collect non-locational information, such as socio-demographic background or the user feedback on the questionnaire. To this date, numerous research projects have been realized using the softGIS methods, including such diverse domains as the relationships between the urban density and the perceived environmental quality [33], child-friendly environments [34] or urban mobility patterns, which is an ongoing project.

In recent years, there has been a development effort to support decision making by integrating softGIS data into the urban planning process. The requirements for sustainability of the service have been raised, and. the deployment of participatory web services and their continuation from one project to the other was the main requirement. Below we provide the examples of the services that have been developed along with the considerations over the problems encountered and the software development methods used.

SoftGIS questionnaires

SoftGIS questionnaires has been developed for many municipalities and cities in Finland including Helsinki and Espoo - the two biggest cities in Finland. These questionnaires were developed to provide flexibility in adding new features and contents with as good as possible usability. Usability, data reliability, and different requirements for the data collection and research using the data were the main priorities for developing these questionnaires. As a result, we implemented a platform where questionnaires were defined with writing JSON and new features could be easily added with the help of Javascript and html. The ease of use was aimed at software developers with a knowledge of javascript, html and JSON formats. The questionnaire has been successfully been deployed in a number of cases since the first version was used, including, besides Finland, also Japan and Australia. Although the questionnaires did fulfill their purpose and they are still used there is a constant problem of the cost of setting up a new instance of the questionnaire. Developing and deploying such a questionnaire does require a developer with the right skills. These developers are usually hard to find and expensive. Moreover, combining softGIS with urban planning practices in the form of web questionnaires only provides a low level of participation. To be able to support both higher and lower levels of participation other types of services needed to be implemented.

SoftGIS urban planning service

The softGIS services developed to support urban planning in different stages are a combination of different prototypes. These prototypes has been developed and experimented with in different urban planning cases in Vaasa and Järvenpää. Some of the prototypes are clearly valuable and their maintenance and further development is ongoing. The prototypes developed until today under the softGIS methodology include:

- *geoforms service enabling the creation and deployment of softGIS questionnaires,*
- *dashboard* allowing citizens to view urban planning projects on a map,
- *planning proposal* services, which aims at presenting a draft urban plan and enabling a map-based discussions over the proposal,
- *idea competition* services aiming at allowing citizens to evaluate multiple planning and development ideas,
- *analysis application* which allows for the visualization of questionnaire answers.

The development of the first three services (dashboard, geoforms and planning proposal) has been following the lean development practices, which enabled the efficient usage of scarce resources. Concept problems and failures have been recognized early in the development process, which has saved a lot of development time. The two latter services (idea competition and analysis application) have been following different approaches.

At the moment, the most popular service that has been implemented is the geoforms questionnaire service. The other services are under development or suffer from various problems. Some of the problems that have been considered require changes in the existing urban planning practices and thus cannot be resolved solely by further software development investments. All of the services are still at an initial stage of the development process, therefore it is not easy to attribute their success or failure solely to the software development method. Below we present the services supporting public participation in urban planning developed as part of the family of the softGIS services. In each case we provide the information on the software development method and reflect on the sustainability of a feature.

Geoforms

Geoforms is a service that enables the urban planner or the researcher to create questionnaires, publish them, and download the collected data to their own computers. The software has been used in the cities of Vaasa, Järvenpää and Lisbon (Fig. 2). Some of the main problems encountered during the meetings and interviews with urban planners, has been their lack of time to learn to use a new software. What is more, smaller municipalities do not have enough urban planning cases suitable for usage of the geoforms service. The time that urban planners are able to devote to learning a new software is scarce. Using a questionnaire in an urban planning project has to be done with care and in the right time frame during the process. This filters down the number of projects that are suitable for using the questionnaires to only a fraction of all the ongoing projects in a municipality. The use of the service by each urban planner does not happen often enough to master the user interface. This situation either requires the municipality to assign a person to create questionnaires and handle the participatory service for all planning projects, or calls for a simplification of the questionnaire creation and analysis of the data. Another way to support users and providers of the service is to form user communities and developer communities that would share information about the proper use the geoforms and the best practices. To be able to create such communities the usage of the software should grow to reach a point where such communities would be self sustaining.

Fig. 2. the geoforms application used for place-based research in Lisbon, Portugal

Dashboard

The dashboard is the simplest service in the softGIS family of services. It enables the citizens to browse ongoing planning projects and to navigate to the participatory service that is currently in use for a particular project (Fig. 3). The dashboard solves the problem for the citizen of finding out which projects in a municipality invite the participation and provides easy navigation to the service. This enables the service to support multiple simultaneous projects. The requirement for the dashboard did not come from the customer, but from the development team. The solution has been positively received by the customer. The dashboard has become the main part of the softGIS service and serves as the entrance page for the citizens involved in participatory planning..

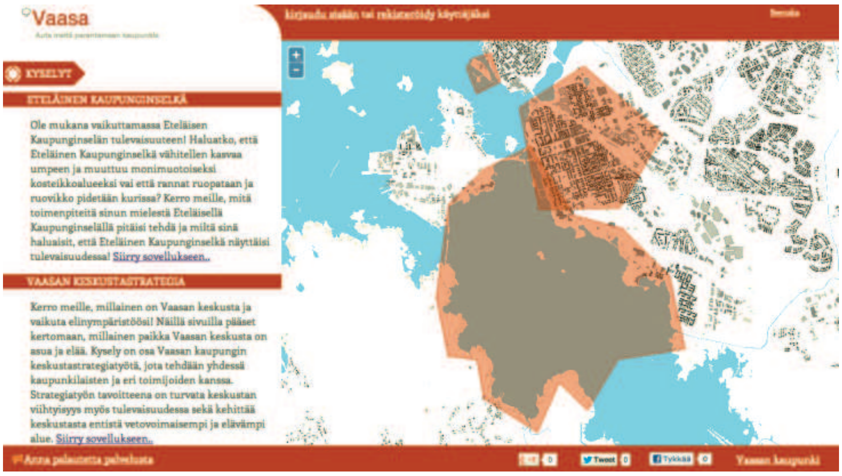

Fig. 3. the dashboard application, currently used in the city of Vaasa, Finland.

Planning proposals

The service has been developed to present the plan proposals on a map and to enable map-based discussions (Fig. 4). The discussion takes a form of an argumentation map [14] albeit with a minimal set of features. The service has been used in the city of Järvenpää for two of the projects: *Lepola III* and *Perhelän kortteli*. The former did not seem to draw the interest of the citizens, and received only a few comments. The latter drew more interest and with a small marketing collected about sixty comments from the users.

Fig. 4. The planning proposal application with a user comment; the application is currently used in the city of Järvenpää, Finland

The planning proposal application is still under development and requires further testing with the end users. Until now, a few problems related to the service have emerged. Most of them have been related to presenting the draft plan in a manner understandable for the citizens. The problem also includes the data format of the plans which is not open or otherwise compatible with web mapping. Nevertheless, the municipalities have shown an interest in further development of the service and the development is ongoing.

Idea competitions

Idea competition is a way to present urban planning ideas to the public for evaluation. In the city of Vaasa an idea competition was organized with the help of an internet evaluation application. Citizens were allowed to view graphic representations of the ideas, read the explanations, and then evaluate the proposals according to several factors, such as: activities, atmosphere, social, aesthetic, and overall. Citizens were also allowed to submit free comments. In the Vaasa case there were four ideas that had been developed to facilitate the evaluation work for the citizens. Thirty six evaluations form the users were collected during the idea competition phase. Fifty percent of the evaluations were directed towards one of the ideas and the rest of the ideas got an equal amount of four evaluations each. This indicates a usability problem in the software as the idea that was listed the first on the list received the half of all contributions.

Further development concerning the idea competitions has not been made due to lack of resources. The idea competitions did not have a clear business model and thus the costs of maintenance and further development could not be covered. In this case, we can say that we did not successfully follow lean methods, which led to the service that did not suit the customer needs, and was not able to guarantee the economic sustainability.

Analysis application

To inform the decision making process, the local knowledge collected through the questionnaires has to be presented in a comprehensible manner to urban planners, according to their informational needs, role in the process, and the level of knowledge and skills. To this date, *softGIS* data exploring applications have been developed separately for specific questionnaires with specific data sets. The analysis has been done for each questionnaire in desktop GIS, and did not automatically support different questionnaires with different semantic combinations of the data. The biggest obstacle to develop a generic visual-analytical application has been the lack of the well defined ontology for collected data. At this stage, the analysis application development is resource-expensive and is not an ongoing effort. Whether such a service is necessary depends largely on the level of skills of the users. If the level of skills of the data recipients allows them for the manual data operation in desktop GIS environment, the service will not be implemented. In this case, following lean thinking prevented spending resources on an unnecessary and overly expensive feature.

TOWARDS LEAN METHODS

The implementation of lean methods in software development is challenging. It might take years of work and require a change in the organizational culture to support the lean thinking. It is typical for project customers to have numerous, overly specific, and even conflicting requirements. In case of the urban planning, some of the requirements might not support the initial idea of public participation in urban planning, nor solve the existing problems faced by the citizens, the planner, or the municipality in general. Evaluating which requirements are actually valid and necessary is a demanding task as such, and being able to explain why something has not been implemented or will not be implemented might be even more challenging. The lean processes are to a large extent about people and their beliefs in how things work and should work. Changing organizational cultures and being able to implement lean software development requires effective communication between the project stakeholders, customers, users and developers of the service to form a common ground.

In the long run, the governments and the municipalities are expected to be the main customers of PPGIS services. For such actors, the contracts with software developers or service providers have to be specific. This is a fundamental problem that hinders implementation of lean software development methods for government projects. Lean software development methods are about not making large designs upfront before testing some basic features in practice. This requires a different kind of model to fund and develop the software to be used by government agencies. Nevertheless, we see the potential in lean methods especially in the context of online PPGIS, which is still an uncertain area for software developers and their customers.

When the agile development movement started, it took years before the benefits and results were found. The benefits of lean development seems to follow the same route. There is a clear hype cycle of lean methods as there is increasing amount of successful books and online materials covering it. However, there is still no clear evidence of the benefits of lean development methods, only a clear incentive towards lean practices. The metrics for lean development in the context of PPGIS still have to be developed and followed. Some of the metrics might be the resources used for the software development, the number of user per service, cases supported by the service and so forth. As we stated earlier we consider the sustainability of the software functions and the whole family of services as the core evaluation criteria.

Sustainability, however, cannot be the sole criterion, especially in such a socially and politically vulnerable and value-laden domain as urban planning. For instance, the goals of the adopting organization might be contrary to that of disadvantaged groups, and there is always a need for the sensitive evaluation of the broader societal influences of the participatory technologies. Nevertheless, if the goal of PPGIS efforts is to continuously improve the decision-making and to provide a long lasting social value, system sustainability remains essential. We might say that the sustainability is the core criterion for the evaluation of the software and its development process, while task and social outcomes should serve as the criteria for the evaluation of the whole PPGIS endeavour.

CONCLUSIONS

In the paper we articulated the need for improved sustainability of the Public Participation GIS services for urban planning, as well as the basic evaluative criteria for the PPGIS efforts. As an effort to overcome the low rates of the real-life adoption of participatory technology, we proposed the use of the lean software development methods for PPGIS software. To exemplify the software development methods in use, we presented several ongoing development projects within the softGIS service family, along with the examples of practical implementations in urban planning cases in Finland. The future work will focus on the evaluative criteria for the software development processes, the sustainability of the services, as well as the task and social outcomes of PPGIS projects. The knowledge base will be broadened by expanding the customer base for the software including the municipalities and planning agencies in Finland and in other countries, such as Poland and Portugal, as well as among different customer and user groups. The long term goal of current softGIS efforts is to develop a set of sustainable and flexible tools for public participation in urban planning that are able to operate in various cultural, institutional and organizational settings, thus contributing to sustainable urban development globally.

ACKNOWLEDGEMENTS

The authors would like to thank Piotr Jankowski for reviewing the draft version of the paper and one anonymous reviewer for the insightful comments. Michał Czepkiewicz would like to thank Cyryl Kwaśniewski for inspiring discussions. The cooperation between the authors was possible thanks to the funding from the European Union within the Interdisciplinary Environmental Life Sciences PhD Programme at the Adam Mickiewicz University in Poznań. Kristoffer Snabb would like to thank TEKES and all the partners of the Urbaani Arki research project for funding the software development and the work done in the last years.

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LAND-USE SUITABILITY ANALYSIS OF BELGRADE CITY SUBURBS USING MACHINE LEARNING ALGORITHM

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Abstract

This paper treats development issues of the suburban areas of Belgrade city. A considerable growth that the city had experienced has led to excessive consumption of land and also to degradation of the landscape and loss of the natural biodiversity. This is why an augmentation of the current Master Plan within the administrative extents of the city is considered to be vital for consistent planning of suburban areas development. Model used in this paper considered defining land-use suitability, relying on available thematic data, including the following sources: topography, land-cover, geology, protected areas and some synthetic maps derived from these sources in a GIS environment. For this purpose Support Vector Machines (SVM) algorithm has been implemented in a typical supervised classification learning task. Two modelling schemes have been involved (since the main problem of the study was the unavailability of the land-use suitability in the testing area): MODEL1 has been built in the extents of the training area having only two land-use suitability classes at disposal (Unsuitable and Very Unsuitable) and extrapolated to the testing area within which the same two classes were known (thus available for model performance evaluation), while MODEL2 has been trained on all four land-use suitability classes, and extrapolated to the testing area, with unknown land-use classes. The second model was then correlated with the first one in order to estimate its otherwise disputable performance. Results of MODEL1 were satisfactory, with high overall accuracy (85%). MODEL2 visually shows a good tendency, and since it has at least 85% accuracy for those coincident two classes (Unsuitable and Very Unsuitable) with MODEL1, it is justified to assume that remaining two classes match similar accuracy rates. The model could be improved by more thorough optimization of the classifier parameters, which will require much longer experimenting costs.

Keywords: land-use, suitability, machine learning, GIS, Belgrade

Recommended Citation: DJURIĆ, U., MARJANOVIĆ, M., ŠUŠIĆ, V., PETROVIĆ, R., ABOLMASOV, B., ZEČEVIĆ, S., BASARIĆ, I. (2013) Land use suitability analysis of Belgrade city suburbs using machine learning algorithm. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Land-use suitability (LUS) analysis is a tool used to define future land uses or their potential. Suitability techniques enable environmental managers, planners and engineers to analyze the interactions among various factors. Analysts are then able to map these interactions in a variety of ways. Public officials and developers can use these maps to set policies and make decisions regarding the use of land. Contemporary environmental managers and planners are aware of the technological advancements in land-use allocation and suitability modelling. New methods of spatial analysis are now commonly used in the development of land-use plans, environmental impact reviews, and site selection studies for many different land uses and public and private facilities [1]. One of the state-of-the-art methods involve machine learning techniques implemented hereinafter. Conventional methods on the other hand, are still needed to validate the outcomes and to calibrate these methods, which are still to be developed and perfected.

The main objective of this study is to use available public data and process them in a GIS environment for estimating a model of LUS. There was a strong motif supporting this research, since in-charged City's government services have shown interest in extending the Master Plan (MP) to the Belgrade suburb areas, thus needing a sound LUS assessment.

Belgrade has a long history of development under MP framework. First MP was *The Plan of Borough in the trench* by Emilijan Josimović from 1867 and last one (in power) is *Master Plan of Belgrade 2021* (adopted in 2003). The first pro-European Town Plan of Belgrade was introduced by Alban Chambon, a French architect, in 1912 (Institute of Urbanism – Belgrade; http://www.urbel.com). Since then, MPs had been published and adopted successively in 15–20 years intervals.

The earliest applications of suitability analysis conducted by engineering geologists and civil engineers for Belgrade MP area, in form of hand-drawn sieve mapping overlays was done by Šutić [2]. Later, numerous researchers performed similar suitability analysis for different purposes (urban planning, defining best/optimal road routes etc), but first work involving suitability analysis in GIS environment has been done in 2009/2010 [3], [4] but none for Belgrade area.

CASE STUDY AREA

The study area includes the territory of Belgrade City, the capital of the Republic of Serbia. For the purpose of machine learning, study area has been divided into the following splits: training and testing area (Fig. 1). The training area included the territory of Belgrade MP, while the remaining part of the Belgrade City territory (which is herein considered as suburban area) was adopted as the testing area. The basic descriptions of these areas are given in Table 1. Geographic extents of Case Study Area are: 4994905N; 4902405S; 7419130E and 7488830W (ArcGIS predefined spatial reference system: MGI_Transverse_Mercator/Zone 7)

Table 1. Basic data about Case Study Area (Republic of Serbia population Census 2011 – First Results; www.stat.gov.rs)

Case Study Area	Area (km^2)	Population (2011)
Training	776	1 373 000
Testing	2446	266 121

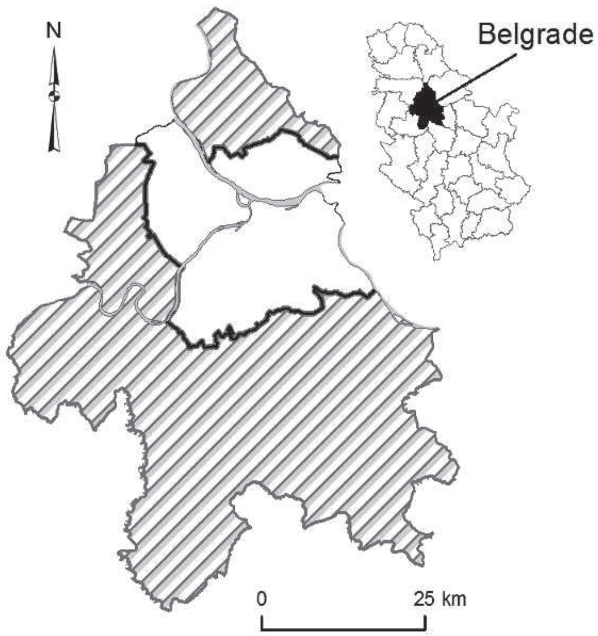

Fig. 1. Geographic location of the study area (blank=training, hatched=testing area).

DATASET

The dataset has been assembled from different resources, and required different pre-processing manipulations, dependent on the model requirements. It has been established as a set of featured raster layers in a GIS environment.

COMPRESSIBILITY raster was made by reclassifying geological units. Basic Geological Maps in 1:100 000 scale (sheets: Belgrade, Pančevo, Obrenovac and Smederevo) were digitized and then reclassified by using ground compressibility as a criterion. Five categories were defined by the degree of ground compressibility [5], [6]: Very high, High, Medium, Low and Very low. Very high degree of compressibility was considered as very unsuitable for urbanization, and vice-versa (Fig. 2-a). The reclassification was done because original geological units were very diverse and complex for the analysis since they counted more than 50 classes.

The *LAND COVER* project is a part of the Corine program (European Environment Agency; www.eea.europa.eu) and is intended to provide consistent localized geographical information on the land cover of all European countries. Corine methodology implies visual interpretation of false color composites (4, 3, 2) of Landsat TM images (30 m resolution), which turned as a very convenient resource for this research. The Corine land cover classes comprise of three levels, and herein, the third level has been used at 1:100 000 scale. New (intermediate) classification was formed, because the second level of Corine classes was too simple and third was too complex (Fig. 2-b). Land cover classes were modified (reclassified) into five classes (Table 2)

Table 2. Land cover raster classification

Corine Classes (Level 3)	**Reclassification**
Continuous urban fabric	Class 1 (Built-up area)
Discontinuous urban fabric	
Industrial or commercial units	
Port areas	
Airports	
Construction sites	
Pastures	Class 2 (Suitable for the urbanization)
Natural grasslands	
Non-irrigated arable land	Class 3 (Conditionally suitable for the urbanization)
Complex cultivation patterns	
Land principally occupied by agriculture, with significant areas of natural vegetation	
Beaches, dunes, sands	
Green urban areas	Class 4 (Unsuitable for the urbanization)
Sport and leisure facilities	
Vineyards, Fruit trees and berry plantations	
Broad-leaved forest	
Coniferous forest	
Mixed forest	
Transitional woodland-shrub	
Road and rail networks and associated land	
Mineral extraction sites	Class 5 (Very unsuitable for the urbanization)
Dump sites	
Inland marshes	
Water courses, Water bodies	

When analyzing an area for urban development relief characteristics in generally play a major role [7]. Therefore, initial computations considered generating 50 m resolution *DIGITAL ELEVATION MODEL* (DEM) [8], by digitized 2.5 m equidistance contours, using *Topo to raster* interpolation method [9], [10], [11] of the *Spatial Analyst* extension in the ArcGIS 10. DEM has been further used to generate *SLOPE* and *ASPECT* rasters [12].

Urban planners consider *ASPECT* to be a significant attribute when projecting urban development [7], since it is necessary to calculate the solar illumination for each location/cell/pixel [13]. Criteria used for this model is that the most suitable for building are the flat and westward exposed terrains. Vice-versa, the least suitable is a terrain exposed to the north (Fig. 2-c). However, for the basic experimenting design, non-classified (continual numeric) *ASPECT* has been used.

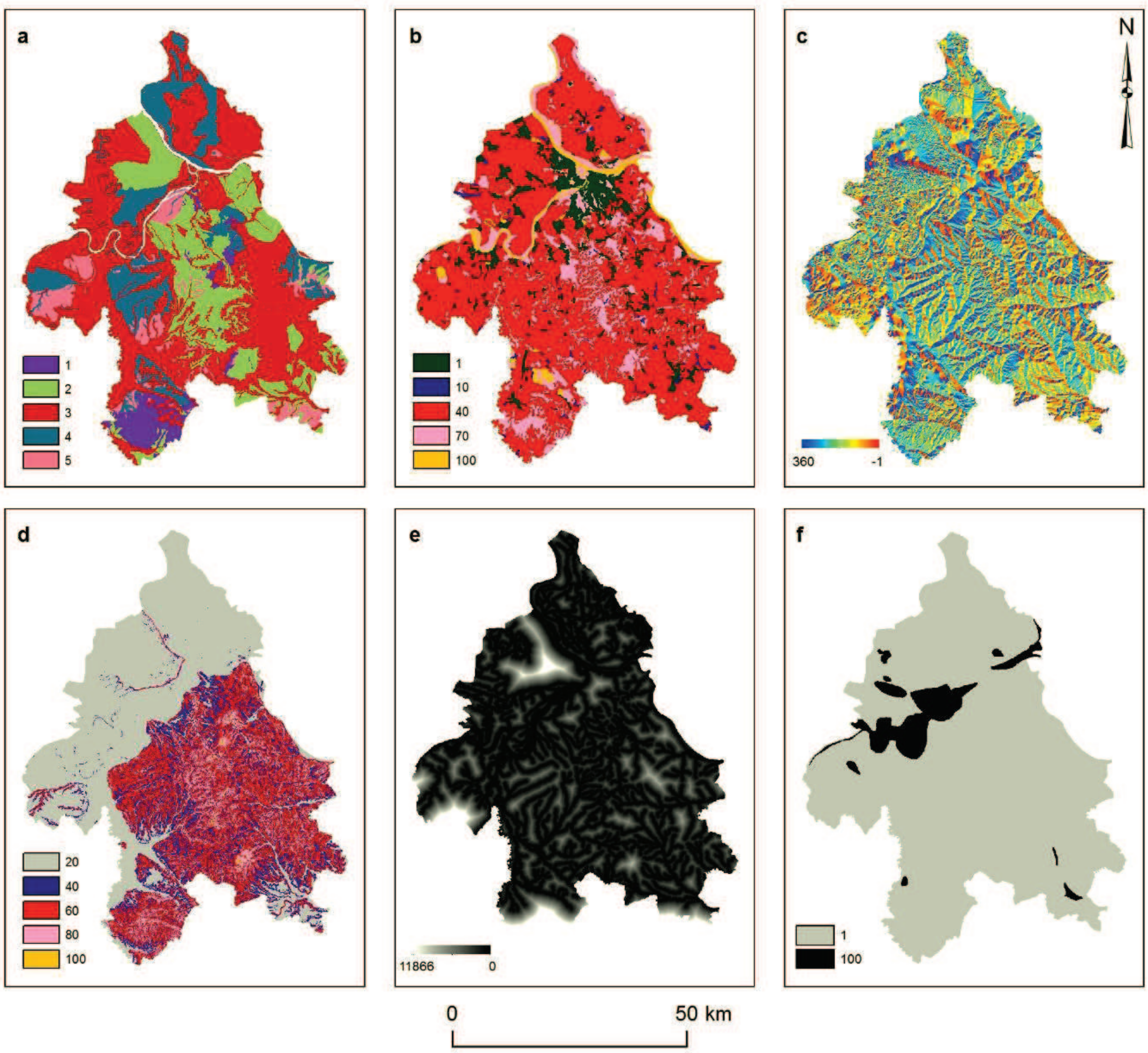

Fig. 2. Dataset: a) Ground compressibility (1=Very Low, 2=Low, 3=Medium, 4=Very High, 5=High); b) Land Cover (1=Built-up area, 10=Suitable for the urbanization, 40=Conditionally suitable for the urbanization, 70=Unsuitable for the urbanization, 100=Very unsuitable for the urbanization); c) Aspect (scale in degrees); d) Slope (20=Very Low, 40=Low, 60=Medium, 80=Very High, 100=High)
e) Hydrology (distance in meters) f) Protected areas (1=Non-protected, 100=Protected)

SLOPE raster is found significant for the model since all of the landslides on the territory of the City of Belgrade are formed on slopes greater than 7° [4]. Therefore, lower slope values as well as flat terrain were considered to be more suitable for building and vice versa (Fig. 2-d).

HYDROLOGY raster was made by buffering (*Euclidian distance* module in ArcGIS 10) digitized occasional and permanent stream flows, (Fig. 2-e). Streams were digitalized from Topographic maps of Belgrade (scale 1:100 000).

PROTECTED AREAS is an attribute raster resulting from compiling two maps: Zones of Sanitary Protection of Fresh Water Sources and Swamp Habitat, both on the administrative territory of the City of Belgrade. Extents of registered features are digitized from existing maps. According to the current legislation and Rule Book for defining and maintaining zones of sanitary protection of sources for water supplying, "zone of sanitary protection is an area around water supplying object, where building and activities of built objects as well as the conducting of any other activity is being surveyed". Swamp habitat is considered to be an area either protected by the decree of Institute of Nature Conservation of Serbia in order to protect biodiversity or simply not suitable for building because of its geotechnical characteristics. Therefore, marked territories from both maps were considered as areas where building is forbidden, hence evaluated as not suitable (Fig. 2-f).

METHODS

Support Vector Machines (SVM) algorithm is a sub-branch of Neural Network algorithms, which has been proven successful in various applications, including different types of spatial modelling [14]. Herein, this state-of-the-art machine learning algorithm has been implemented in a typical supervised classification learning task, which could be briefly described as follows.

The main objective is to exploit the possibility of automating the process of mapping, i.e. making a plausible prediction of spatial distribution of land-use suitability (LUS) classes $C=\{c_1, c_2,\ldots,c_l\}$, where l stands for the number of LUC classes. The procedure assumes that there is a reliable interpretation of LUS classes in one representative region, called training region. Let $P=\{\mathbf{x}|\mathbf{x}\in R^n\}$ be the set of all possible pixels extracted from the raster representation of a given area, then each pixel instance $\mathbf{x}$ is represented by n-dimensional vector $\mathbf{x}=\{x_1, x_2,\ldots,x_n\}$, where each x_i represents one of the n attributes (geology, land cover, stream buffer, slope, aspect and protected areas). A function f_c which maps $P\rightarrow C$ is called a classification if for each $\mathbf{x}\in P$ it holds that $f_c(\mathbf{x})=c_j$ whenever a pixel $\mathbf{x}$ belongs to the LUS class c_j. For a given training area, there is a limited set of m examples $(\mathbf{x}_i, c_j)$, $\mathbf{x}_i\in R^n$, $c_j\in C$; $i=1,\ldots,m$. The machine learning approach tries to find a function $f_c^{'}$ which is a good approximation of unknown function f_c, using only the examples from the training set.

Originally, SVM is a linear binary classifier, but one can easily transform l-classes problem (multinomial classes) into a sequence of l (one-versus-all) or $l(l$-1)/2 (one-versus-one) binary classification tasks, where using different voting schemes leads to a final decision [15], [16]. For the simplicity, let a binary training set $(\mathbf{x}_i,c_j)$, $\mathbf{x}_i\in R^n$, $c_j\in\{-1,1\}$ be considered. SVM algorithm attempts to generate a separating hyper-plane in the original space of n coordinates between two distinct classes (Fig. 3). During the training stage the algorithm seeks for a hyper-plane which best separates the samples of binary classes (classes 1 and –1). Let h_1: **w**x+b=1 and h_{-1}: **wx**+b=–1 (**w**,**x**$\in R^n$, $b\in R$) be the possible hyper-planes such that majority of 1 class instances lie above h_1 (**wx**+b>1) and majority of –1 class fall below h_{-1} (**wx**+b<–1), whereas the elements belonging to either h_1, h_{-1} are defined as Support Vectors (Fig. 3). Finding another hyper-plane h: **wx**+b=0 as the best separation assumes calculating **w** and b, i.e. solving the nonlinear convex programming problem. The best separation can be formulated by defining the maximum margin M between the two classes. Since $M = 2\|\mathbf{w}\|^{-1}$, maximizing the margin leads to the constrained optimization problem and obtaining optimal **w***. Despite of having some instances misclassified it is still possible to balance between the incorrectly classified instances and the width of the separating margin by introducing the positive slack variables ε_i and the penalty parameter C, representing (i) the distances of misclassified points to the initial hyper-plane and (ii) the penalty for misclassified training points, that trades-off the margin size for the number of erroneous classifications, respectively. The goal is to find a hyper-plane that minimizes misclassification errors while maximizing the margin between classes, which is done by solving the optimization problem (in its dual form). Support Vectors for which $C>\alpha_i>0$ condition holds, belong either to h_1 or h_{-1} (their **w*** is a non-zero value). Let x_a and x_b be two Support Vectors ($C>\alpha_a,\alpha_b>0$) for which c_a=1 and c_b=–1, such that b could be calculated from $b^*=-0.5\mathbf{w}^*(\mathbf{x}_a+\mathbf{x}_b)$, so that:

$$f_c^{'}(\mathbf{x}_i) = \mathrm{sgn}\sum_{i=1}^{g}\alpha_i c_i(\mathbf{x}_i \cdot \mathbf{x}) + b^* \quad (1)$$

It is desirable to further increase the dimensionality of R by introducing kernel function which maps $R^n\rightarrow R^d$, $n<<d$, i.e. $\mathbf{x}\rightarrow\phi(\mathbf{x})$, thus allowing the basic linear variant of the SVM classifier (Eq. 1) to be applied in the R^d space, and then retransformed back to the original R^n space. The most common are Radial-Basis Function kernels, with their dimensionality defined by the kernel width γ [16]. Thus, it is possible to model the function by optimizing only two parameters C and γ (hypothetically, on a significantly smaller training sets sizes).

The SVM algorithm has been implemented in Weka 3.7. developer suite, with LibSVM extension package.

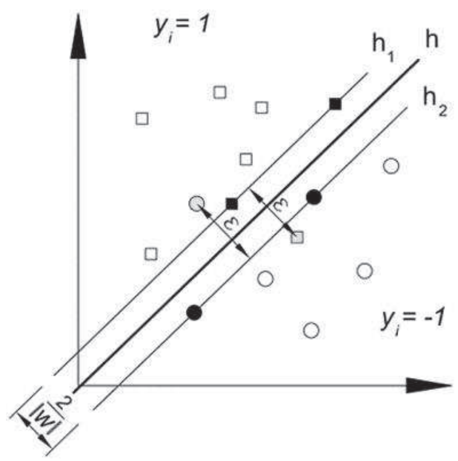

Fig. 3. General binary classification case. Shaded points represent misclassified instances.

RESULTS AND DISCUSSION

The input data have had to be pre-processed to reduce the computational cost of the model. In this context, the following measures were undertaken: nominal data, such as *COMPRESSIBILITY* and *LAND COVER* have been binarized into the appropriate number of dummy variables (0 and 1 class), while ordinal data have been 0–1 normalized. The set finally contained 14 input attributes (4 original and 10 synthetic dummy attributes) derived from the original input set (Fig. 2) and the LUS class reference.

The SVM experiment has been designed so that approximately one third (292918 instances) of the total area has been used for training and the remaining two thirds (977097 instances) for testing of the algorithm. These splits were selected in accordance with the administrative extents of the city territory (MP territory and wider territory of the City of Belgrade), thus disabling strategies for balancing of the LUS classes in training/testing splits and limiting the possibilities for improving the training. The only optimization measure has thus been involved by adjusting the C, γ parameter pair during the optimization stage, done through a 5-fold cross-validation (for both models, MODEL1 and MODEL2 as proposed later) over the training split. This procedure has been involved in order to prevent the overfit problem, which causes overoptimistic training, while yielding poorer results in the test split. Due to the considerable time-consumption (in each cross-validation cycle the classifier building lasted for 10 h, while implementation took another 2 h on conventional machine with the following configuration: Intel i5 processor 3.3 GHz, 16GB RAM, 3GB of which were available for the Java emulation by the 64-bit OS Windows 7) the optimization of the parameters was also rather limited. Only four combinations of the following C, γ pairs were considered (100, 4) and (10, 0.1). Higher accuracies were achieved with the first pair, hence C=100 and γ=4 were the parameters of choice.

Since the model could have been evaluated in the testing area by the incomplete LUS reference, involving only Unsuitable and Very Unsuitable class, the model was first built on the modified training reference, wherein the Conditionally Suitable and Suitable classes (=0) were merged against Unsuitable and Very Unsuitable (=1), leading to a binary classification task. This model was labelled as MODEL1. Subsequently, MODEL2 was proposed as a hypothetic model of the original (all four) suitability classes mapped onto the testing area. The difference is thus that MODEL1 trained on only two classes while MODEL2 trained over all four LUS classes, but they bout could be evaluated by those two classes. The hypothesis implies that if MODEL1 yields a plausible result it is justified to assume MODEL2. MODEL2 thus relied on its ability to distinguish between *Conditionally Suitable* + *Suitable* class versus *Unsuitable* + *Very Unsuitable* class, while distinguishing among all four classes could not be properly validated due to the lack of a complete LUS reference for the testing area. However, if it shows a similar success as MODEL1 in distinguishing *Conditionally Suitable* + *Suitable* versus *Unsuitable* + *Very Unsuitable*, it is most certainly capable of distinguishing among all four suitability classes (*Very Unsuitable*, *Unsuitable*, *Conditionally Suitable* and *Suitable*), giving a complete, predictive model of LUS.

For the easier notation let class *Conditionally Suitable* + *Suitable* equal CLASS0 and *Unsuitable* + *Very Unsuitable* CLASS1. Results of the MODEL1, with 89.28% of accuracy, seemingly sound very convincing and go in favour of the model. Visually (Fig. 4) it is also a suggestive model, which manages to capture some regularity in the pattern distribution and follows the trends from the training area. However, the shear figures of the class-specific performance measurement are rather unbalanced (Table 3), because MODEL1 seems to map CLASS0 much more efficiently than CLASS1. Very high True Positives rate (TP rate) reaching 0.98 suggests solid precision for mapping CLASS0, while TP rate for CLASS1 reached only 0.04, yielding average of 0.89 for both classes. In the same time, False Positive rate (FP rate) was high in CLASS0 and low in CLASS1, which gave very poor performance considering some FP-TP rate trade-off measurement (such as ROC Area for instance), making the MODEL1 result plausible but disputable.

Table 3. Contingency Tables of MODEL1 and MODEL2

		LUS reference					**LUS reference**	
		true	false				true	false
MOD-EL1	positive (CLASS0)	868780	20013		MOD-EL2	positive (CLASS0)	829019	77251
	negative (CLASS1)	84737	3567			negative (CLASS1)	59545	11047

Nevertheless, a relieving circumstance is that the size of CLASS1 was much lower than that of CLASS0, which is a common case in the spatial prediction framework. Herein, the CLASS1 counted less than 10% in both, training and testing splits. This practically means that out of 88304 CLASS1 instances, only 3567 were correctly classified but the class size which it was working against (CLASS0) was much bigger, nearly 9 times as much. This aspect has been considered in MODEL2, and as expected, some improvements were noticed. Thus, the outcome of MODEL1 can be taken with certain reserve. Perhaps the best way to truly evaluate the performance would be with some fuzzyfied similarity approaches, such as Fuzzy Kappa statistics [17].

MODEL 2 has been trained under the same experimenting design, i.e. using the same C, γ parameter pair (100, 4) after 5-fold cross-validation, and the same training/testing splits. As indicated above, the balance of the classes was slightly more convenient, and accordingly, the results have been improved (Figure 5). In MODEL2 overall accuracy reached 85% which is similar to MODEL1, but has significantly better TP/FP rates for CLASS0 and CLASS1 (0.91 and 0.84, respectively). Particularly encouraging are the trends and patterns which are extending from the referent LUS map (the bold contoured – training area in Fig. 5), which is evident from the visual inspection of the map (note the continuation of the units bordering the training area in Fig. 5).

The initial post-processing (filtering by 8x8 majority filter) did not resulted in higher precision, but the fact that there are some logical errors (class islands, pixelation and so forth) which should be exploited by some more advanced filtering scheme.

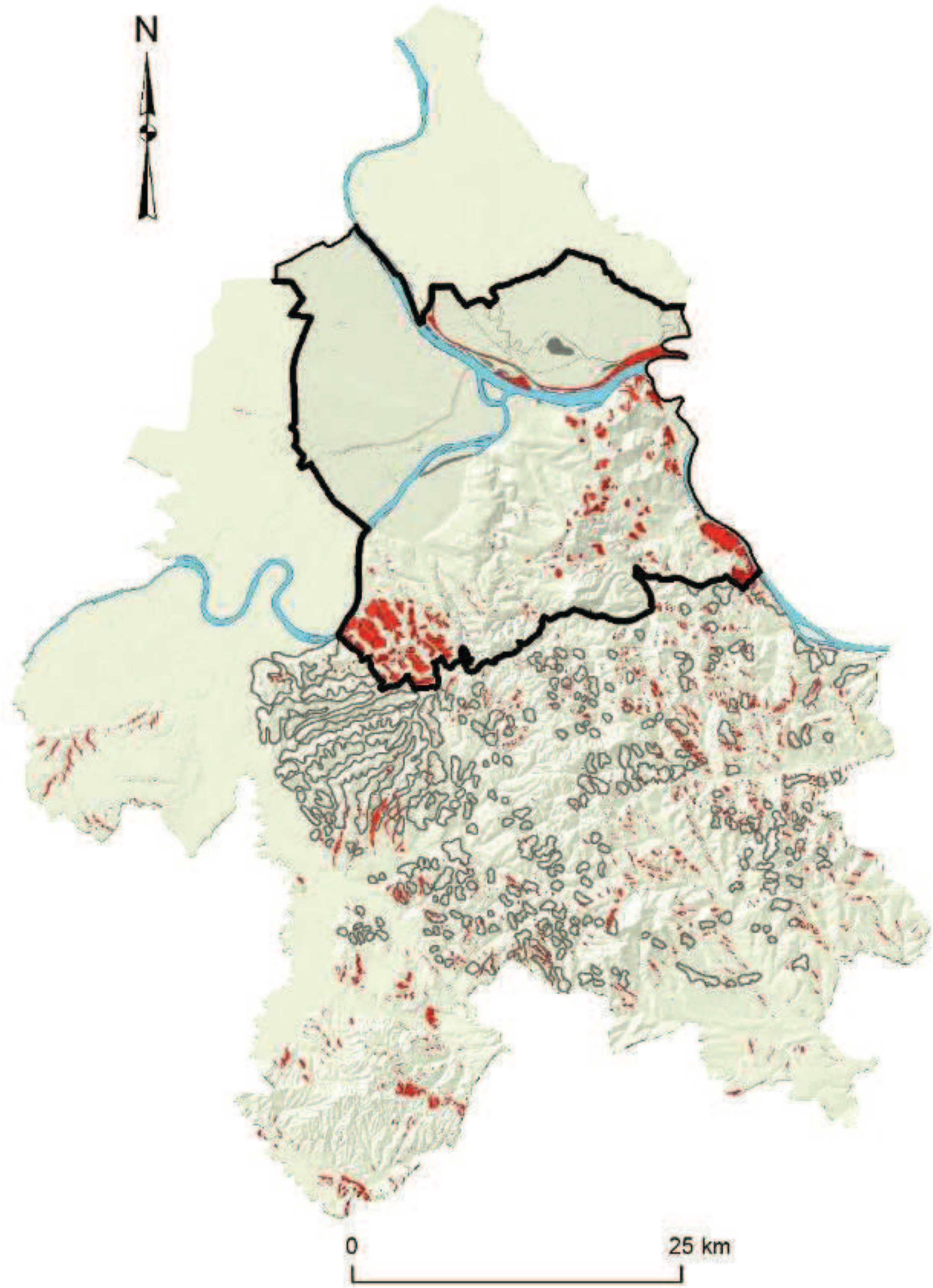

Fig. 4. SVM MODEL1. LUS CLASS1 of MODEL1 is shown red. Referent (testing) LUS CLASS1 (*Unsuitable + Very Unsuitable*) shown in black contours. Training area (MP area) is contoured bold black.

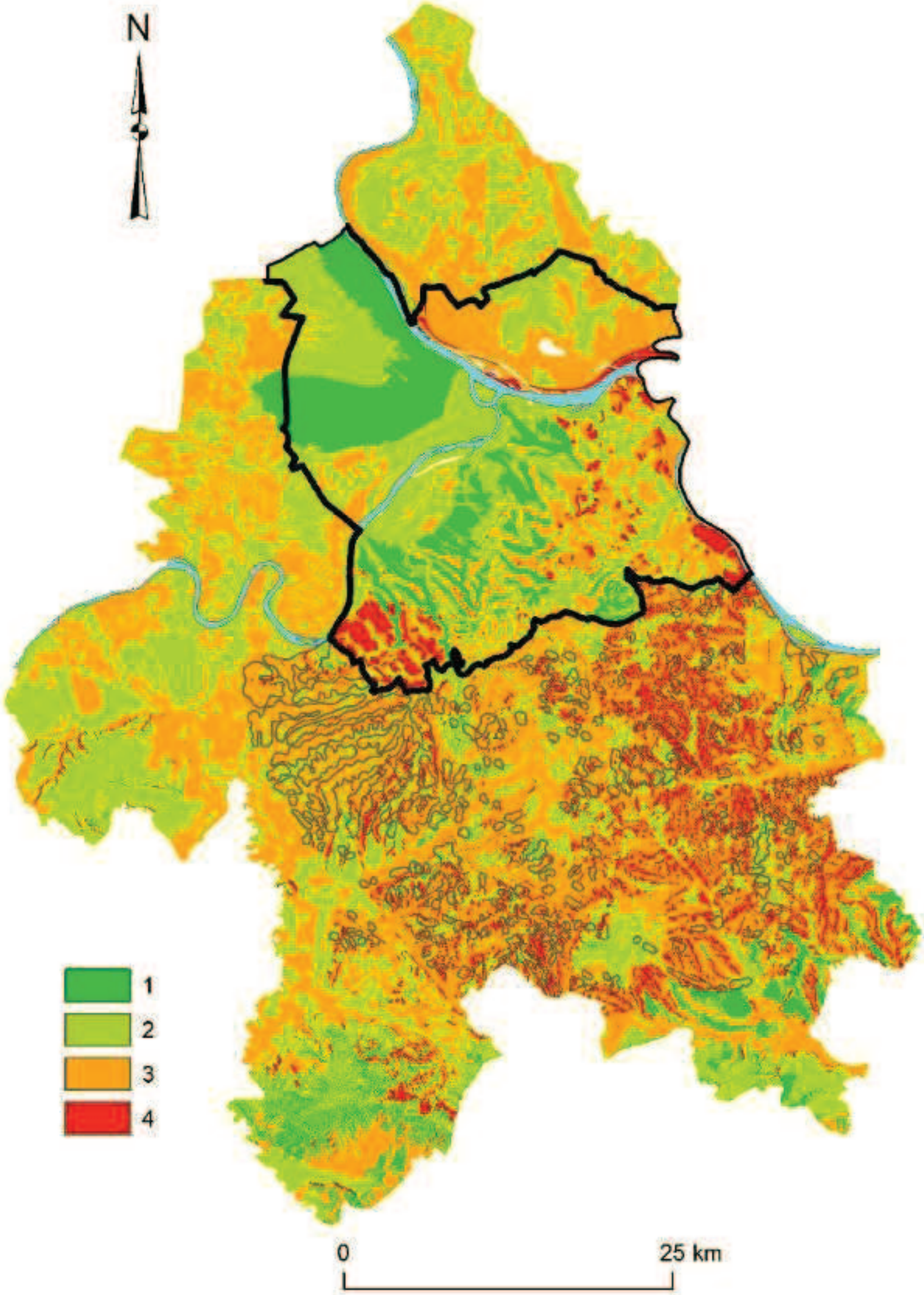

Fig. 5. SVM MODEL2. 1=*Suitable*, 2=*Conditionally Suitable*, 3=*Unsuitable*, 4=*Very Unsuitable*. Referent (testing) LUS CLASS1 is shown in black contours. Training area (contoured bold black) shows a present LUS map based on MP for the City of Belgrade.

CONCLUSION

The study completes a typical supervised machine-learning-based classification task, targeted at prediction of the spatial distribution of referent LUS classes on the area with unknown LUS. Modelling design followed a typical training/testing configuration by using the state-of-the-art SVM machine learning algorithm. The results prove convincing, reaching high accuracies for some classes, allowing a speculation on the actual application of the model (if the interest of the corresponding city service proves realistic). The biggest shortcoming of the model concerns the *Unsuitable + Very Unsuitable* class, which does not yield significant accuracy. In this context, some progress is evident in transiting form MODEL1 to MODEL2 which has to be related to the fact that class balance plays important role in the learning process, thus favoring the result of MODEL2 which has more classes than MODEL1, and therefore a better balance of the class populations available for learning. However, this is an on-going research and there are several directions to look for improvements. Firstly, more advanced post-processing schemes could be involved to eliminate logical errors and therefore raise the modelling performance. Secondly, input dataset could be enriched with some additional data, e.g. water table levels, or data from borehole sampling (if these become at disposal by the courtesy of corresponding city services). Finally, the model could be improved by more thorough optimization of the classifier parameters, which will require much longer experimenting costs (time-wise).

ACKNOWLEDGMENTS

The research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia. Project № TR 36009.

Authors would like to thank Ivica Tornjanski, dipl. ing. geol. and Vesna Tahov dipl. ing. geol. from Urban Planning Institute of Belgrade, for providing us necessary data for modelling.

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DEFORMATION MONITORING WITH SEMI-AUTOMATIC PROCESSING OF INSAR ARTIFICIAL REFLECTOR DATA

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Abstract

InSAR is a method allowing to monitor Earth-surface deformations using satellite data. In our project, we use this method to monitor deformations in the area of Northern-Bohemian coal basin (between the Most and Chomutov cities). Due to a significant decorrelation of the area, there were 11 corner reflectors installed in the area, in order to provide a coherent reflection back to the satellite.

However, due to the fact that the reflectors are about 3-5 kilometers far away from each other, the problem of phase unwrapping (ambiguity resolution) is not trivial. In our project, we have 15 TerraSAR-X scenes available up to now, with the interval of about 33 days. We process only the reflector information, with interpolated coordinates and phase. The processing is performed partially manually, partially automatically.

Software packages developed for InSAR are not suitable for our problems due to various reasons; we use them only for certain auxiliary tasks.

Keywords: synthetic aperture radar, interferometry, persistent scatterers, artificial reflectors

Recommended Citation: HLAVÁČOVÁ, I., HALOUNOVÁ, L., SVOBODOVÁ, K. (2013) Deformation monitoring with semi-automatic processing of INSAR artificial reflektor data. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Synthetic aperture radar (SAR) interferometry (InSAR) is becoming a well-known technology for deformation mapping. Instead of in-situ measurements, often performed for each point independently, it uses satellite radar data to process a whole area of interest at the same time. However, the method gives reasonable results only in city areas where there are many artificial objects. In the countryside, we often encounter the decorrelation effect: the microproperties of the surface change between the two acquisitions (in the order of the radar wavelength, i.e. a few cm).

Conventional InSAR allows to process two radar images, with the result of deformations estimated to occur between the two dates of acquisition. This is often considered as insufficient, and therefore the persistent scatterers (PS, or PSInSAR) method was developed, processing a series of scenes, resulting in the deformation series or estimated deformation velocity (more often). In order to deal with the limited amount of computational memory, disc space and also computational time, not all pixels of the scenes are processed, only those that are considered more precise or coherent (in the first iteration, pixels with high intensity and low intensity variability are selected).

A key problem of the InSAR method is phase unwrapping. The principle is that the deformations are estimated as a difference in phase between the two scenes (corrected for other influences, such as flat-Earth and topography, both computed for the known orbit parameters and a given digital elevation model (DEM)). However, phase is (by definition) wrapped in the $(-\pi,\pi)$ interval, though the deformation is a real number. Therefore, the phase must be unwrapped in order to stand for the deformation, and the multiple of 2π to be added to the phase is ambiguous.

Phase unwrapping is the method for estimating the phase ambiguity. The problem is relative, reference both in space and time must be specified. Then, it is usually assumed, that the unwrapped phase difference between two neighbouring points and two consecutive scenes is always in the $(-\pi,\pi)$ interval. This statement makes a limitation to the maximum detectable deformation and depends both on the scene resolution (resp. density of the processed points) and the interval between the particular acquisitions.

In addition, due to noise, the condition of phase difference between two neighbouring points cannot be always fulfilled. Different methods (and implementations) of the phase unwrapping problem differ in the way of dealing with this problem. Usually an independent information (such as coherence) is used to make cuts, prohibiting the phase unwrapping path to cross them.

In our project, we are monitoring deformations in the Northern-Bohemian coal basin, between the cities of Most and Chomutov. There is a huge open-pit mine in the area, with some villages and industrial zones around it. Most of the processed area of interest is decorrelated due to vegetation (the open-pit mine and the Ore mountains). Therefore, there were 11 artificial reflectors installed in the area, providing a strong reflection back to the radar, and therefore expected to be coherent.

By misunderstanding, the reflectors were not designed as trihedrals, but as dihedrals, and therefore the requirements for orientation accuracy are stronger. Also, the intensity of the reflected signal varies by two orders, and also the accuracy of the estimated deformations varies a lot.

METHODOLOGY

For processing, we use data acquired by the TerraSAR-X satellite (operated by DLR), in the StripMap mode with resolution of approx. 3x3 m. The scenes are acquired usually once per 33 days, with some exceptions, on the descending track, early in the morning. The acquisitions have been performed since June 2011, so up to now, there are 15 scenes available. The incidence angle is the lowest possible - about 30 degrees.

In the image, the reflector looks as a group (with a shape of a cross or rectangle, depends on the strength of the reflected signal) of very bright pixels and can be usually found by the naked eye. This is not the case of reflector no. 9, which is situated in an area affected by layover. Here, the reflector cannot be found by the naked eye, but its position can be estimated using the *ptarg* script, enclosed in the GAMMA software [1].

The *ptarg* script enables to estimate the position of the reflector with a subpixel precision. Better position precision allows better evaluation both of the phase (which is interpolated) and other phase influences (flat-Earth phase and topographic phase), which are then subtracted. The interpolated intensity reaches from approx. $1 \cdot 10^6$ (reflector 8) through $6 \cdot 10^7$ (reflectors 1, 6) to $1 \cdot 10^8$ (reflector 9, situated in the layover area). The interpolated positions of each reflector also vary among the images: standard deviations reach from 0.08 to 0.15 px in the range direction, and are a bit smaller in the azimuth direction. It can be said that the lower the intensity, the higher position standard deviation. The variability can be caused either by inaccurate orientation of the reflector, or by the surroundings of the reflector.

The layout of the particular reflectors in the area of interest is shown in figure 1.

Reflector 1 is situated in the industrial area Komořany, among buildings. Reflector 2 is situated right inside the open-pit mine, near a small house desgined for various measurements. Reflector 3 is situated in a built-up area near the industrial zone Záluží, reflectors 4 and 5 are situated in villages Horní Jiřetín and Černice. Reflector 6 is situated at the edge of the open-pit mine. Reflector 7 is in the Jezeří castle, more than 100 m above reflector 6. Reflector 8 is - similarly to reflector 6 - at the edge of the open-pit mine. Reflector 9 is in the forest near the Jezeří dam, reflector 10 is in the village of Vysoká Pec and reflector 11 is in the industrial zone near the Vrskmaň village.

The DEM used

InSAR method can be used either for DEM generation (if there are no Earth-surface deformations in the area of interest), or for deformation monitoring. In the latter case, a DEM is neccessary for estimation and subtraction of the topography phase component. Its value depends significantly on the orbit setout (perpendicular baseline) between the two scenes.

First, we tried to use ASTER GDEM V1 [2], but the resulting interferograms were very noisy due to the noisy DEM. Therefore, we use the SRTM (Shuttle Radar Topography Mission) DEM acquired in X-band (processed by DLR) [3]. However, this DEM does not cover the whole area at our latitude. Fortunately, there are no reflectors in such a 'hole', but the 'hole' is in the bottom-left corner of the area of interest (figure 1), covering the (coherent) city of Most. In future, we plan to use ASTER GDEM V2, known to be more precise.

In addition, the SRTM DEM was acquired in 2000 using interferometric technique. Since that time, there have been many changes in the area of the open-pit mines, resulting in false 'DEM-error phase changes'. In order to avoid these errors (in order to be able to estimate atmospheric contribution), the SRTM-X DEM was combined with a DEM acquired using aerial photogrammetry (available only for the area of open-pit mines) received from the Czech Coal company. Unfortunately, the photogrammetry DEM is not available for the 'hole' in the SRTM-X DEM.

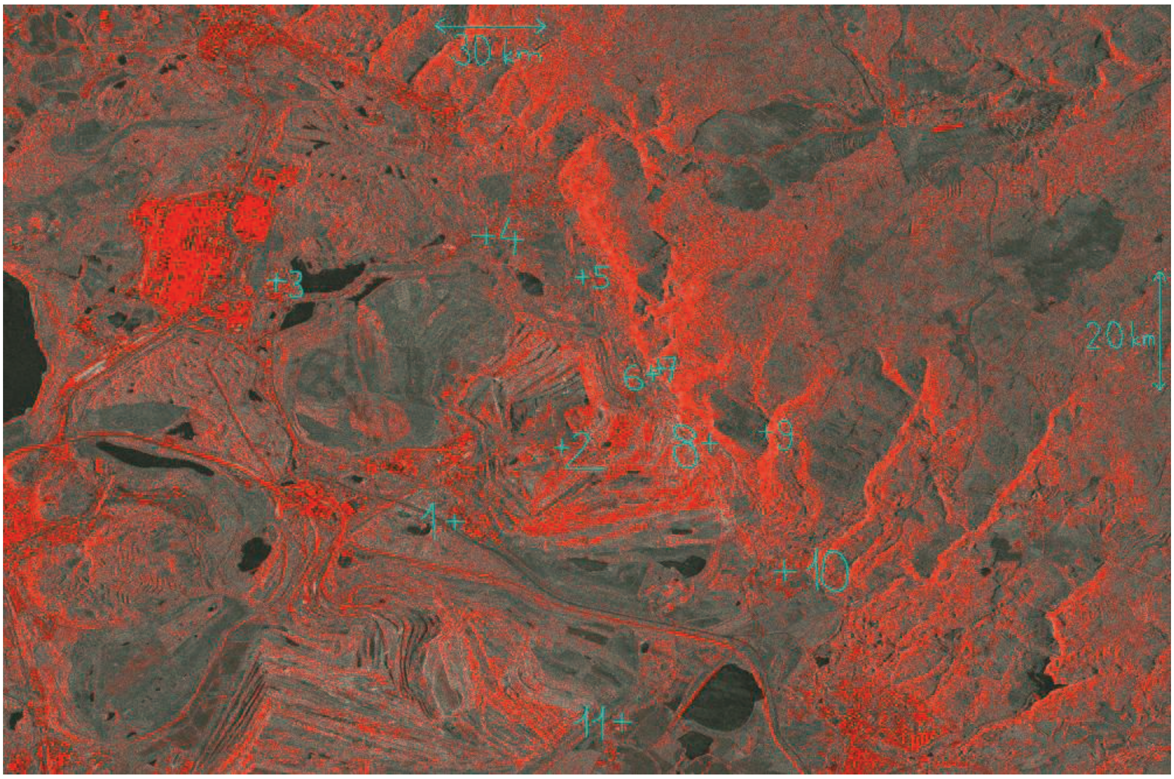

Fig. 1. The area of interest with the positions of the individual reflectors (1-11). The image is flipped by the vertical axis and a bit rotated. Red points signify higher intensity, and therefore lower probability of decorrelation. (c) DLR.

Results from PSInSAR processing

There are several software packages for PSInSAR processing. We use two of them: the GAMMA software, which does not give reasonable results for 15 scenes (too noisy), and StaMPS [4]. StaMPS gives reasonable results in our case since the time we have had more than 8 scenes available; however, it has some disadvantages: the corner with no DEM data is processed as the altitude was 0; and although the reflectors were selected in the first step to have enough quality, they were excluded during consecutive processing, so we do not have the results for the reflectors.

Figure 2 shows the deformation estimated by the StaMPS package in the area of interest: as expected, the most area with highest subsidence is the Ervěnice corridor, with approximate deformation of about 1-2 cm/year.

Semi-automatic processing

In order to get the deformations for the particular reflectors, we were forced to perform manual processing; however, due to its time demands, some parts of it were automatized.

First, the coordinates of the reflectors are estimated in the GAMMA *ptarg* script, together with the interpolated phase and intesity. It is expected that the interpolated values are more accurate than the values for the whole pixel [5]. Then, these values are imported into MATLAB, where the phase corrections (flat-Earth phase, topographic phase) are computed (baseline legth is also interpolated from values computed by GAMMA *base_perp* script) and subtracted for all possible scene pairs (with 15 scenes, there are 105 interferograms).

A reference scene (for temporal referencing) is selected as a scene approximately in the middle of the time series, a scene with no visible atmospheric effect and a scene without significant problems (will be dealt below). In our case, it is the April 2012 scene (the tenth in the series).

For each reflector pair, automatic adjustment is performed, together with ambiguity corrections. First, all phase differences (for all reflector pairs) are wrapped into the $(-\pi,\pi)$ interval. A set of 4 scenes is then picked up, around the reference scene, and the adjustment is performed, interferograms with high residues are corrected for 2π multiples. In the next iteration, one more scene is added to the current set, the adjustment is performed again, with high residues only belonging to the interferograms with the new scene. This way, all scenes are added to the set step by step, and the adjustment is performed for all of them.

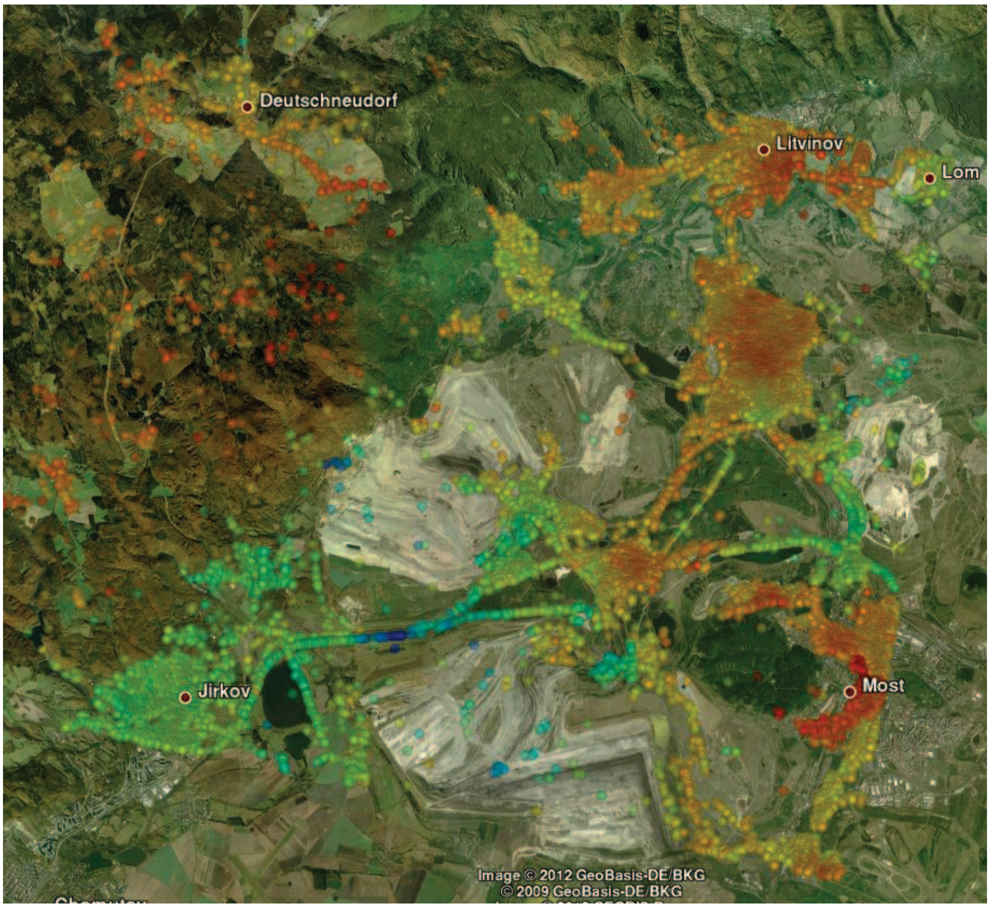

Fig. 2. Estimated deformation velocities for the area of interest using the StaMPS software. Dark blue corresponds to subsidence of 13 mm/year, dark red corresponds to uplift of 8 mm/year. The bottom-right corner (image is geocoded) corresponds to no DEM data, i.e. irrelevant results. (c) DLR and Google Earth.

Then, spatial consistency is enforced. From all reflector pairs, triangles are constructed, and within each triangle, the estimated deformations are summed up: the expected sum is zero for all acqusition times. The real sums are either zero, or a multiple of 2 π. The process of estimation which reflector pairs are to be corrected for which scenes, is still performed manually; we plan to do it automatically, but it has not been implemented yet.

If a triangle has a non-zero sum, it is never clear which reflector pair is to be corrected. Or, the sum in a triangle can be zero and there may be two scenes to be corrected. To simplify the considerations, which reflector pairs should be corrected, all the triangles are 'decomposed' into the reflector pairs again and if a triangle sum is non-zero, such a sum is attributed to all reflector pairs in the triangle. Then, for each reflector pair, the number of non-zero triangles are summed up, and the reflector pair with the highest number of non-zero triangles is corrected. The process is iterative.

However, the process is not as simple as it looks. The process is performed independently for each acquisition time; and due to the fact that the set is referenced in time, it may happen that the reference scene is 'right' to be corrected, not the other ones. Also, for some scenes it is sufficient to correct a small number of scenes (easily identifiable), while for other scenes it is not easy to identify the scenes to be corrected (some must be just chosen) and the number of corrected reflector pairs may finally reach 15-20. In our project, this is the case of scenes acquired in July 2011, December 2011 and August 2011 (in a smaller scale). In a case of correction, the correction concerns all interferograms containing the one scene to be corrected and one reflector pair.

Expected deformations in the area of interest are lower than 1 cm per year (actually, levelling results show that one of the reflectors moved 2 cm up in three years, the other reflectors are moving more slowly).

The last step is to review the deformation time series for all reflector pairs, and in some cases, the phases are corrected for a multiple of π in this case, the corrections are performed for all interferograms containing the scene and all reflector pairs containing the reflector. This step is also performed manually, we also plan to automatize it, together with an evaluation of the hops in individual time series.

Phase ambiguity 2 π corresponds to 15 mm for the TerraSAR-X data. That means that 2 π corrections are by 15 mm deformations, which is relatively high value, considering the time between acquisitions, which is usually 33 days. Therefore no large hops in the time series are expected.

RESULTS AND DISCUSSION

Unfortunately, it is impossible to get rid of all hops higher than π, because of the spatial consistency condition. In addition, in some cases there are also hops up and down lower than □, which are also considered unreal. We have therefore decided to give away the estimated deformations for the most noisy acquisition times: July 2011 (heavy rain) and December 2011 (thin layer of snow, maybe also snowing; reflectors were cleaned except for refl. 7).

In some cases, the results are disputable. For example the end of the time series (June-September 2012) for reflector 8: it goes straight up with regard to reflectors 5,6,7 (which are situated close to it), but there are large hops with regard to reflectors 10 and 11, which are also situated close to it. If the hops were corrected, the situation would turn around and the hops would be in relation to other reflectors. In addition, it seems that reflector 8 is uplifting also at the beginning of the time series.

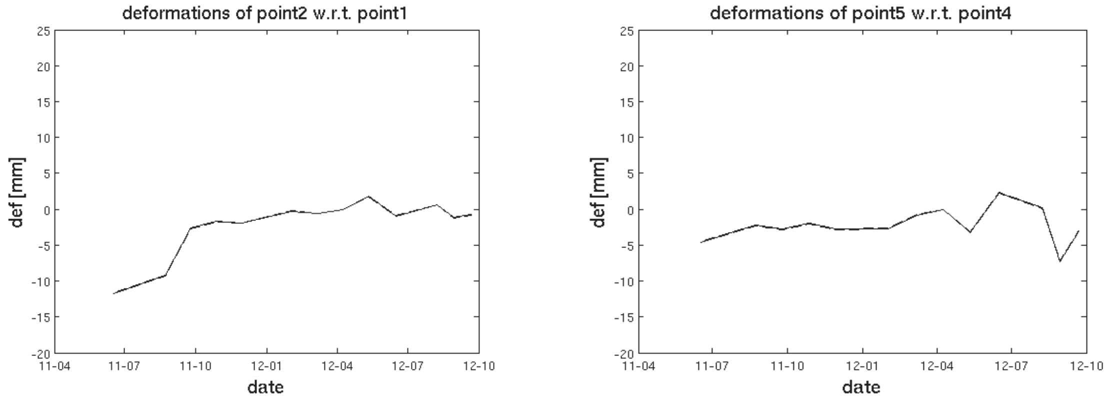

Fig. 3. Estimated deformations for reflector pairs 2-1 and 5-4. The dashed lines (if visible) stand for twice the estimated standard deviation.

A similar case is with the scene acquired in August 2011 for reflector 9.

However, it seems that reflector 2 (w.r.t. the others) uplifts at the beginning of the time series (June-September 2011) and then it stays approximately constant. It is also possible that it subsides at the same time period (the subsidence would be a little smaller, with a small uplift in September). It is also possible that the August 2011 scene should have been also excluded from the adjustment due to problems with spatial consistency (as the scenes acquired in June and December 2011 were).

It also seems that reflector 7 subsides at the beginning of the time series (June 2011 - March 2012) by a centimeter (approximately), but at the end of the time series, it goes back up to the original level. Reflectors 3 and 4 (close to each other) seem to oscillate up and down at the end of the time series (w.r.t. refl. 1).

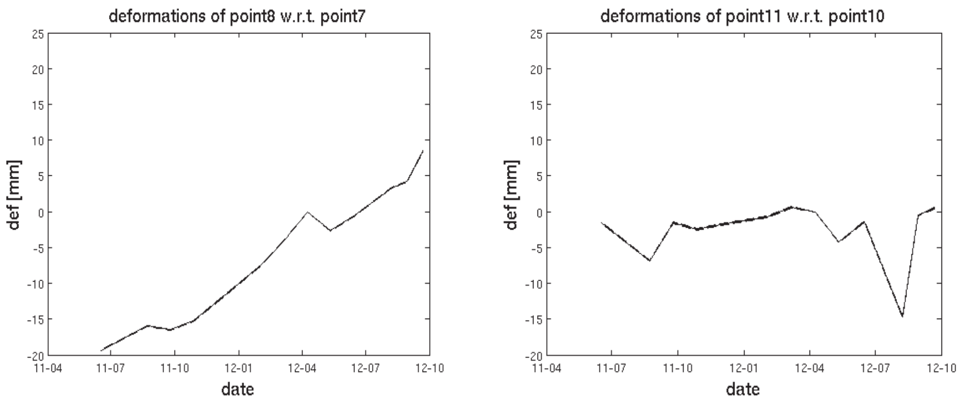

Fig. 4. Estimated deformations for reflector pairs 8-7 and 11-10. The dashed lines (if visible) stand for twice the estimated standard deviation.

The causes of subsidence/uplift are not known. Most of the reflectors are situated in areas expected to be stable: this is the case of reflectors 1, 3, 4, 5, 7, 9, 10, 11. However, levelling results (unfortunately, from a different time period than our measurements) show a slight uplift of reflectors 1, 11 (and a more significant uplift of reflector 2). Some deformations (especially reflectors 2, 6, 8) may be attributed to a changing soil humidity.

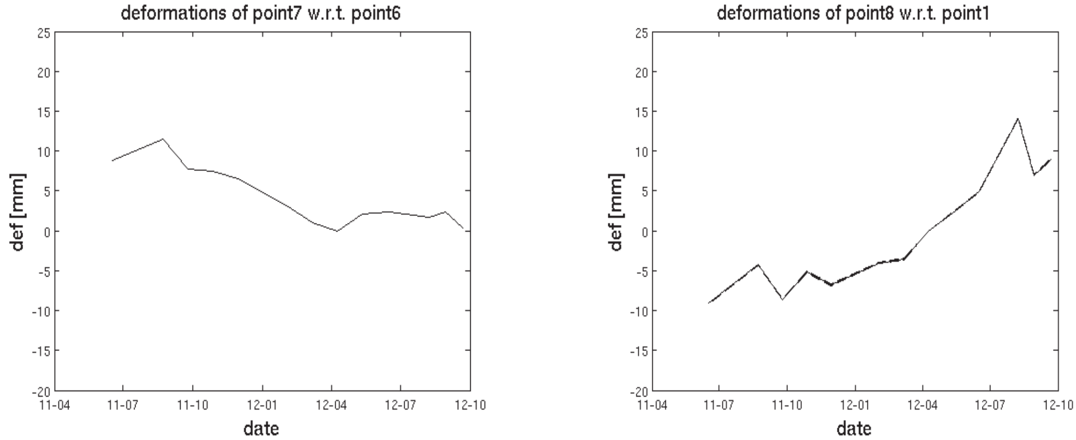

Fig. 5. Estimated deformations for reflector pairs 7-6 and 8-1. The dashed lines (if visible) stand for twice the estimated standard deviation.

The estimated deformations are still in satellite line-of-sight (LOS). The vertical deformations are expected to be lower by approx. 15% (incidence angle is 30 degrees).

CONCLUSIONS AND FUTURE WORK

The key problem of the InSAR technique is the ambiguity resolution. This is the case even in our project, with as many as 15 scenes, and with the expected deformations lower than 1 cm per year; with the radar wavelength of 3 cm, corresponding to the ambiguity cycle of 15 mm and temporal resolution of approx. 1 month. Still, there are some scenes which need to be excluded from adjustment due to high errors - they can make the ambiguity resolution process even more difficult.

We can never say that a point is stable w.r.t. another one. In all cases, there are some deformations detected, and they are much higher than their estimated standard deviations. However, the problem is the interpretation of the hops: if they are real (caused e.g. by soil humidity variations or other effects, which can be also detected by levelling), or not (caused e.g. by atmospheric delay variations, differences in orbit situations, or even by the fact that the center of the reflector was found at different coordinates and therefore interpolated for a different position).

Concerning the atmospheric delay variations, we found a significant (atmospheric) trend for two dates of acquisition: June 2011 and May 2012. During the spatial consistency enforcement, there were smaller problems with these two scenes, and therefore these scenes were not excluded. Much more significant problems were with scenes acquired in July 2011 (excluded), August 2011 (finally not excluded) and December 2011. Another problematic scene was the one acquired in August 2012 (here, we still wait for the scenes to be acquired in future, in order to decide whether to exclude it or not). During the December 2011 acqusition, there was a slight layer of snow (the reflectors were cleaned except for refl. 7, but they were cleaned few hours before the acquisition, not right before due to technical reasons). During the July 2011 acquisition, there was a heavy rain, possible to bring noise into the phase delay (with such a short radar wavelength).

For comparison, there are levelling results available. The reflectors were installed in 2008 and levelled approximately once a year. The accuracy is not known. But from levelling, it is known that reflector 2 uplifts approx. 2 cm per 3 years (the last levelling date is September 2011), reflector 11 uplifts by 5 mm per 3 years and the other reflectors uplift or subside in a smaller scale. These are much smaller amounts of deformation than estimated from InSAR, but their temporal resolution is also much smaller; so the results may be OK.

In future, we plan to automatize the process of ambiguity resolution, especially the step of the spatial consistency enforcement. However, it is not yet clear how the disputable cases will be solved: the automatic procedure will probably apply only for the simple cases.

Also, we plan to get into the StaMPS sottware in a way to be able to process the reflector information.

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QUANTITATIVE EVALUATION OF SOCIALLY EXCLUDED LOCALITIES. CASE STUDY OF OSTRAVA CITY.

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Abstract

Socially excluded localities represent a serious problem for both the society and the local administration. They require careful monitoring of their origin and development in order to take appropriate measures. This paper focuses on the quantitative evaluation of socially excluded localities in Ostrava. Different aspects were used for the evaluation: economic, societal, demographic, urban, health, environmental and spatial. Three categories of localities were distinguished on the basis of a joined expert evaluation of indicators and each socially excluded locality was classified. Subsequently, a characteristic set of indicators' values for each category is provided. The proposed set of indicators allows characterizing of problematic localities (and their searching) and also revealing of the symptoms' diversity which is useful in terms of monitoring localities, designing appropriate measures, and monitoring their impacts. The most important findings are related to the strong population growth in some localities with poor housing conditions and the likely health risks. The quantitative measurement of single aspects allows determining other problematic localities in the territory that have not yet been uncovered within the expert evaluation.

Keywords: social exclusion, quantitative evaluation, microanalysis, Ostrava, unemployment

Recommended Citation: INSPEKTOR, T., HORÁK, J., IVAN, I., HRUŠKA-TVRDÝ, L., KRAUSOVÁ, A. (2013) Quantitative evaluation of sociály excluded localities. Case study of Ostrava city. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Social exclusion and social segregation are associated with various socio-economic, structural and institutional reasons discussed by many authors. They have identified two basic categories - external (structural) and internal (personal) causes.

External causes (effects) are identified as those that are out of reach and control of excluded people who are unable to influence (or only with difficulties) them by their own actions [1]. External causes originate from common societal conditions or arise from actions of people who are not excluded. Examples may include the labour market, housing policy, social policy, self-government policy concerning social sphere, ethnicity, racism, discrimination, etc. These structural reasons can also be classified into two groups - failures of civic integration and failures of economic integration [2].

Internal influences represent the results of immediate decisions of socially excluded people. They can directly stimulate the status of social exclusion and to control it. Such individuals experience loss of working habits during long-term unemployment, long-term inability to manage money and to meet their financial obligations or apathy and low motivation to deal with their own problems [1].

The spatial concentration of these factors multiplies their final effect. One of the most important indicators of these localities is unemployment which influences the level of exclusion in various dimensions [3]. This is incorporated with the dependence of local residents on social benefits or income from illegal activities [4], [5].

Different causes for formation and development of socially excluded localities are reflected in dimensions of social exclusion which document conditions and specific profile of each locality. Economic, social and political dimensions are usually used in various approaches of authors. Other aspects may be individual, group or spatial dimension [6]; cultural dimension, the exclusion from safety and mobility and symbolic exclusion [2].

The consequence of social exclusion is the growing trend of residential separation especially in metropolitan areas and large cities [7] which is caused by the process of spatial differentiation in society [8], [9]. According to the spatial scale, it is possible to distinguish spatial segregation between core cities and their background in the metropolitan areas and urban regions, between districts within cities, between residential blocks [10], [9] or an segregation into smaller units (but respecting the requirement of a minimum group size).

Socially excluded localities are featured and categorized by various authors according to local conditions. Usually their identification and description originate from thorough studies conducted by experts. This approach may suffer from insufficient regularity of evaluations (even worse if they are provided sporadically, influenced by limited financial sources) and time delays between carrying out the survey and delivering results to decision makers. The expert based evaluation cannot run continuously. The local policy prefers evaluations fitted to local conditions, but in such cases some criteria may lack transparency, ability to independent re-evaluation, universality or applicability in other cities or regions. If some categorisation of localities is provided the questions arise concerning utilizable number of classes, their homogeneity, temporal stability of the classification system and the stability of localities' memberships.

The aim of the research is to select appropriate quantitative indicators for continuous monitoring of socially excluded localities, quantify the state and development of localities and evaluate a classification of localities based on such indicators. This approach is demonstrated on evaluation of socially excluded localities in Ostrava identified by experts in previous years [11], [12].

SELECTION OF MONITORING INDICATORS

Due to the highly variable size of explored localities (ranging from 0.2 hectares for Zelezna Street to 14 ha for Liscina) and not corresponding boundaries it is difficult to use administrative or statistical units including the smallest enumeration districts. Possible adjustment of the boundaries of the standard territorial division would lead to the dilution and emanating of differences. It restricts the use of statistical census. In addition, localities are often subject of relatively dynamic development and therefore a ten-year census interval with roughly a two-year delay to the publication of the results may not be realistic for the purposes of monitoring localities. The preference is given to indicators based on data from registers of public sector (local authorities, labour offices, social authorities, police etc.) which offers a fine spatial and temporal resolution.

Utilisation of such registers requires to run processes of harmonisation and geocoding of data due to the common absence of direct georeferencing in any coordinate system. Harmonisation represents unification of structures and unification of address description, including identification and replacement of abnormal names [13]. During geocoding, data is aggregated to address points which are the smallest spatial unit for further spatial processing. The point based location enables to individually geographically bound localities under the study. In this way it is possible to calculate accurate enumeration of quantitative indicators in selected area and even to study an internal spatial distribution.

Selection of indicators originates from following description of main symptoms of social exclusion in our environment:

Economic aspects include the lack of income, increased unemployment, higher debt, dependence on non-insurance social benefits, increased occurrence of usury, illegal employment and illegal income. In addition to these individual problems, it is possible to describe also group (external) aspects such as limited investment in housing and low operational funding from the owners.

Economic aspects are only monitored with the following indicators of unemployment due to data scarcity: share of unemployed to the number of people in the productive age (PUC_OPV) which is highly correlated to the rate of unemployment, share of registered unemployed with a low level of education (PCVABC), share of long-term unemployment (PCE12), share of health handicapped unemployed (PCZPS), specific rate of unemployment until 25 years, specific rate of unemployment over 50 years.

Social aspects are expressed by presence of separation symptoms based on ethnicity, culture, variations in crime and violence, higher rates of radicalism and extremism, low levels of education, higher rates of apathy and negative perceptions of their housing. Examples of group symptoms include lower levels of self-organization of the community, weaker external assistance, or stigmatization of places from the majority society.

Societal aspects are represented by evaluating education, crime and the level of self-organization. The educational level is estimated by the above indicator PCVABC. The intensity of crime is evaluated by an index of crime [14] from 2009 (specifying places of incidents, not residence of offenders). The level of self-organization is evaluated by experts.

Demographic aspects of the problematic spatially segregated localities can be expressed by increased birth rate, lower life expectancy, high proportion of pre-productive population, the larger size of families, and sometimes even higher number of incomplete families. It is possible to assess age structure, expressed by age pyramid and its type, the average age and age index from the demographic aspects.

Urban aspects are determined especially by overcrowded housing, deprived housing stock and low facilities of household and locality. Urban aspects were only evaluated by experts (condition and equipment of flats).

Health aspects of segregated localities mainly include symptoms of the drug problem, higher epidemiological risk and a higher incidence of health handicapped children. Evaluation of the occurrence of health handicapped children and the higher occurrence of collected syringes was accomplished.

Environmental aspects include worsened ecological status of the locality due to e.g. proximity of dumps, landfills or polluted industrial areas, but also deteriorated internal conditions of community such as unwholesome common places.

The environmental aspects were not included in the monitoring due to the fact of longer stability environmental conditions (not needed to monitor them frequently).

Spatial aspects usually point out the appearance of some of the above mentioned aspects in the geographical space. The poorer classes have been found to be dispersed over the spatially segregated pockets of streets formed by the interruption of the city grid due to railway lines and large industrial buildings [15]. Physical barriers can be also formed by surrounding abandoned land (desolate areas or green areas). Similarly, social barriers exist in terms of the difference of socio-economic status between groups living inside and outside the locality.

Spatial aspects include assessment of physical and economic segregation of localities. Economic segregation was evaluated only on the basis of the distance-decay profile of PUC_OPV to the distance of 300 m. Physical segregation was primarily assessed by evaluating the street accessibility from the surroundings. Additionally the local transport accessibility was evaluated using the ratio of selected targets in the city accessible in 30 minutes. They are represented by the transport stops in residential, transport, commercial and health centres. The number of selected targets in each category is limited to three stops and therefore the maximum number is twelve targets.

CLASSIFICATION OF LOCALITIES

The status, profile and development of localities in the city are obviously not equal (for many internal and external reasons) and (instead of individual profiling and customisation) high number of localities requires classifying them into the limited number of categories where the type of interventions can be better customised and more efficient.

Expert evaluation of localities was based especially on the above explained quantitative indicators. Demographical and unemployment data was studied in one month intervals for two years (i.e. fig. 1) using status and annual changes. Other indicators use one year aggregation (crime intensity and structure) or even a total aggregation for the whole period (occurrence of health handicapped children) due to the low occurrence of events. The street accessibility was stable in the explored time period.

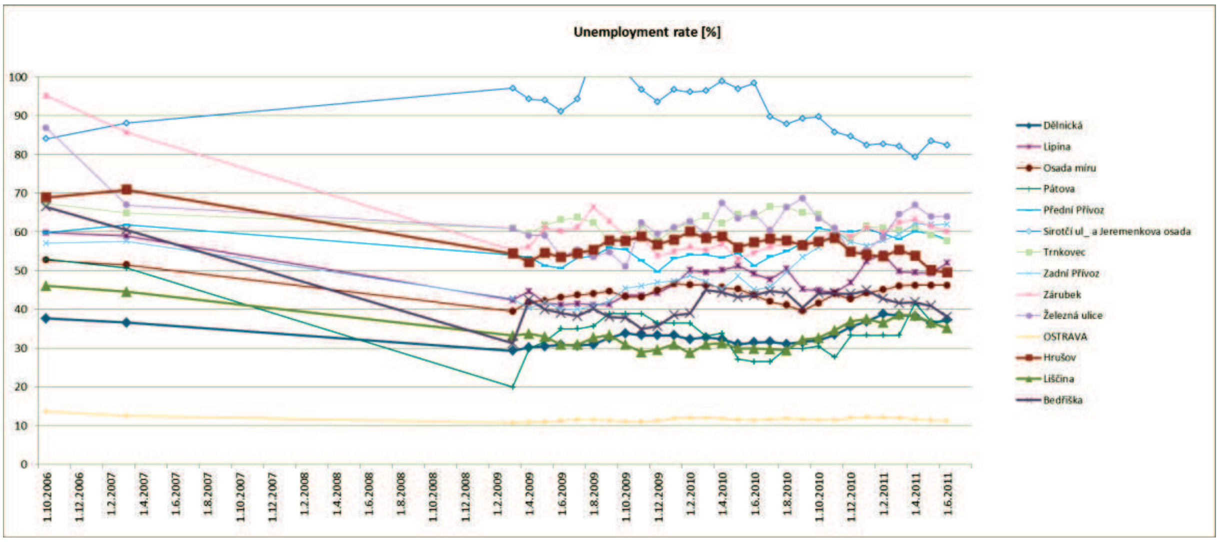

Fig. 1. Estimation of unemployment rate in socially excluded localities

Initial evaluation of the situation, exploratory data analysis and expert evaluation lead to the suggestion of three categories which are practical for taking specific measures in localities. The first category offers relatively better conditions and promising development. The second transition category covers localities which may easily change the trajectory both towards the first or the third category and where the interventions are strongly required to influence the development in a positive way. Subsequently the third, depressed category represents extremely bad conditions, where standard interventions seem to be useless and only radical tools may help.

All socially excluded localities were initially divided to these categories by experts. Consequently the characteristic set of indicating values for each category is provided. The temporal evolution of selected indicators was monitored in order to explore the stability of classification, homogeneity of categories and their usability for customisation of intervention measures.

The evaluation is organised into 2 parts:

- a basic description of categories using selected indicators accompanied with discussion of homogeneity of these groups and individual deviations (profiling) of localities,
- monitoring temporal development of selected indicators and exploring the stability of classification.

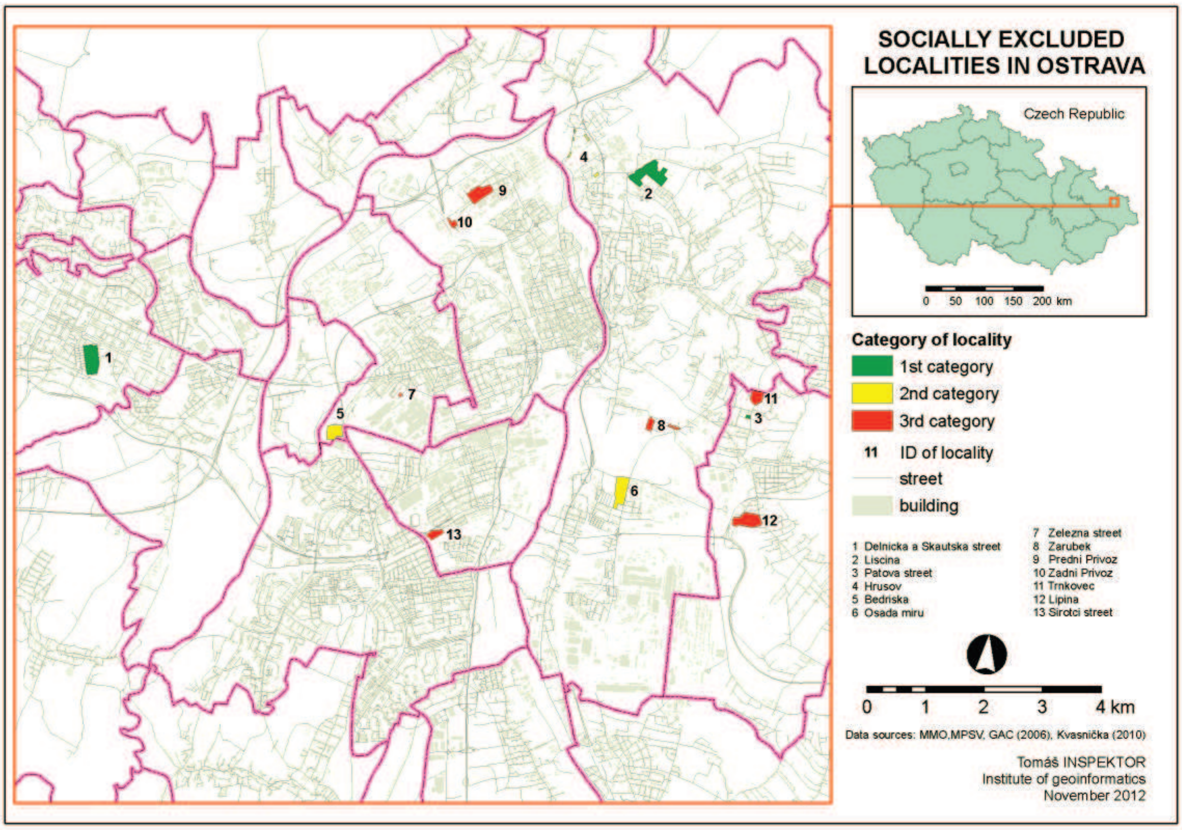

Fig. 2. Initial classification of socially excluded localities

Category I. (promising category)

The first category integrates localities with improved conditions and good prospects. Based on the joined evaluation of indicators' status and development, following main characteristics can be depicted – regressive or stagnant age pyramid, improved situation in unemployment (both intensity and structure), low to medium local crime, low degree of spatial segregation and relatively good housing conditions. Specification of typical values and limits of indicators for explored localities is provided bellow including description of individual deviations from the common profile.

Three localities were initially assigned to this category: Delnicka, Liscina and Patova Street.

The demographic profile of the category is typical by a shifted age distribution which is reflected by the low age index (67), considerably less than the average of Ostrava (148). One fifth of the population are bellow age of 15. Nevertheless the average age (34) does not significantly differ from the average of Ostrava. The average age pyramid for the whole category (Fig. 3) is a stagnant type. This trend is different for Delnicka which has a strong regressive type of age distribution.

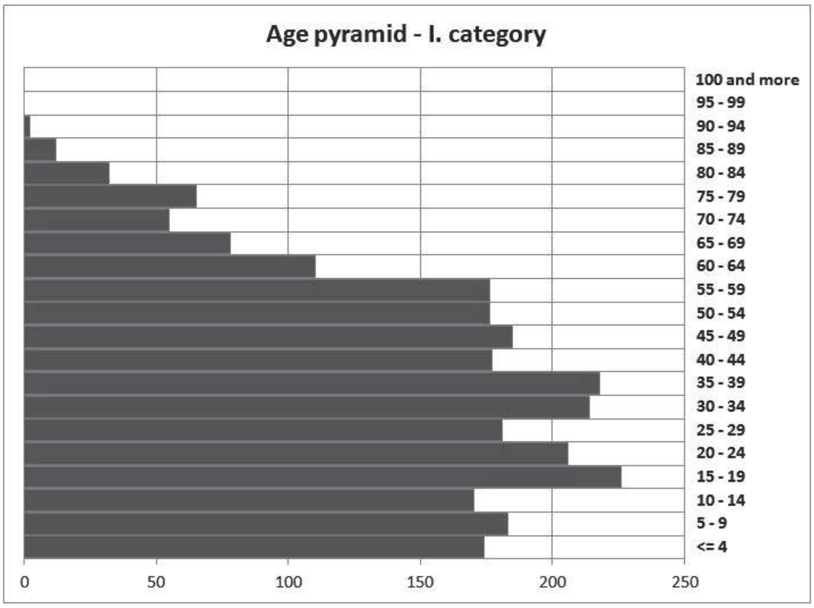

Fig. 3. Age pyramid in the 1st category

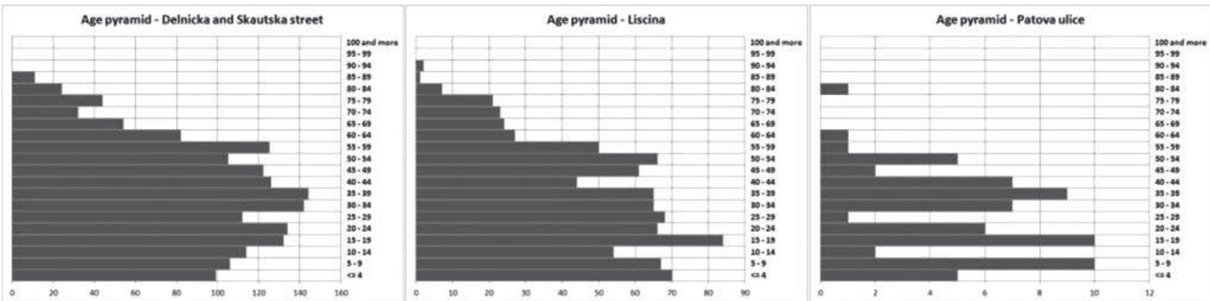

Fig. 4. Age pyramids for localities classified in the 1st category

The crime monitoring does not show significant changes in intensity and structure of local crime. The intensity varies on average between 45-60% in Ostrava. The average structure of crime in these localities shows a significantly smaller proportion of thefts (26% instead of the average 40% in 2009), more sexually motivated incidents and also higher number of crimes against youth.

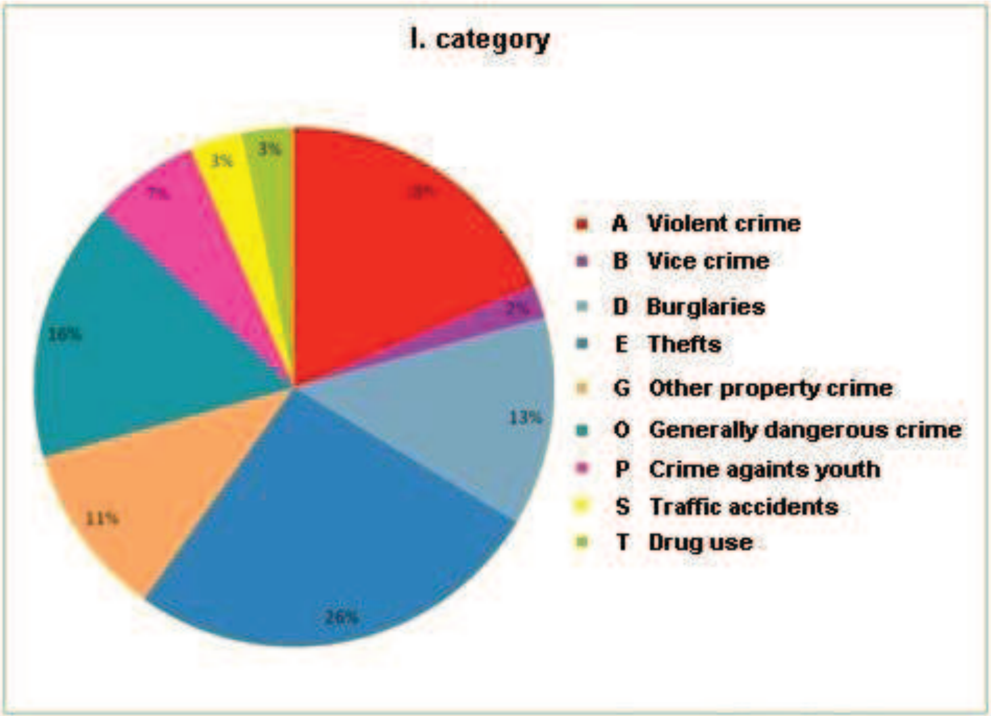

Fig. 5. Structure of the crime in 2009 in the first category

The unemployment rate was estimated on average between 30-40% in the period 2007-2011, while individual localities possessed values between 33 and 38% during last year. The share of people with low education is on average between 60 and 70%, which is roughly 25-30% above the average of Ostrava, which is still significantly less than in the other two types of localities. The deviation is in the case of Patova (100%). The long-term unemployment has reflected the positive trend in this category since the end of 2010 and no significant differences among categories were discovered.

Quality of housing and living spaces indicate relatively good conditions assuring standard flat equipment.

Physical segregation occurs less in this category (except of Liscina). On the other hand, economic segregation is evident. Significant economic segregation is not evident only at Liscina because it is located close to another locality with similar parameters.

Local transport accessibility ranges from very low level (Patova street only 42%) to maximal level (Delnicka 100%).

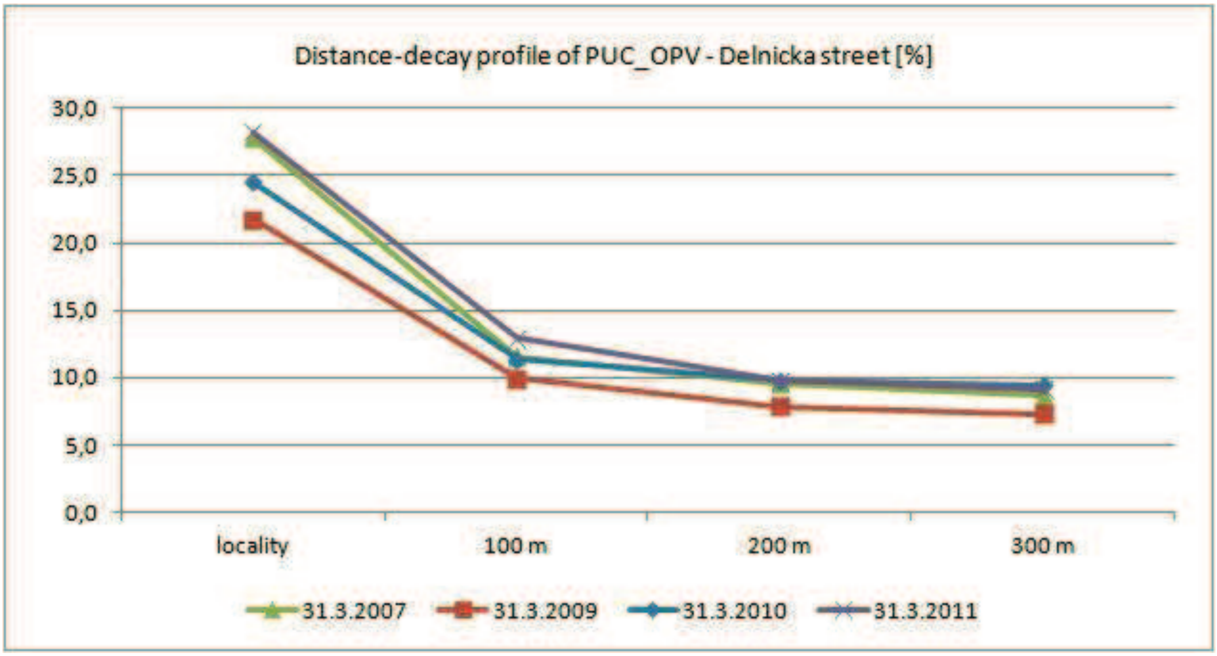

Fig. 6. Distance-decay profile of PUCOPV of Delnicka locality

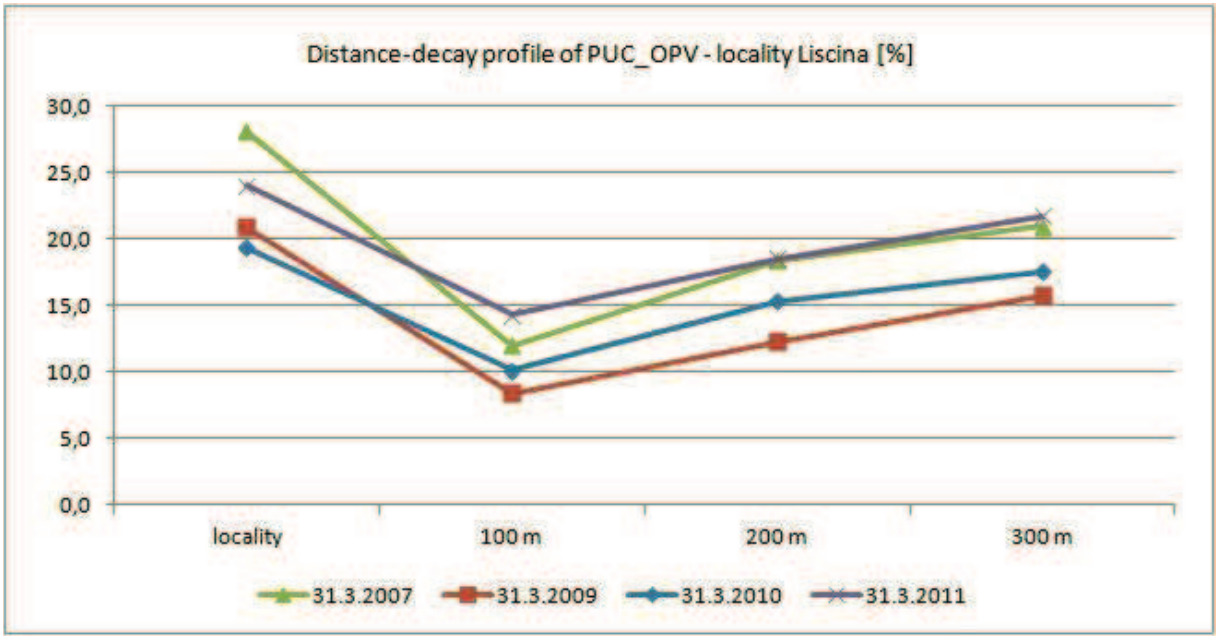

Fig. 7. Distance-decay profile of PUCOPV of Liscina locality

Category II. (middle category)

The second, transition category represents intermediate situation which may be easily converted into 1st or 3rd category. This category includes localities with middle situations of unemployment, lower or middle levels of spatial segregation, low local crime, the variable quality of housing and progressive age pyramid. We can include Hrusov, Bedriska and Osada miru to this category. The medium-sized localities are placed here (from 250 to 850 inhabitants). In total, there are about 2350 people, of which around 1/3 are under the age of 15.

The demographic profile of this category demonstrates a large share of young population and a very low share of retired. The average age is 28, which is 11 years less than the average of Ostrava. Age index is 26, which is 5.5 times less than the average of Ostrava. The average age pyramid for whole category (Fig. 8) is strongly progressive (only Bedriska shows slightly stagnant type - see Figure 9).

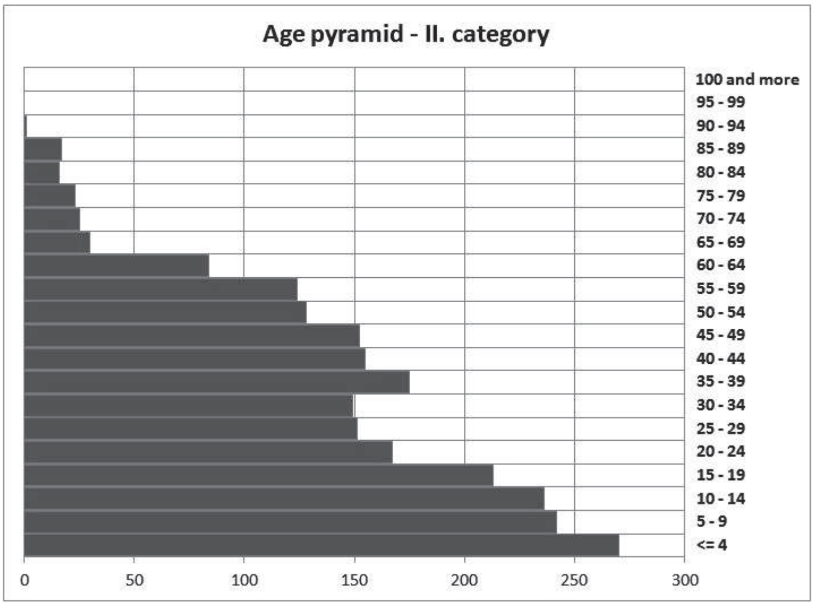

Fig. 8. Age pyramid in the 2nd category

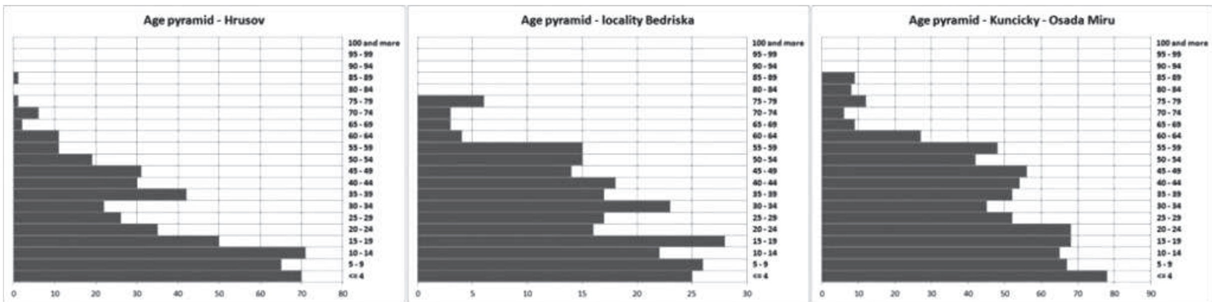

Fig. 9. Age pyramids for localities classified in the 2nd category

The average crime index in 2009 was 57 per 1000 inhabitants which is around 83% of the average of Ostrava (684), but significantly more than in category 1. The intensity of local crime significantly decline in 2010 and 2011 and the difference between first and second category is currently low. The average structure of crime in these locations showed significantly higher proportion of crime against youth (9% instead of 2% in 2009), more burglaries and more sexually motivated incidents. The crime index in individual localities differs in time.

The unemployment rate estimated in the period 2007-2011 consists on average of 47-52%. The share of unemployed with a low education is on average around 80%, which is 40% above the average of Ostrava. The long-term unemployment situation in the 2nd and 3rd category is the same (15-20% above the average Ostrava).

Housing conditions are rather poor. The basic social equipment is available, but in certain locations occurrence of mould is very common, as are the problems with common areas or isolation.

Physical segregation is generally very significant in this category. Extreme separation occurs in Bedriska locality, but other localities have also significant barriers. On the other hand, the front part of locality Hrusov is easily accessible and without physical barriers. Economic segregation is also clearly expressed.

Local transport accessibility is above average for all the localities, even in case of Bedriska, showing that the physical separation does not limit the public transport accessibility.

This category can be described as transitional, mixed. Especially people with low income are moved into these localities. However, the localities are not intended as a residence for the non-payers, or for people who are unable to obtain conventional rental housing.

Some localities have a chance for an improvement; however segregation in others would gradually lead to deeper crisis (3rd category). Localities need a greater intervention to help them recover. Therefore it is recommended to undertake strong interventions and target them to (achieve) the first category.

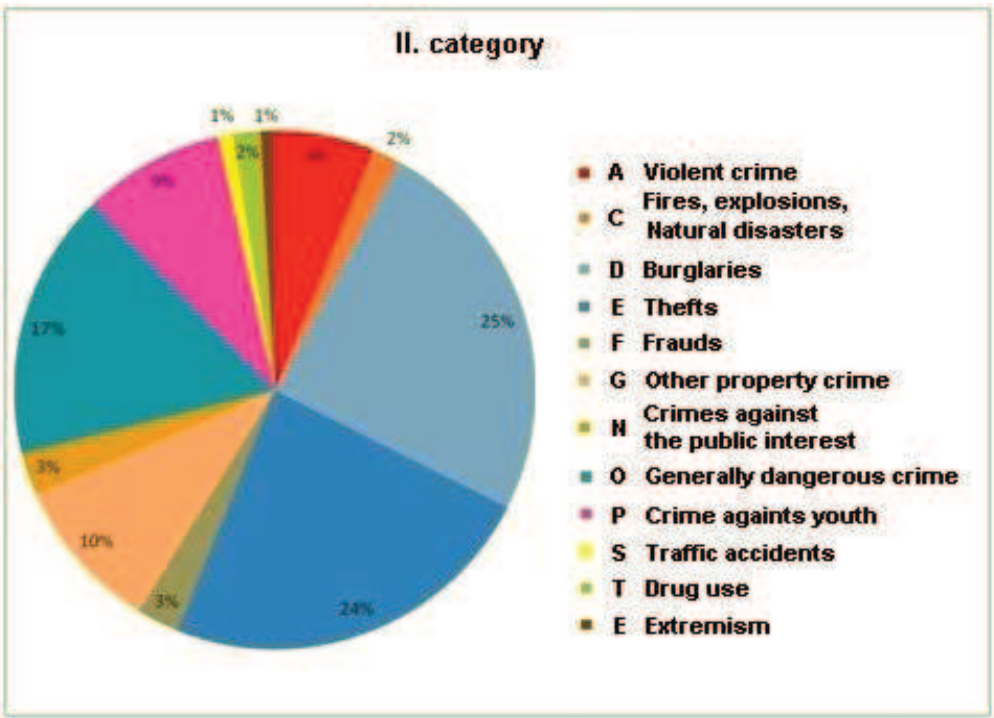

Fig. 10. Structure of the crime in 2009 in the second category

Category III. (depressed category)

The third category represents highly depressed localities with extremely bad conditions where the standard interventions seem to be useless.

Typical symptoms of his category include critical situation of unemployment, strong spatial segregation, and generally poor quality of housing, medium to high local crime. Paradoxically, the group of inhabitants shows a very low age index and a progressive age pyramid.

In this category we can include Zelezna street, Zarubek, Predni a Zadni Privoz, Trnkovec, Lipina, Sirotci street and Jeremenkova osada. In terms of the size, it is from small to medium sites (from 170 to 400 inhabitants). In total, there are about 1950 people, of which around 1/3 under the age of 15.

The average age is 27, which is 12 years less than the average of Ostrava and very close to the second category. Age index for the whole category is 20, which is 7.5 times less than the average of Ostrava. The average age pyramid for the whole category (Fig. 11) is a strongly progressive type (but some locations such as Lipina or Trnkovec do not have as strong growth in the youth population - see Figure 12). Some of the localities show highly variable age distribution inside the locality (Fig. 13).

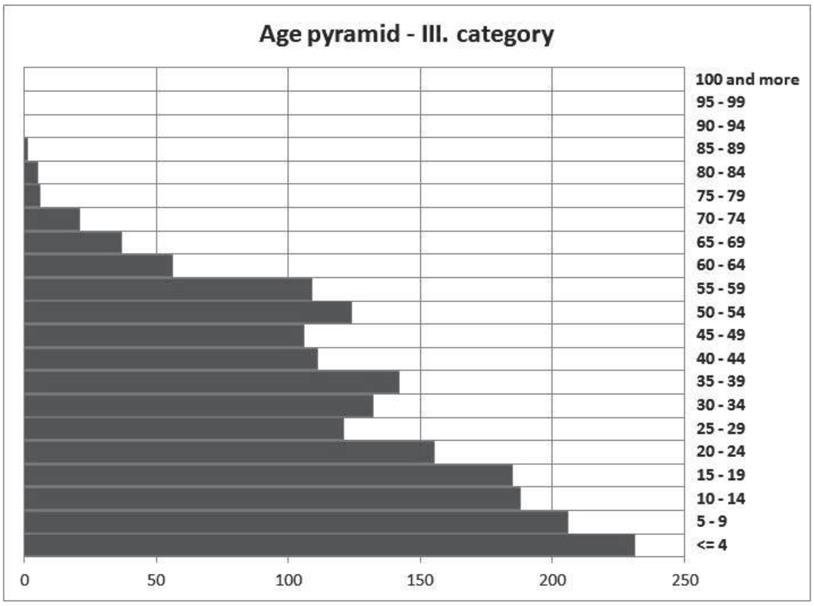

Fig. 11. Age pyramid in the 3rd category

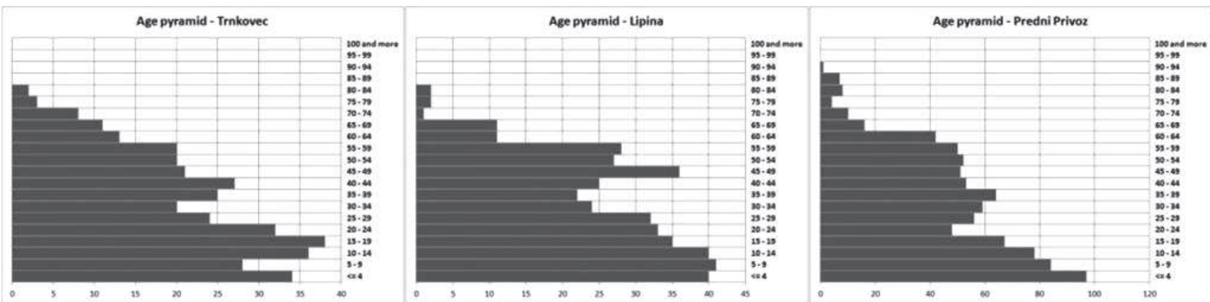

Fig. 12. Age pyramids for selected localities classified in the 3rd category

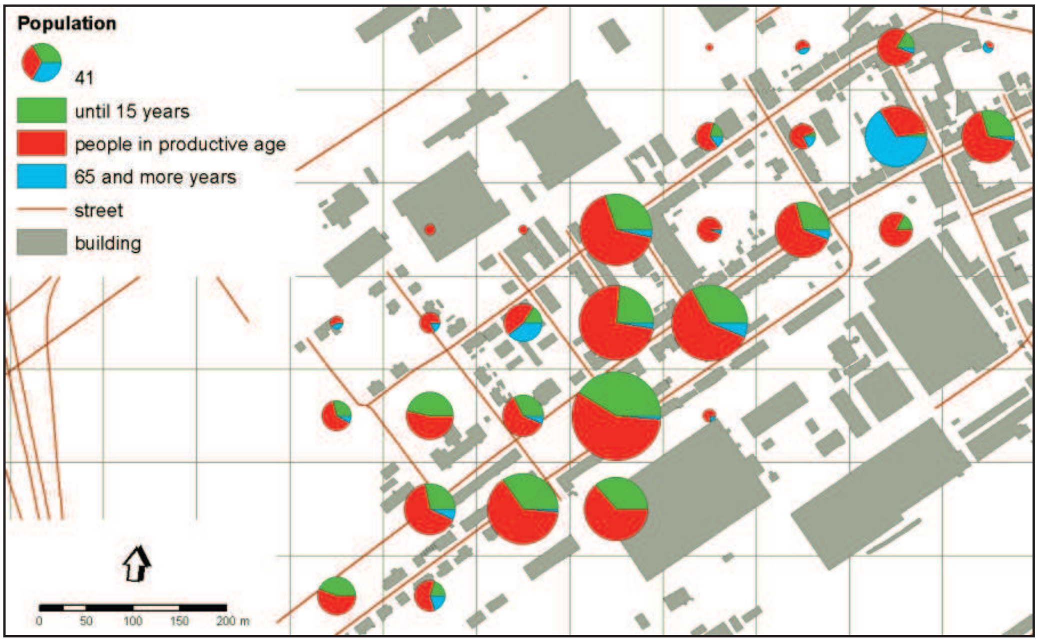

Fig. 13. Variable age distribution in Predni Privoz locality (30. 9. 2009)

The average crime index in 2009 was 526, which is similar to the second category. However, both in 2010 and 2011 excessive local crime was recorded (1.5 times more than average of Ostrava). The average structure of the crime of these sites has shown a shift to the extreme in comparison to the second category, particularly the high proportion of crime against youth (11% instead of 2%) or greater intensity of burglary (30% instead of 15%). In comparison to the second category, it is represented by more violent crime (13% instead of the average 5%). However, each locality shows a different type of crime. The worst situation according to the intensity and structure is showed in Sirotci street and Privoz.

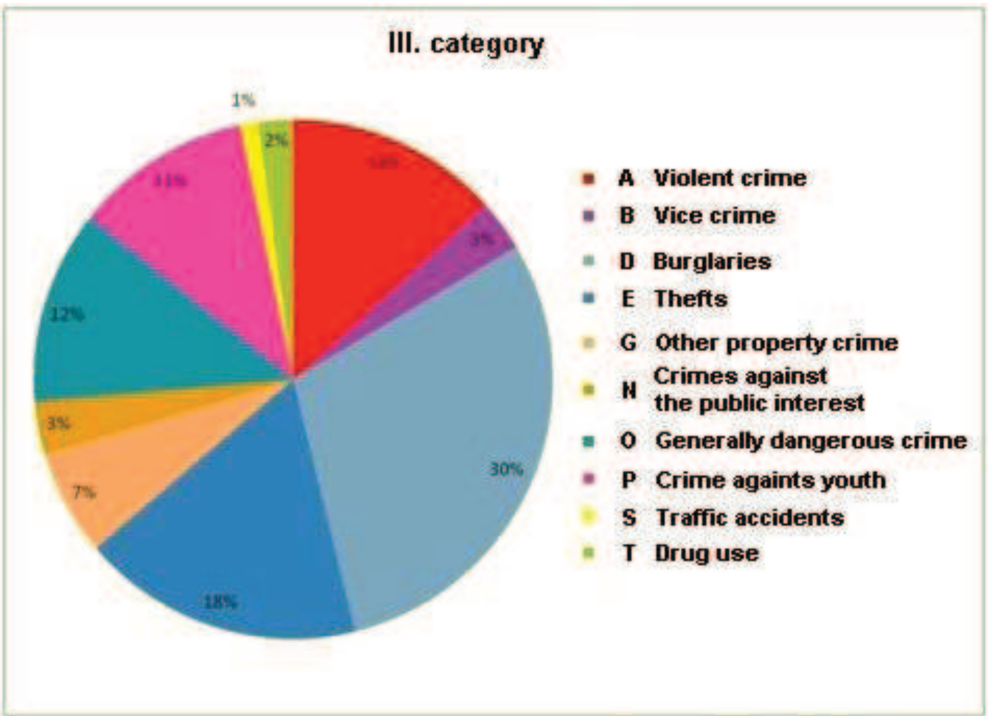

Fig. 14. Structure of the crime in 2009 in the third category

The unemployment rate ranges between 50 and 100% for the period 2007-2011. The worst situation is in Sirotci and Jeremenkova street (between 80 and 100%, it decreased in the first half of 2011), while the best figures are in Lipina (usually around 50%). The ratio of people with a low education is between 83 and 87% on average, which is approximately 50% above the average of Ostrava. The long-term unemployment situation in the 2nd and 3rd category is the same.

Typical housing conditions include many issues and overall poor situation. Following problems usually occur: common areas are destroyed or flooded, sanitary facilities are shared and non-functional, front doors and windows are missing, flats are occasionally affected by mould, parts of buildings are uninhabitable (e.g. impaired statics of structures), etc. The only exception is Predni Privoz with satisfactory housing conditions.

Physical segregation is usually very strong; with occurrence of physical barriers, heaps, dumps, fences or other barriers of communication. Better situation is only in Predni Privoz which is easily accessible from two sides. Very strong economic segregation occurs in most localities, with exception of Predni Privoz and Zarubek where it is slightly better.

Local public transport accessibility is low in Trnkovec and Lipina localities, while others are in a better condition, especially Zelezna and Sirotci localities.

The situation in this category is generally the worst. They are significant problematic localities with a poor development and generally a very little perspective. This is confirmed by empirical findings in these localities. Mostly defaulters and people with low incomes move to these localities. Individuals and families living there are unable to obtain conventional rental housing for different social reasons.

Typically in most of these localities, the house-owners do not invest in maintenance and repairs of the buildings and flats. Residents are not identified with the place where they live (they do not consider their residence as a good address for housing). The goal of most residents of these localities is to move away, i.e. obtain housing in other parts of Ostrava.

Temporal development of selected indicators in categories

The development of selected indicators was monitored throughout the explored time period for the three categories. The localities did not change their class membership for this evaluation which is not practical but motivated our aim to evaluate the separability of classes and to understand global trends of indicators. In practice we envisage that the definition of category will not change (fixing the measures/interventions to be taken), but the probability of locality membership is a subject of temporal changes which leads to switching locality membership among categories.

The graphs demonstrate how large gaps exist among mean characteristics of categories (and also the average of the city) or if they overlap (see fig.15). Also the trends in categories can be easily detected.

The examples are provided for several indicators of intensity and structure of unemployment.

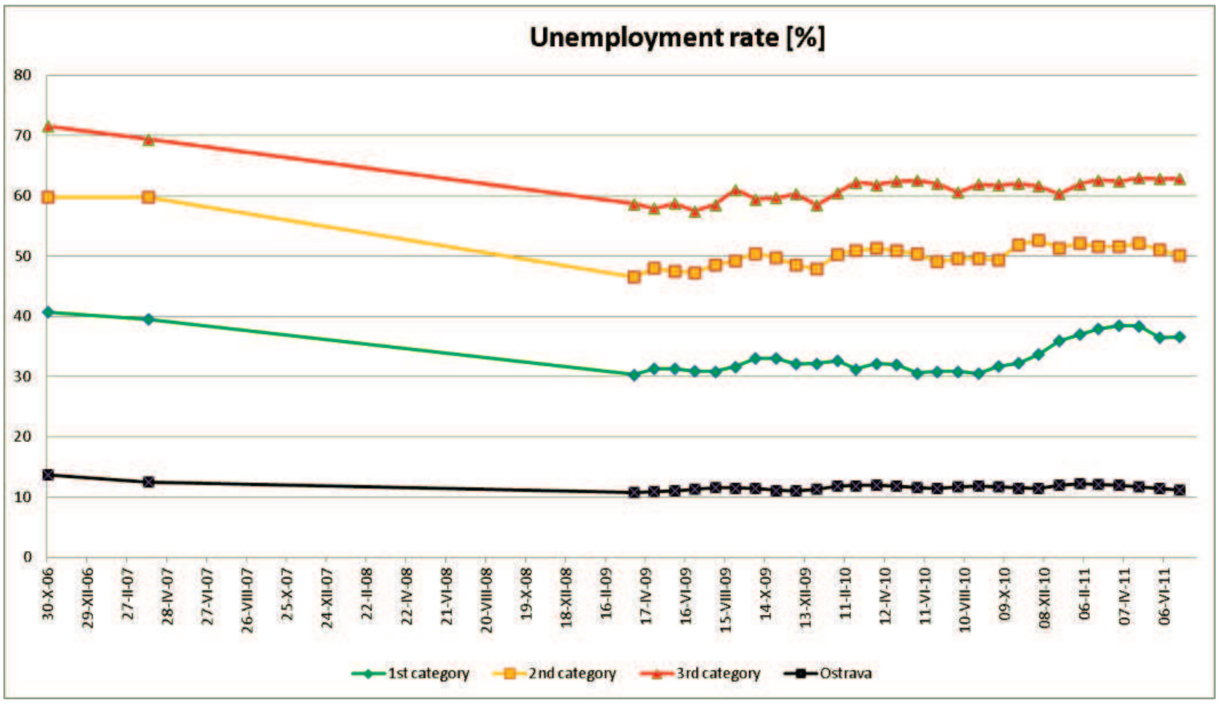

Fig. 15. Estimation of unemployment rate for each category of localities and Ostrava in the period from 2006 to 2011

While the unemployment rate for Ostrava in the period 2009 - 2011 ranges between 10 and 12%, the values for the first category are between 30 and 40%, 2nd category has an average unemployment rate of between 45 and 54% (2009-2011) and 3rd category, on average, 58 to 63% (2009-2011). The first category is more sensitive to changes in labour market which can be seen in the different progress in the first half of 2011, where the unemployment rate was increased by almost 9% while the increase in Ostrava was just 1%.

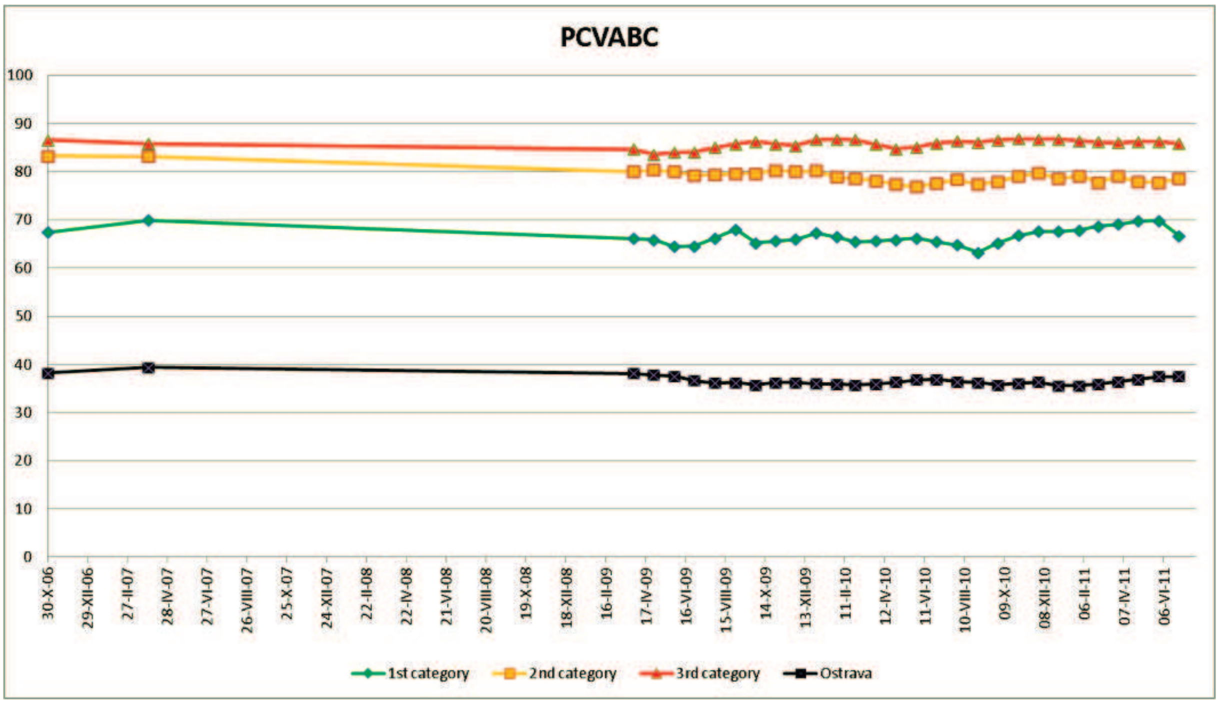

Fig. 16. Share of unemployed with low education for each category of localities and Ostrava in the period from 2006 to 2011

The ratio of unemployed with low education demonstrates a stable situation. More oscillations occur in the first category which is connected to the temporary seasonal employment. Fig. 16 shows a clear distinction between three defined categories (at least in terms of the average value). The smaller difference between the 2nd and 3rd categories is given by approaching the maximum possible limit.

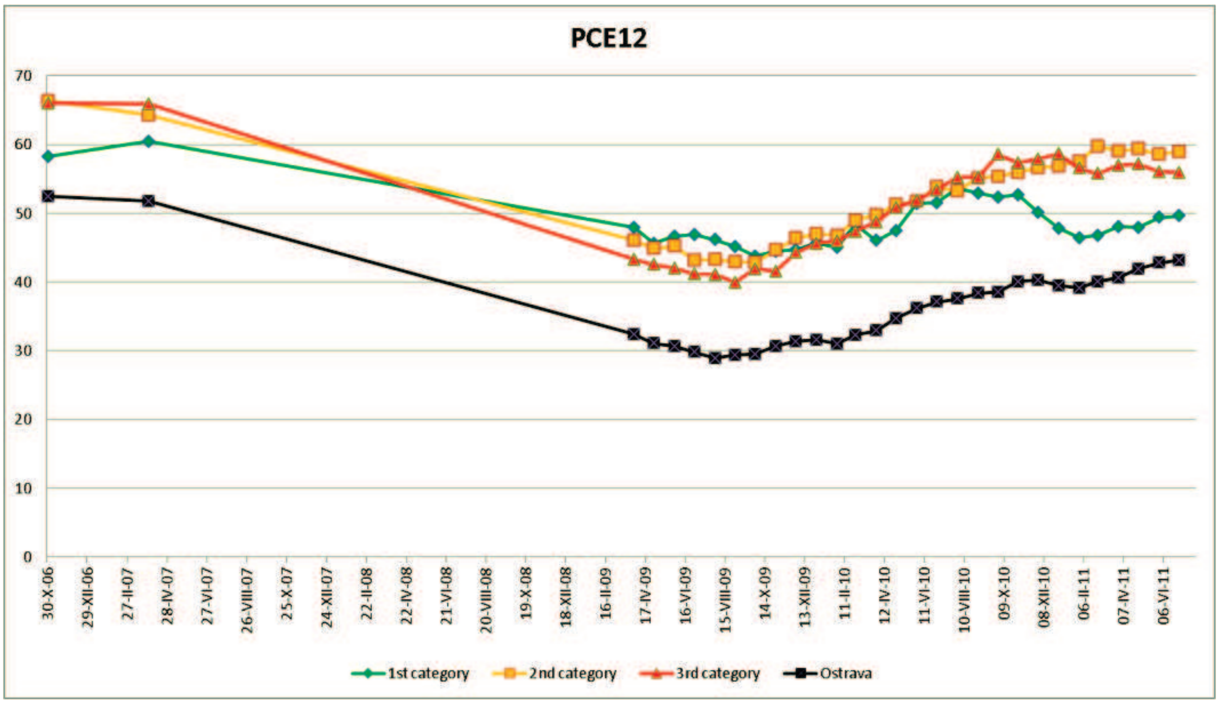

Fig. 17. Share of long-term unemployment for each category of localities and Ostrava in the period from 2006 to 2011

The development of long-term unemployment was affected by the economic crisis in 2008. The long-term unemployment is generally about 15% above the average of the city. It is impossible to find significant differences among categories with the exception of the first half of 2011 where the 1st category follows a different, lower trajectory. This change is caused by the corresponding increase of unemployment rate (short evidence of new unemployed people). In our case, the indicator does not provide any useful information for characterization of categories and localities.

DISCUSSION AND CONCLUSION

Our aim was to deliver a set of suitable quantitative indicators for detailed spatial and temporal monitoring of socially excluded localities using the example of Ostrava city. Requirements for high spatiotemporal resolution prioritize data which originates in information systems of the public sector (registers). Data sets originating in both local and national registers seem to be suitable for calculating indicators which are appropriate for detail characterization of socially excluded localities. In this way three new localities in Ostrava were identified and proposed for further monitoring and the increased focus of local authorities [16].

Main symptoms of social exclusion in our environment were described and potentially corresponding indicators (based on public registers) were proposed.

Selection of data sets, their harmonisation, integration and geocoding enable the enumeration of selected quantitative indicators inside geographical boundaries of localities.

Three categories of exclusion criticality were established on the base of initial expert evaluation using exploratory data analysis of a full set of quantitative indicators. This classification is intended to differentiate intervention tools applied in localities by local authorities.

Proposed set of indicators allows characterizing of problematic localities. They show considerable diversity of characteristics of the localities which is useful in terms of monitoring localities, designing appropriate measures, and monitoring their impacts.

The most useful indicators for classification of localities are physical segregation, unemployment rate, proportion of people with low education, type of pyramid age and housing conditions. In our case, these indicators show stable behaviour for the whole time period and good association to the evaluation of criticality. They are also proposed (considered) for searching and identification of new problematic localities which may arise in the territory and which are not recognised yet.

Almost all other evaluated indicators are suitable for monitoring of individual features and specific evolution of localities. They demonstrate higher temporal instability and a low discrimination capability. The intensity of local crime oscillates namely after the overall decreasing of criminality since 2010. The age index provides a high temporal stability and supplements the evaluation of the age pyramid. Share of health handicapped unemployed (PCZPS) as well as indicators of health handicapped young children incidence provide other specific features uncorrelated with categories of criticality. Similarly, the local transport accessibility describes a specific important feature which seems to be independent of our classification of localities in the case of Ostrava.

Monitoring of long-term unemployment did not provide a satisfactory contribution to the evaluation.

The balance of the proposed evaluation (based only on quantitative measures) will be improved by adding selected qualitative criteria like organization of community activities, the existence (availability) of investment and development plans.

Monitoring of localities and categories brings also significant empirical findings, i.e. the occurrence of high natality and the high ratio of children in locations with very poor housing conditions and significant health risks, the relatively good local transport accessibility in most of localities. These outputs are important for design and planning of appropriate interventions.

Using data from public registers provides three main advantages:

- independent, objective and repeatability measurements with low costs,
- ability to measure and evaluate feedback of applied interventions very soon and consequently ability to further customise applied tools
- possibility to discover new localities with symptoms of social exclusion which are currently not recognised by experts.

Unfortunately quantitative evaluation and utilisation of such data source are not simple and encounter many problems.

Concerning data sources and its processing of following issues must be taken into account. Used data sources are “live” registers where the process of data editing is continuous and influencing not only new data records, but also some older records (thus a repeated export may provide slightly different results). Primary location uncertainty may occur in registers when more than one address per object exists and it is necessary to select the most appropriate address. Data are geo-referenced using address matching and the success is always less than 100%. Data are integrated from several sources which causes higher risk of inconsistencies (i.e. number of registered unemployed might be higher than the number of residents) due to the methodical differences (i.e. kind of address), time shifting, etc. It is important to mention that data coming from the information systems of public authorities require the security of personal data protection and therefore special attention has to be applied to assure confidentiality.

One of the most difficult issues comes from the scarcity of data sources. The existing list of indicators is not complex enough and describes only several aspects (dimensions) of social exclusion. Some socially excluded localities may stay hidden and not distinguishable, or some significant processes in localities may be uncovered (i.e. currently we are not able to monitor changes in health conditions, income, ethnicity, cultural, personal activity, perception of own identity and other significant personal attributes). The scarcity of existing data sources may be eliminated by integrating other data sources from local authorities and by utilisating of monitoring of social networks to address personal attitudes.

These issues should motivate further research.

ACKNOWLEDGMENT

The project was supported by the Grant Agency of the Czech Republic (“The Industrial City in a Post-Industrial Society”, GA 403/09/1720”).

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EVALUATING LAND USE CHANGE IN RAPIDLY URBANIZING NIGERIA: CASE STUDY OF YOLA, ADAMAWA STATE

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Abstract

This paper examines the land use change pattern of rapidly developing city of Yola, Nigeria with a view of finding the explanatory variables for the changes. To achieve this objective, two basic steps are followed: i) land use change detection analysis was performed using Landsat image of 1987 and 2005, ii) a model of land use change pattern was developed using Geographically Weighted Regression (GWR) to estimate the strength of the relationship between land use change and its associated factors. The classification accuracy and kappa statistics of the images are satisfactory. For the 1987 image, the overall classification accuracy of 87.07% and a kappa statistic of 83.37% are observed, whereas, 92.26% (overall accuracy) and 90.41% (kappa statistic) for 2005 were reported. In order to develop the GWR model, several candidate explanatory variables were identified and assessed. The result shows that population, administrative wards, population density, and new layouts are the most important variables that explain the changes. The GWR model result gives a strong Adjusted-R^2 of 0.967. While, the Local R^2 values varied spatially ranging from 0.26 to 0.96. The Akaike's Information Criterion (AIC) is (111.14); a smaller value of AICs is fine on local modelling. The spatial patterns of residuals showed some under prediction and over prediction. However, the model exhibits no spatial autocorrelation as evidenced by Moran's-I (0.02); this means that the residuals are randomly distributed. The coefficient surface maps indicate how the relationship of each explanatory variable varies across space. Areas with large coefficients indicate the locations where that particular explanatory variable is most important in explaining the depended variable.

Keywords: GIS, RS, Geographically Weighted Regression, Developing city

Recommended Citation: ISMAILA, A. B. (2013) Evaluating land use change in rapidly urbanizing Nigeria: Case study of Yola, Adamawa State. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Urban areas are not only the engines of global economic growth but also magnets for new residents flooding in from rural areas [1], [2]. Over the past decades, world-wide urban areas have experienced rapid changes and growth in both population and area size [2]. For instance, in Nigeria, urban population over the last three decades has been growing at a faster rate close to about 5.8% per annum and projections indicate that more than 60% of Nigerians will live in urban areas by the year 2025 [3]. Due to this rapid urbanization, scientists, urban planners and engineers are facing many challenges, including the loss of forest lands, shortage of utilities and resources, aggravated traffic congestion, environmental problems, and ultimately an alteration to the land use patterns [4]. These problems certainly pose greatest sustainable development challenges for Nigeria's urban Centres by progressively complicating and exacerbating interrelated problems of human settlements and the environment.

Yola, just like many other cities in Nigeria is not an exception. It has witnessed a remarkable expansion, growth and development including; buildings, roads, deforestation and many other anthropogenic activities since its inception in 1976 as the State capital of the former Gongola State and later as the capital of Adamawa State in 1991. Over this period, no detailed and comprehensive attempt has been made to evaluate the rate of these changes and understand the relationship with its associated factors. However, understanding and monitoring urban systems requires both reliable data sources and robust analytical methods [5], [4]. Traditionally, surveying and mapping methods have been the major approaches for obtaining urban information. These methods, however, are labour-intensive and cannot provide timely information [4]. In comparison, Geographic Information System (GIS) and Remote Sensing (RS) technology plays a vital role in providing accurate and reliable information with cost effective and lesser time.

Therefore, this study aims to examine the changes in land use pattern of Yola from 1987 to 2005 using GIS and RS technologies, and then develop a Geographically Weighted Regression (GWR) model to estimate the strength of the relationship between land use change and its associated factors.

Geographically Weighted Regression

GWR is a local spatial statistical technique used to analyse spatial nonstationarity, defined as when the measurement of relationships among variables differs from location to location [6]. Unlike conventional model such as Ordinary Least Squares (OLS) which conveys only a single set of parameter estimates assuming to apply equally to all parts of the region (eq. 1), which produces a single regression equation to summarize global relationships among the explanatory and dependent variables, GWR generates spatial data that express the spatial variation in the relationships among variables. Maps generated from these data play a key role in exploring and interpreting spatial nonstationarity.

$$y_i = \beta_0 + \sum_k \beta_k x_{ik} + \varepsilon_i \quad (1)$$

where y_i is the estimated value of the dependent variable for observation i, β_0 is the intercept, β_k is the parameter estimate for variable k, x_{ik} the value for the kth variable for observation i and ε_i is the error term.

In OLS, the parameter estimates β_k are assumed to be spatially stationary. But in reality, there will be intrinsic differences in relationships over space, which may be a non-stationary character. The non-stationary problem can be measured using GWR [6], [7]. Conceptually, the GWR permits the parameter estimates of a multiple linear regression model to vary locally (eq. 2).

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) x_{ik} + \varepsilon_i \quad (2)$$

where (u_i, v_i) denotes the coordinates of the ith location of the observation i [6].

MATERIALS AND METHODS

Study area

Yola is the administrative capital of Adamawa State of Nigeria. It is a twin settlement consisting of Jimeta - administrative and commercial center, and Yola Town - the traditional settlement. Yola is located on latitude 9°14″ N and longitude 12°28′ E (Fig. 1). It has total land coverage of 662.47 square kilometers and a population of 395,871 persons [8]. 2012 projection gives the population as 410,598 persons. The study area comprises of twenty two (22) administrative wards from three (3) local government areas (Yola North, Yola South, and Girei).

Yola has a tropical climate marked by rainy and dry seasons. The maximum temperature can reach 40^o C particularly in April, while minimum temperature can be as low as 18^o C between December and January. The mean annual rainfall is less than 1,000 mm [9].

Materials

The key issues to be analysed in this study and the corresponding research methods are illustrated by the flowchart in Fig. 2. First, the temporal and spatial characteristics of land use change in the past two decades are investigated. Second, the driving forces of urban area growth and spatial distribution are examined. Table 1 present all the data used in this study, including socioeconomic data since 1987, two Landsat remote sensing images for 1987, and 2005, Digital Elevation Model (DEM) data, road network map for 2005, Yola administrative boundary, political ward boundary, etc., collected from various sources.

Software

Several sets of software were used in this study. ArcMap® 9.3 was utilized for georeferencing, creation of map layers, databases, OLS and GWR. Stitch Map® 2.0 was used to extract Google earth image for the purpose of updating a base map of Yola. TNTmips® 6.4 was utilized for image processing of satellite images. Lastly, Microsoft excel was used for descriptive analysis.

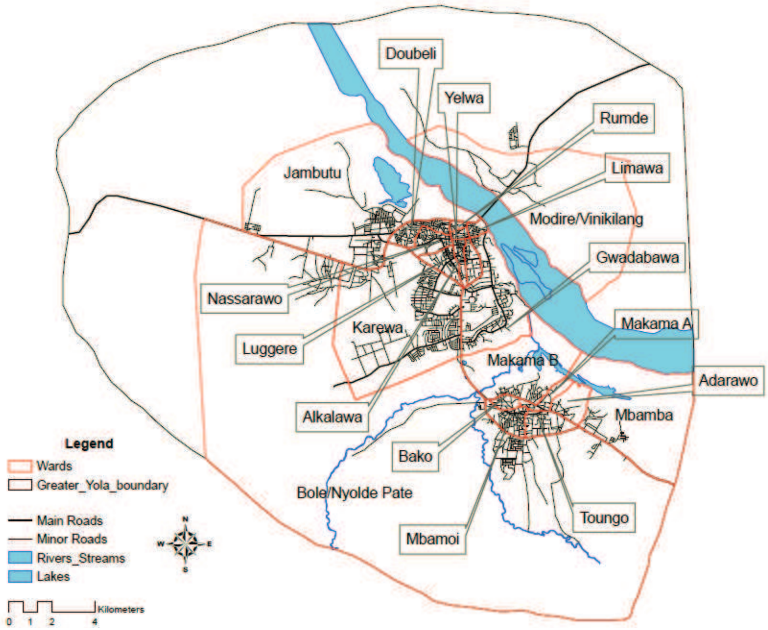


Fig. 1. Study area.

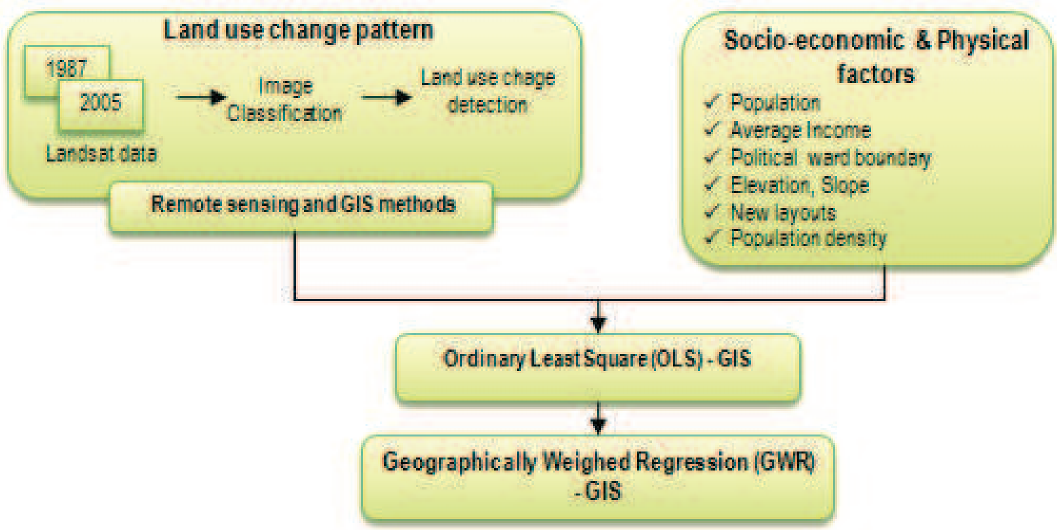


Fig. 2. Flowchart of this study.

Methods

Conversion of analogue data to digital format

The analogue maps were scanned and georeferenced to UTM zone 32N and datum “Minna-Nigeria” using GPS coordinates as ground control points (GCP), and then digitized into: road network, political ward boundary, and Yola administrative boundary vector layers. The road network was further updated using the Google earth image.

Table 1. Data used in the study.

Data Type	Year	Description	Source
Landsat TM image	1987/11/07	Resolution 30 x 30 m	[10]
Landsat ETM+ image	2005/11/08	Resolution 30 x 30 m	[10]
Google Earth image	2005		[11]
ASTER DEM **Road network map**	2008 2005	30 meters Major and Minor roads	[12] Digitized from Google Earth image
Greater Yola administrative boundary		1:50,000	[13]
Political Ward boundary		1:50,000	[13]
Ground Truth	2005		Google Earth image, existing maps, prior knowledge of the study area, and field survey
GPS Coordinates	2006	Road Junctions coordinate	[14]
Population	2005	Projected using 1991 Census data using 3% growth rate	[15]
Average Income	2002	Based on political ward basis	[16]
Housing Finance	2002	Based on political ward basis	[16]
Slope, Elevation		Derived from ASTER DEM	ASTER DEM
Distance Airport Noise contour		Derived	
Layouts	2005	Land subdivision	[13]
Area	2005	Ward basis	
Population density	2005		Generated from available data

* Layouts refers to the land use subdivision e.g., residential, commercial, etc.

* Ground truth is the reference data related to various land uses, e.g., water bodies, forest, agricultural, built-up, etc. collected from the field or ancillary data.

* Housing finance is the financial support received from Mortgage Banks, local and international bodies for the purpose of housing construction.

Image processing

The two Landsat (TM and ETM+) satellite images were processed using the TNTmips® 6.4 software. However, before classification, the images were re-projected to UTM zone 32 and an attempt was made to superimpose them properly with the existing vector layers, and then study area extracted using a vector layer of Yola administrative boundary. Images enhanced using histogram equalization and principal component analysis (PCA) which synthesized the signal from all individual channels into a group of main principal components (PC) [17] was applied so as to reduce the amount of channels to be classified.

The first two PCs account for 94.48% and 95.03% for TM and ETM+ respectively. Whereas, the correlation matrix result of both images shows that bands (3, 4, and 5) might include almost as much as the entire channels considered. Therefore, these three bands were used in the classification process. Based on [18], [15] land use classification method, a supervised classification based on the maximum likelihood approach was performed using the ground truth data to derive spectral signatures for seven land use classes of interest (water bodies, forest, agricultural, built-up, rock outcrop, vacant area, and vegetation). Since, the result of a supervised classification usually has some percentage of misclassification due to noise and unknown pixels, it is therefore necessary to test the accuracy of the classification by using field knowledge and other ancillary data [19]. As such, while performing the classification, accuracy assessment in terms of classification error and separability of the land use classes has been checked. These assessments were performed by providing the ground truth data in a raster format and output in the form of: error/confusion matrix consisting of percentages of individual land use class accuracy, overall accuracy, kappa statistics/coefficient (K_{hat}), and the co-occurrence matrix was generated automatically by the software. The K_{hat} is a measure of overall accuracy of image classification and individual category accuracy as a means of actual agreement between classification and observation [20]. It lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy, Kappa values are characterized into 3 groups: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement, whereas, a minimum of 85% overall accuracy is required [18], [20]. The K_{hat} [20] is defined by

$$K_{hat} = \frac{p_0 - p_1}{1 - p_1} \tag{3}$$

where p_0 is the overall accuracy of classification given by sum over the diagonal matrix elements:

$$p_0 = \frac{1}{N}\sum_i X_{ii} \tag{4}$$

From this number the fraction p_1 of pixels that could have been accidentally correctly has to be subtracted:

$$p_1 = \frac{1}{N^2} \sum_i \left(\sum_j X_{ij} . \sum_j X_{ji} \right) \tag{5}$$

The co-occurrence procedure analyses the spatial associations of pairs of classes. It determines the frequency with which cells of each class pair occur adjacent to each other in the image. These values allow one to judge which classes are spatially associated. A positive value in the co-occurrence matrix indicates that two classes are adjacent to each other more often than random chance would predict. A negative value indicates that two classes tend not to occur together [22]. Having come-up with the land use maps for the two different dates, then areas occupy by each land use was computed, changes determined, and final maps generated using TNTmips®, ArcMap® while Microsoft Excel was used for descriptive analysis.

Variables selection and GWR

The change in land use detected from the classification analysis is considered as the dependent variable for the GWR model. Therefore, in order to develop the GWR model, several candidate explanatory variables that may explain these changes were identified and assessed. These variables include; population of Yola in 2005, population density, average monthly income, political ward area in hectares, elevation, and slope. Finally, the variables were analysed using the scatter - plot (ArcMap® graph function), OLS, and spatial autocorrelation analysis (ArcMap® Spatial Statistic tool).

RESULTS AND DISCUSSIONS

Land use map of 1987

Table 2 shows the accuracy (error/confusion matrix) of land use classification for 1987. The result indicates an overall classification accuracy of about 87.07% and a kappa statistic of agreement of 83.37%. Therefore, it is clear that the classification result met the minimum 85% for overall accuracy and 80% for kappa statistic stipulated by [18], [23]. On the other hand, a large separability value and negative co-occurrence values are observed in the co-occurrence matrix (Table 3) which indicates that two classes tend not to occur together. The percentage of land use for this period indicates that forest accounts for 29.76%, agricultural (22.71%), vacant area (21.98%), rock outcrop (13.78%), built-up (7.07%), vegetation (2.44%), and water bodies covers 2.26% (Figs. 3 and 4).

Land use map of 2005

The accuracy assessment of land use classification map of 2005 indicates an overall accuracy of about 92.26% and a kappa statistic of 90.41% (Table 4). [18], [23]. Minimum accuracy assessment was satisfied and even stronger than the result obtained in 1987 case. This can be attributed to the fact that the researcher has a better knowledge of the study area during this period. However, in respect to co-occurrence analysis a similar result to 1987 is observed, i.e., large separability values and negative co-occurrence values (Table 5) which indicates that two classes tend not to occur together. Fig. 5 shows that agricultural use (44.97%) constitutes the highest percentage, forest accounts for 13.91%, rock outcrop (17.08%), vacant land (12.40%), built-up (6.67%), water bodies (3.36%), and vegetation (1.61%) has the least area coverage. The 2005 land use classification map is shown in (Fig. 6).

Table 2. Accuracy assessment of 1987 classification map.

	Ground Truth Data									
	Name	Water bodies	Forest	Agricultural	Built-up area	Rock outcrop	Vacant land	Veget. cover	**Total**	**Accuracy**
Classification	Water bodies	**1762**	0	0	0	42	0	0	1804	97.67%
	Forest	0	**11044**	1	33	2750	0	0	13828	79.87%
	Grass/Farm land	13	0	**3920**	5	197	0	0	4135	94.80%
	Built-up area	7	0	43	**2718**	0	172	0	2940	92.45%
	Rock outcrop	0	0	134	11	**6907**	10	0	7062	97.81%
	Vacant land	5	25	462	313	296	**3490**	0	4591	76.02%
	Vegetation cover	20	0	0	0	0	0	**717**	737	97.29%
	Total	1807	11069	4560	3080	10192	3672	717	35097	
	Accuracy	97.51%	99.77%	85.96%	88.25%	67.77%	95.04%	100.0 %		
Overall Accuracy = 87.07% **Khat Statistic** = 83.37%										

Table 3. Co-occurrence analysis of 1987 classification map.

	Water bodies (2.86%)	Forest (36.49%)	Agricultural (13.38%)	Built-up area (6.39%)	Rock outcrop (10.43%)	Vacant land (27.98%)	Vegetation cover (2.46%)
Water bodies (2.86%)	**1414.422**	-140.956 103.766	-95.296 130.300	-67.155 153.925	-100.691 114.689	-130.790 148.489	-40.071 85.216
Forest (36.49%)	-140.956 103.766	**549.774**	-316.124 43.186	-213.684 78.891	-267.246 21.587	-507.338 59.402	-125.849 48.787
Grass/Farmland (13.38%)	-95.296 130.300	-316.124 43.186	**917.853**	-153.665 38.259	-190.529 23.491	-276.200 19.277	-83.979 89.617
Built-up area (6.39%)	-67.155 153.925	-213.684 78.891	-153.665 38.259	**1192.393**	-141.431 57.951	-186.258 27.807	-74.373 121.219
Rock outcrop (10.43%)	-100.691 114.689	-267.246 21.587	-190.529 23.491	-141.431 57.951	**1008.398**	-242.457 39.558	-89.507 67.143
Vacant land (27.98%)	-130.790 148.489	-507.338 59.402	-276.200 19.277	-186.258 27.807	-242.457 39.558	**642.028**	-118.981 105.370
Vegetation cover cover (2.46%)	-40.071 85.216	-125.849 48.787	-83.979 89.617	-74.373 121.219	-89.507 67.143	-118.981 105.370	**1417.963**

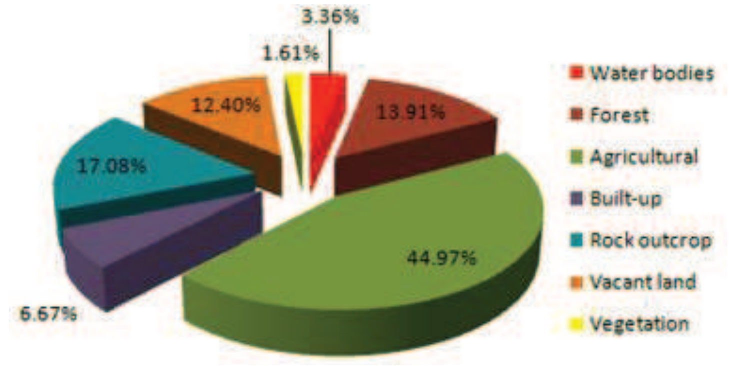


Fig. 5. Percentage cover comparison of land use classes 2005.

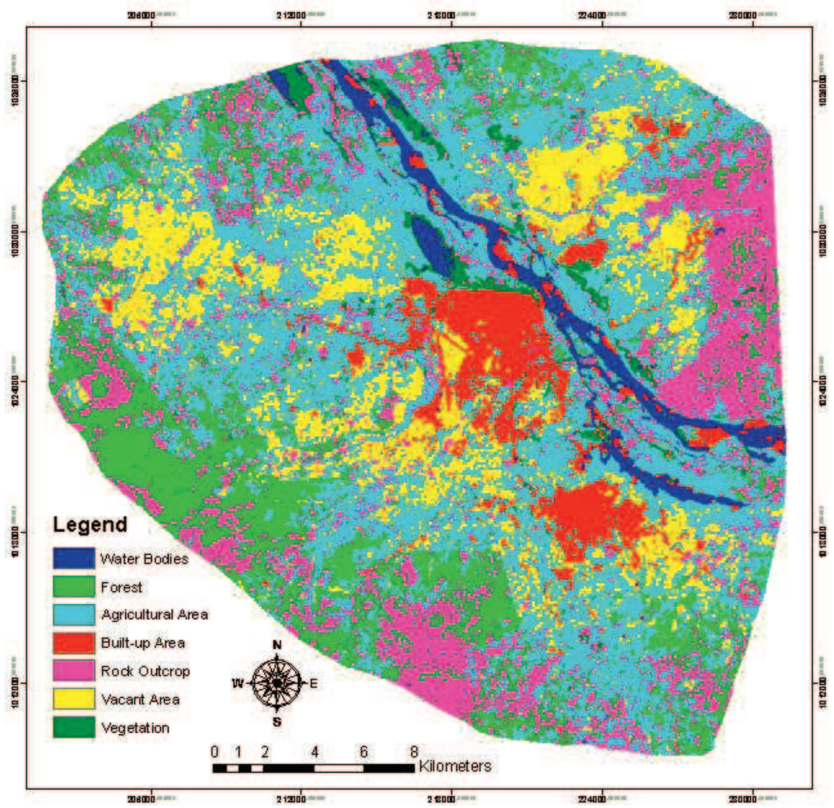


Fig. 6. Land use map of 2005.

Change detection analysis

The areas covered by each land use type for the two periods were compared. Then the directions of the changes (positive or negative) in each land use type 1987 and 2005 were determined (Figs. 7 and 8, and Table 6). Positive change indicates an increase whereas negative change means a decrease.

Remotely sensed images are vital in land use change detection as it provides spatial and temporal information about the land use condition of an area. In this study, an 18 year time span (1987 - 2005) which is moderately enough in showing long history of land use, is considered. These time periods were chosen based on the availability of satellite image and other ancillary data.

The most commonly used land change detection methods includes i) image overlay ii) classification comparisons of land use statistics iii) change vector analysis iv) principal component analysis and v) image rationing and vi) the differencing of normalized difference vegetation index (NDVI) [24]. However, the method used in this study was post-classification comparison and multi-date composite image change detection [25]. This method is widely used and easy to understand. The advantage of this method includes the detailed from-to information that can be extracted. Change detection was carried out in order to obtain from-to information about changes in land use and especially to observe the trend of land use pattern which have a great contribution in preparing future planning proposals.

From Fig. 7 and Table 6, it can be observed that forest, vacant land, vegetation has been changed by -9,991.38, -4,136.70, and -200.16 hectares respectively. Whereas, water bodies (569.19 ha), agricultural land (10,181.80 ha), built-up (204.99 ha), and rock outcrop (3,371.90 ha) have increased. From this, it can be concluded that the forest areas is decreasing very drastically. The main reason for the reduction is severe deforestation due to encroachment and improper cutting down of trees for firewood, farming, and construction purposes. This reason is also applicable to the decreased observed in vegetated areas. On the other hand, agricultural land and the exposure of rock outcrop have increased dramatically. Built-up areas have also increased. These changes have great implications on global warming and the sustainability of the city of Yola and its environs.

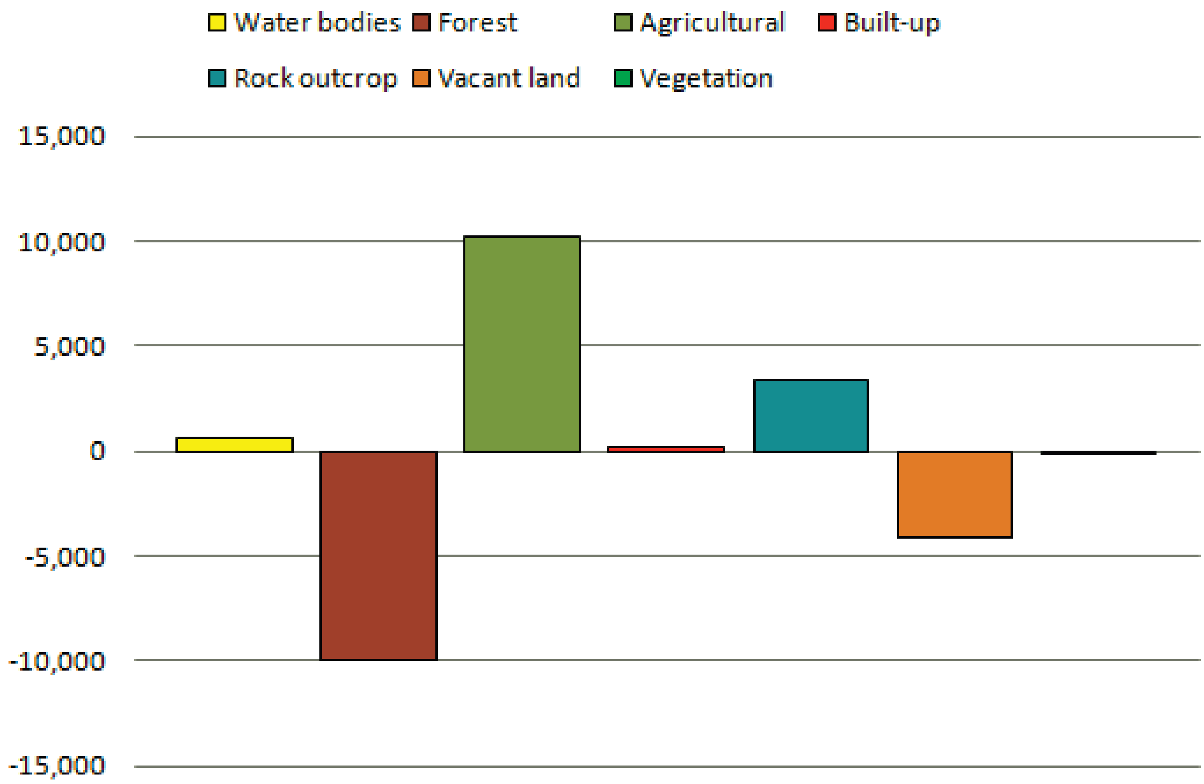


Fig. 7. Land use change between 1987 and 2005.

Table 6. Summary of land use classes for the two periods with their area coverage.

Land use Type	**1987**		**2005**		**Change between 1987 and 2005**	**Average change between 1987 and 2005**
	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(Ha/yr)
Water bodies	1,493.97	2.26	2,063.16	3.36	569.19	31.62167
Forest	19,716.60	29.76	9,725.22	13.91	**-9,991.38**	-555.077
Agricultural	15,042.60	22.71	25,224.40	44.97	10,181.80	565.6556
Built-up	4,683.27	7.07	4,888.26	6.67	204.99	11.38833
Rock outcrop	9,130.50	13.78	12,502.40	17.08	3,371.90	187.3278
Vacant land	14,562.40	21.98	10,425.70	12.40	**-4,136.70**	-229.817
Vegetation	1,617.84	2.44	1,417.68	1.61	**-200.16**	-11.12
Total	**66,247.18**	**100.00**	**66,246.82**	**100.00**	**-**	**-**

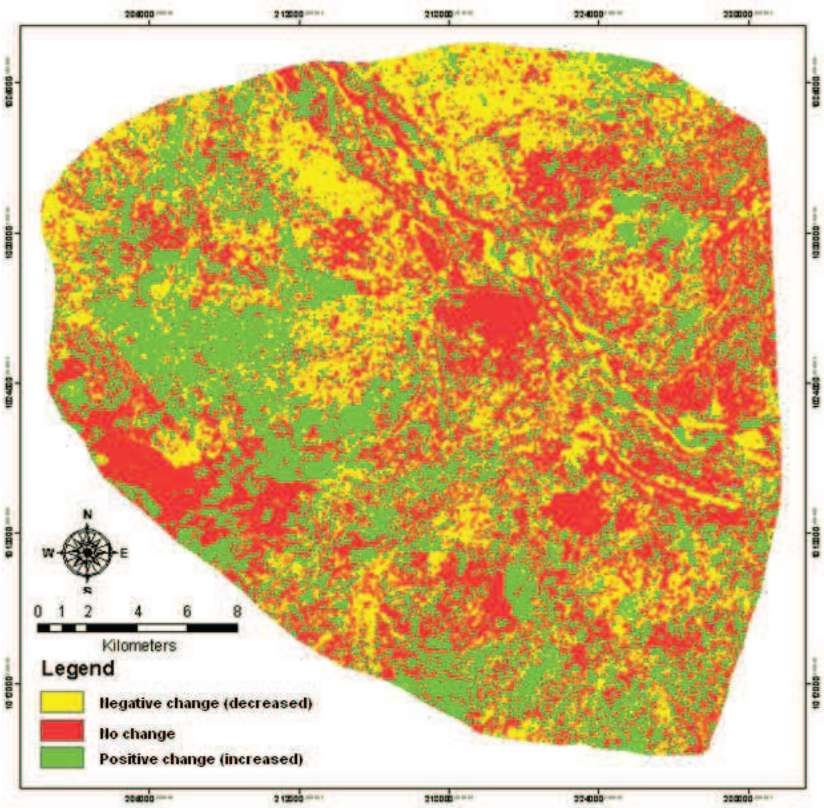


Fig. 8. Land use change map between 1987 and 2005.

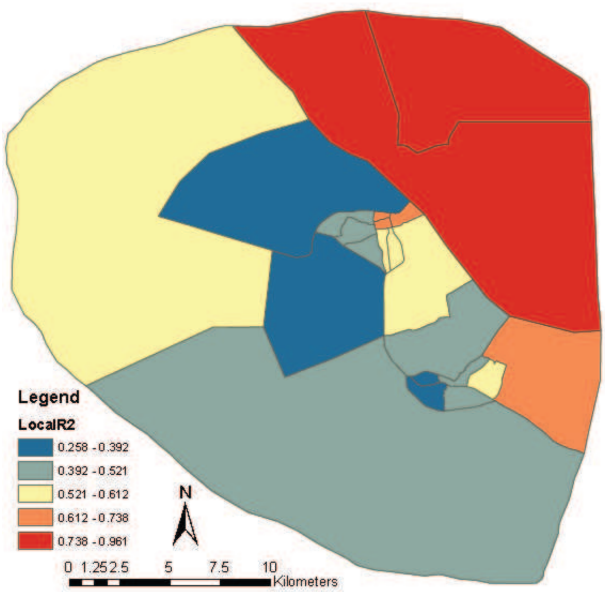
Geographically Weighted Regression model

The statistics: Adjusted R^2, Akaike's Information Criterion (AIC), Variance Inflation Factor (VIF), p-value, robust probability, and Moran's I, etc., reported from the analyses were used in identifying the contribution of each explanatory variable. The result shows that population of

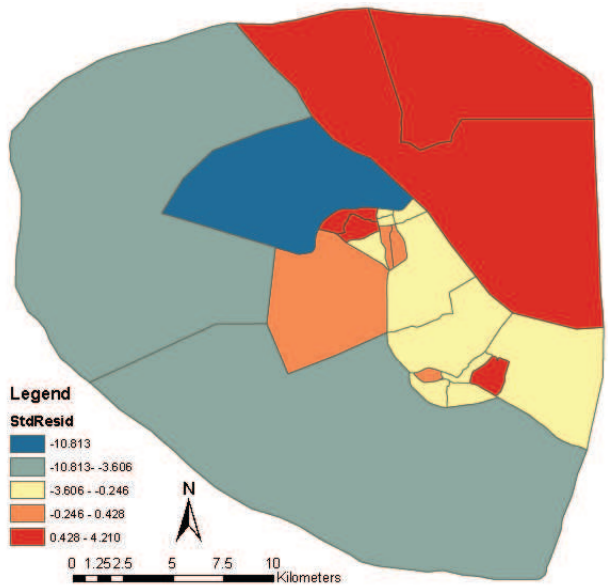
Yola in 2005, political ward area in hectares, population density, and new layouts are the most important variables that explain the changes. Finally, the GWR analysis was performed.

The GWR model result gives a strong Adjusted-R^2 of 0.967. However, the Local R^2 values varied spatially ranging from 0.26 to 0.96 (Fig. 10a). The AICs (111.14); a smaller value of AICs is fine on local modelling (Fotheringham et al., 2002). The spatial patterns of residuals in fig. 10 (b) show some under prediction and over prediction. However the model exhibits no spatial autocorrelation as evidenced by Moran's-I (0.02), which means the residuals of the over and under predictions are randomly distributed. Figs. 10 (c) – (f) shows the coefficient surface maps which indicate how the relationship of each explanatory variable varies across space. Areas with large coefficients indicate the locations where that particular explanatory variable is most important in explaining the depended variable.

a.



b.



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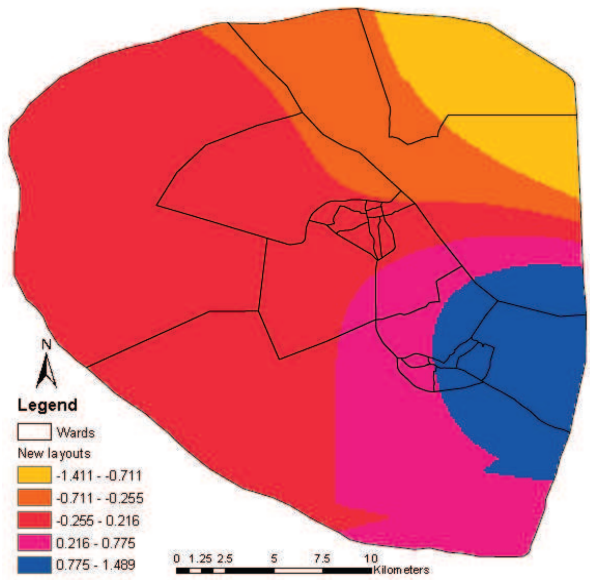

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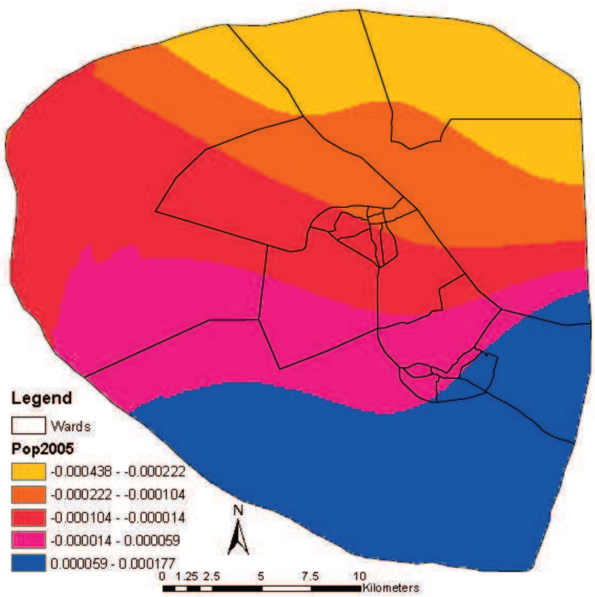

e. f.

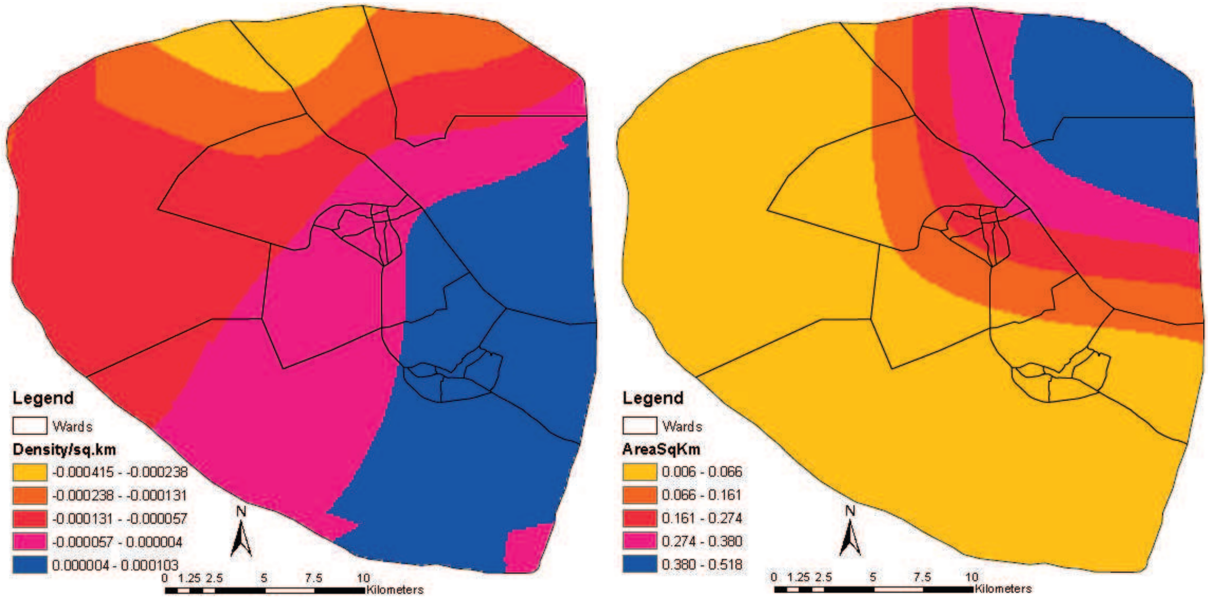

Fig. 10. Parameter estimates of GWR: (a) Local R^2, (b) Std. Residuals, (c) New_layouts, (d) Pop2005, (e) DensitySqKm, (f) AreaSqKm

CONCLUSION

The use of satellite imagery and its integration into a GIS can provide a timely and appropriate tool for studying land use change of urban areas. The thematic maps obtained at relatively low cost and in a short time compare favourably with traditional methods of investigation. This study has looked at land use change in Yola during the past two decades and highlighted a comprehensive analysis of the driving forces behind urban expansion. The causes are examined using GWR approach. Land use change in Yola is influenced by available land area, layouts, population increase, and population density. However, the degree of influence of each variable varied at different location. The GWR model explained considerably more variation in the relationship of the explanatory factors when compared to conventional OLS models. The random distribution of standard residuals confirmed that the probability of missing variables to explain land use change in the study area is very low, which further strengthen the model. The localized regression estimates exhibited the relationships between the dependent and explanatory variables varied spatially.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to The Scientific and Technological Research Council of Turkey (TÜBİTAK) for the support received in the course of my Ph.D. program.

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LOCALISATION OF INTERCHANGE NODES IN THE REGIONAL CITIES OF THE CZECH REPUBLIC

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Abstract

This paper deals with the issue of localization of interchange nodes between urban and regional public transport in 13 regional cities (centres of NUTS3) in the Czech Republic. New methodology based on the utilisation of the valid time tables was developed to locate these transport nodes. It does not describe the situation of current flows of passengers but the theoretical localisation of these nodes is studied based on the offer of public transport connections. Then the homogeneity of localised interchange nodes was analysed according to the time of traveling and it was proved that the central role of the key interchange nodes is often even stronger during the evening hours. The assessment of the accessibility of these interchange nodes is also an important part of this paper. The situation in particular cities varies based on the position of this city in the national transport hierarchy but also regional factors take a very important role.

Keywords: interchange node, urban transport, public transport, commuting

Recommended Citation: IVAN, I., TESLA, J. (2013) Localisation of interchange nodes in the regional cities of the Czech Republic. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

The Institute of Geoinformatics has developed the Database of Public Transport Connections which is used for creating public transport service areas since 2006. This database was used by the Ministry of Labour and Social Affairs in the Czech Republic in their Integrated Informational Portal and also for many other needs of this national institution. It was updated three times during the year based on the main updates of the time tables (March, June and December). The main goal of this database is defining the area of interest where unemployed people can search a job which is in the evidence of the labour offices (all employers had a duty to inform the competent labour office about a new vacancy until the end of 2011). The transport accessibility is often a limited factor for job seekers. The database was extended in 2008; new attributes such as the existence of return connection after the end of the shift were added (more in [1]). The last version of the database contains data about connections among all municipalities within 100 kilometres (Euclidean distance); it means more than 12.5 million records; and also among all municipality districts within the same distance (more than 73 million records). Each municipality is for the purposes of the connection database development defined by a random public transport stop. This fact causes many problems mainly in case of larger cities, where a peripheral stop is often selected as the target destination for potential commuting but the journey to the city centre is not considered. However, this part of the commuting process can be significantly time consuming, often more than the first part of the journey. It is important to exclude this limitation and to make the results more realistic. This process could be modified by two possible approaches. All cities could be represented by one central public transport stop close to the population centre or in the city centre and all connections would be searched considering this stop as the destination of commuting. But this approach brings other limiting factors – first of all: which stop to select? It does not cover the whole city; some transport modes are excluded etc. The second approach does not work with one representative stop but with a set of representative stops. These stops play an important role for the change between regional and urban public transport system within the city. The main function of these transport nodes is the function of transport terminals where the flows of commuting people start or end; or they change one transport mode for another [2]. The interchange nodes are especially developed in places of crossing or approaching of two or more public transport links or transport modes. The most important requirement for the interchange nodes from the providers' point of view is the maximisation of securing passengers' safety by using the flyover crossings of roads or railways and footpath. The most important requirement from the passengers' point of view is the time needed to pass the flyover crossings and the whole process of the transport vehicle change; they prefer short one-level transfer. It is important to minimize the distance connected with the change of a transport vehicle. It is not the goal of this paper to find a new possible better transport terminals or interchange nodes but to select the main interchange nodes (stops, stations) from current stops used for the change of transport mode from the regional to urban public transport. The above mentioned methodology was accepted and these interchange nodes will be used as the representative stops of larger cities for developing the database of public transport connections. This paper describes the methodology of localisation of interchange nodes in 13 regional (NUTS3) cities in the Czech Republic; time stability of localised interchange nodes is studied and results of transport accessibility between old and new methodology are compared.

METHODOLOGY OF INTERCHANGE NODES LOCALISATION

It is important to note at the beginning of this chapter that we do not analyse the real commuting flows and do not work with real numbers of passengers but we use the transport connection proposed by the valid time tables. This methodology deals with searching of a public transport (hereafter PT) connection between defined places of origin and a destination (see Fig. 1). The place of origin is defined as one of ten selected surrounding municipalities within 100 kilometres (Euclidean distance) around each of 13 regional cities. There are two important factors of these municipalities. Stable commuting flows (to work and school) among these municipalities and regional city according to results from 1980, 1991 and 2001 censuses (Czech

Statistical Office) must exist there. These municipalities must be in all directions from the regional city to include possible commuting flows from all directions. Randomly chosen urban transport stops (hereafter UTS) stand for a destination. The count of these stops differs from city to city. In case of Prague, each city part has its own randomly selected UTS, so finally 57 UTS were selected. One UTS per city district was selected in Brno and Ostrava too, but to increase the total number of selected UTS, a few more were randomly selected and finally 50 UTS in each city were used. In case of smaller regional cities, 1 % of all UTS within the city were selected with 10 as a minimum.

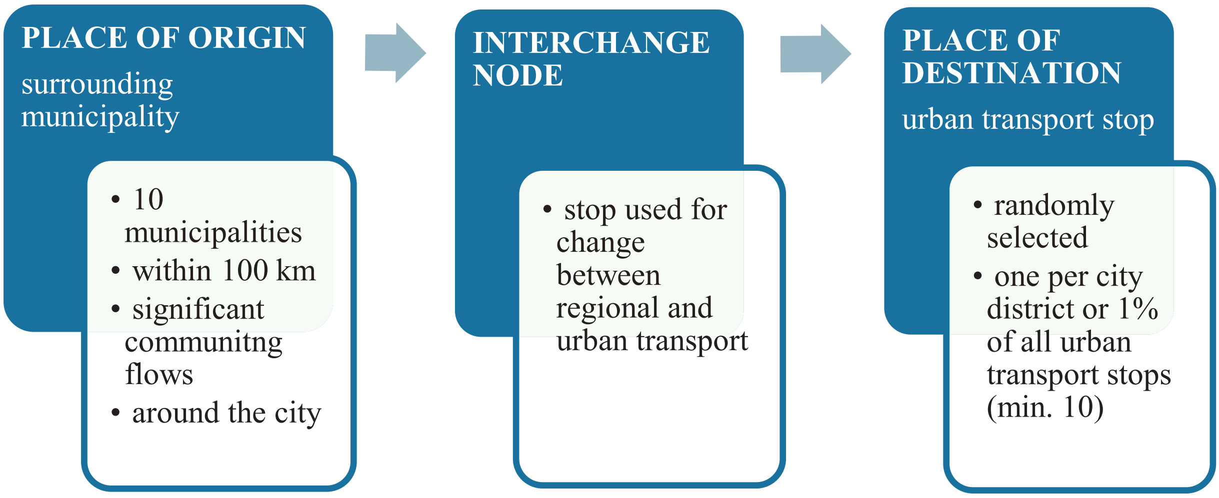

Fig. 1. The scheme of the used methodology

After the selection of places of origin and destination, valid transport connections have been searched using valid time tables with arrival at 8 a.m., 2 p.m. and 10 p.m. All connections have been searched for Tuesday, 22 June 2010 [3], [4]. These connections must meet the criteria used for RPT connections in the Database of Public Transport Connections: total duration of commuting must be less than 90 minutes, the arrival to the final destination cannot be earlier than 60 minutes before the start of the shift and total number of interchanges must be less than 5 [5]. The name and other attributes of a stop used for change between the regional and urban transport system have been saved for each best RPT connection. Overall more than 2.5 thousand of connections (for one commuting time) have been searched in time tables.

In case of Prague, Brno and Ostrava each RPT stop with the frequency of use above 10 is considered as interchange node. In case of other cities the selection of resulting interchange nodes was individual for each city. The total number of selected interchange nodes for 8 a.m. commuting is displayed in the table 1. Bus stops are used more often in case of all cities but when you compare the total number of particular interchanges or even the share of interchanges per stop, the situation will change and almost in all cities the majority of interchanges are made using railway transport. Cities can be more in detail divided according to the frequency of use of railway or bus transport stops. Olomouc, Ústí nad Labem, Brno and Prague are cities with the highest dependence on the railway transport considering the absolute number of interchanges per type of a transport. On the other hand, there are cities dependent on a bus transport – Jihlava, Karlovy Vary, Zlín and České Budějovice belong to this group. This situation is caused mainly by their peripheral position in the railway network hierarchy, out of the main railway corridors. The other possible aspect can be the number of interchanges per stop. The city most dependent on railway transport is Brno, where 55% of all interchanges are made using 33% of localised stops (railway stops) and the share of interchanges per one railway stop is almost 2.5 times higher in case of a bus transport. Brno is also interesting for the centrality of interchanges (similar to Hradec Králové), where the interchange nodes are used 2 times more often (more than 40 per stop) than in other cities (app. 20 per stop). The other cities with high centrality of interchanges using railway transport are Plzeň, Olomouc, Ústí nad Labem and Ostrava. To the contrary, Zlín and České Budějovice rely more on a bus transport.

Table 1. Number of selected interchange nodes in the NUTS3 cities (commuting to 8 a.m.)

NUTS3 Centre	Number of interchange stops			Number of intechanges			Interchanges per stop		
	Bus	Train	**Total**	Bus	Train	Total	Bus	Train	Total
Prague	6	8	14	131	179	310	21.8	22.4	22.1
Ostrava	10	3	13	177	108	285	17.7	36	21.9
Brno	6	3	9	167	205	372	27.8	68.3	41.3
Liberec	4	2	6	51	28	79	12.8	14	13.2
Pardubice	3	2	5	36	30	66	12	15	13.2
Plzeň	4	1	5	58	53	111	14.5	53	22.2
Ústí nad Labem	3	2	5	26	65	91	8.7	32.5	18.2
Jihlava	4	0	4	79	0	79	19.8	---	19.8
Karlovy Vary	3	1	4	54	13	67	18	13	16.8
Zlín	3	1	4	52	8	60	17.3	8	15
České Budějovice	2	1	3	49	11	60	24.5	11	20
Olomouc	2	1	3	15	43	58	7.5	43	19.3
Hradec Králové	1	1	2	43	37	80	43	37	40
Total	51	26	77	938	780	1,718	18.4	30	22.3

TIME STABILITY OF INTERCHANGE NODES

The above presented results describe the 8 a.m. commuting situation (commuting peak hour) but this can vary for different times. We localised these interchange nodes for the needs of commuting; that is why we analyse the situation also for other two times of arrival – 2 p.m. as the beginning of the second shift and for start of the night shift 10 p.m. We are focused on the spatial variability of interchange nodes; whether the interchange nodes and their frequency of use are stable or vary in case of 2 p.m. or 10 p.m. commuting. We studied this spatio-temporal stability of interchange nodes for three biggest cities (Prague, Brno, and Ostrava) and for Hradec Králové as the case of city with 2 equally used interchange nodes. The methodology used for this further analysis was the same as in the case of 8 a.m. commuting. In general, the number of significant interchange nodes decreased and the frequency of use of the most important nodes increased – principle of elitism. Another interesting aspect is a general decrease of existing connections fulfilling the conditions of presented methodology.

Based on 570 searched connections, 14 interchange nodes have been selected in Prague for 8 a.m. commuting. This number has decreased to 11 for 2 p.m. commuting and to 12 for 10 p.m. commuting. This development is quite unique among analyzed cities. The most important interchange node remains the railway station for all commuting times. In case of all analyzed times there is one bus stop with similar frequency of use as the most used node. Less important interchange nodes are often losing their role and the role of a few important interchange nodes is increasing for later time. The decrease is evident mainly in case of bus interchange nodes and increase in case of railway interchange nodes (increasing centrality of Masaryk Railway Station from 10% to 12% of all existing changes). Also the number of missing or unsatisfactory RPT connections is increasing from 15% to 25% for 10 p.m. commuting. The role of one interchange node in Prague is not as central as in case of Brno or Ostrava with share above 20% of all changes located in one stop. This is caused mainly by the large and heavily populated area of the city (almost four times bigger population than in Brno or Ostrava). Prague is a typical city with bigger number of interchange nodes with similar frequency of use without one or two significant central interchange nodes and with preferences of railway transport mode for commuting.

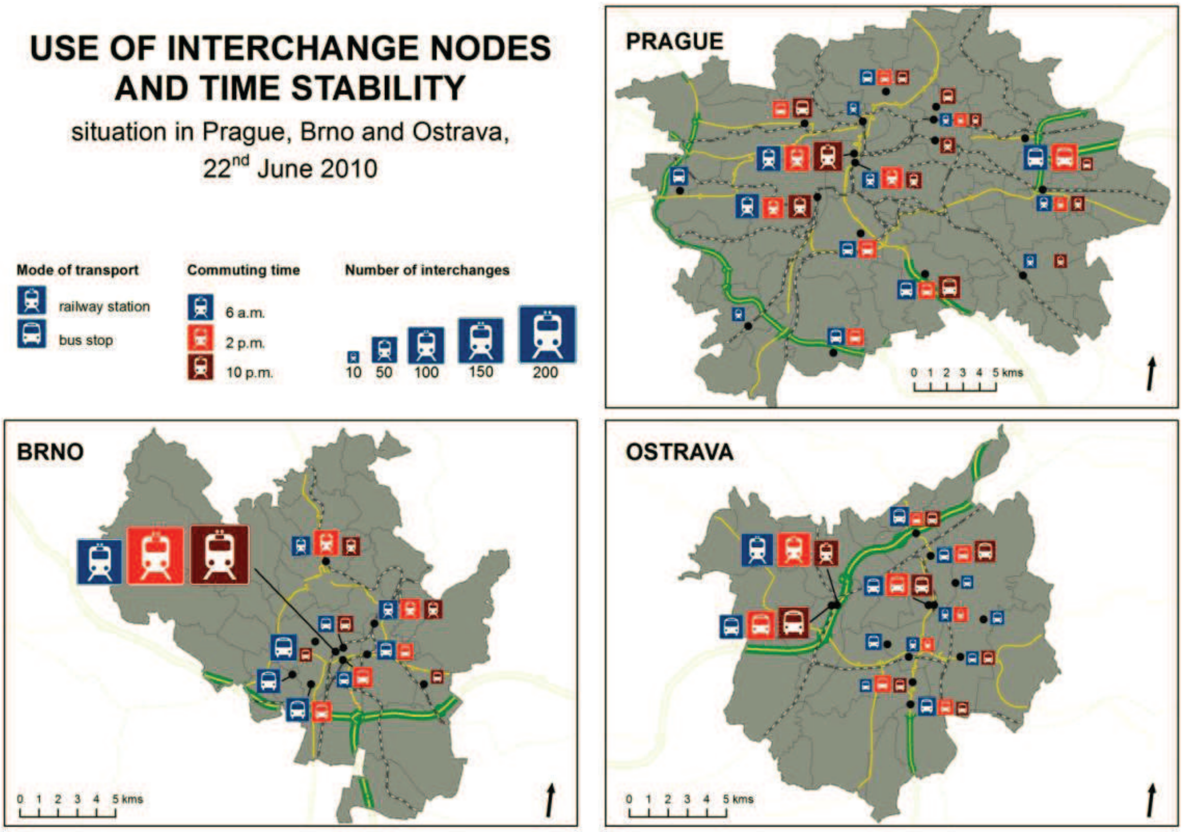

Fig. 2. Use of interchange nodes in Prague, Brno and Ostrava

The most important interchange nodes in Ostrava remain Railway Station Svinov and bus stop Svinov mosty; they service the connections from the western part of the Czech Republic. These two stops remain still the most important interchange nodes but they change their positions for the night shift commuting. In case of 8 a.m. commuting they are used for more than 25% of all interchanges and this share increases to one third of all interchanges for 10 p.m. commuting. The other important interchange node is the Central Bus Station in the city centre with increasing frequency of use from 6% to almost 10%. This stop serves the heavily populated eastern part of the region. Five sparsely used interchange nodes lost their position and were substituted by increasing frequency of use of main nodes in the city. However, the situation should change during next years because the city plan is to develop four main interchange nodes, this analysis locates two of these four planned nodes but only one belongs to the actual most important nodes (Svinov).

The most important interchange node in Brno for 8 a.m. commuting is Central Railway Station which has a frequency of use 31%. There is the lowest number of connections that were not available – these were not searched or they exceeded 90 minutes parameter. Nine interchange nodes were localized for 8 a.m. commuting, for 2 p.m. commuting six and finally, for 10 p.m. also six interchange nodes. Central Railway Station remains the most important interchange node for all three commuting times and frequency of its use increase from 31% up to 44,2% for 10 p.m. commuting. Central Railway Station remains the most important interchange node in all three commuting times and its role is rapidly increasing during the day which causes, similar to Ostrava, decrease of important interchange nodes – mainly bus stops. Mendlovo náměstí, Nemocnice Bohunice a Ústřední Hřbitov have altogether 25% frequency of use for 8 a.m. commuting and for 10 p.m. commuting only stop Mendlovo náměstí remains the interchange node with frequency of use of 3%.

COMPARISON OF ACCESSIBLE AREAS

This methodology has been used for the first time for three biggest cities in the Czech Republic – Prague, Brno and Ostrava. The Database of Public Transport Connections has extended almost 250 thousands of combinations [6]. Only 12% of these connections meet the criteria of the methodology of valid transport connection. Searching was carried out in program TRAM which is being developed at VŠB – Technical University of Ostrava; it works directly with the library of the time tables [1]. This extension has proved the convenience of this approach and thus the application of this extension has been applied to other ten regional capitals.

Automated connection search among individual interchange stops and all municipalities within 100 km from Prague, Brno and Ostrava in both directions was carried out after the selection of interchange nodes. The search was carried out according to the same criteria as the connection search between the municipalities; time tables 2009/2010 updated to 14th June 2010 were used and 14th June 2010 was determined as a day of search. Results of the search were afterwards compared to the results of the connection search between municipalities in term of approachable area. Situation of commuting at 6 a.m., 7 a.m., 8 a.m., 2 p.m. or 10 p.m. was compared in both cases. Resulting situation in case of commuting to the cities (interchange nodes are considered to be final destinations) from municipalities within 100 km is displayed in the map below (Fig. 3). This direction of commuting is more frequent in the morning when people commute to the city to work or school. Above mentioned options, when as a final stop could be chosen any RPT stop and any stop in the city with the role of an interchange node, were studied. There is a significant difference between the number of municipalities when it is possible to use any final stop in the final destination and the number of municipalities when it is possible to use only any of the interchange nodes. It is caused by the fact that individual connections use as a final stop mostly these at the outskirts, so the connection does not reflect a long time that is needed to pass heavily urbanized areas in the cities on the way to city centre. In case of Prague, there is a significant decline in the number of municipalities from which is the city approachable. If it is possible to use any final stop in Prague, it is approachable from 1100 municipalities from surroundings. However, if it is possible to use only any of the interchange nodes, the number of municipalities drops to 302, it means more than 70%. It shows that previous results are not realistic in case of Prague. There is not such a significant decline in case of Brno and Ostrava (the number drops to 391 from 750 in case of Brno-almost 50% and in case of Ostrava it is 143 municipalities out of 252 which means 43% drop). Absolute numbers of municipalities cannot be compared due to different residential structure or closeness to the borders, however percentage declines are comparable.

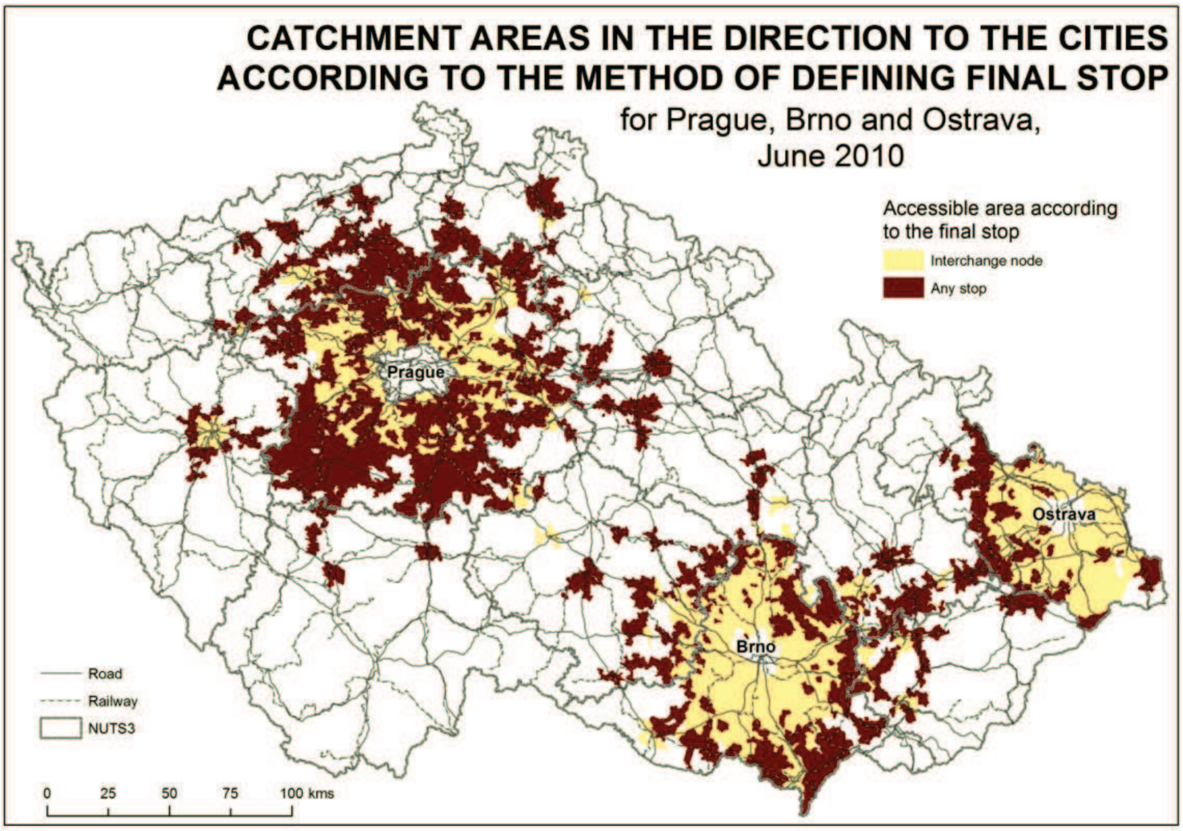

Fig. 3. Catchment areas in the direction to the cities according to the method of defining final stop

There are even more significant drops in case of analysing commuting to the other direction, i.e. from interchange nodes in the cities to surrounding municipalities in the radius of 100 km. This direction is used mainly in the afternoon to travel from work to the place of residence. The map (Fig. 4) shows differences; the most significant drops are again in case of Prague. If it is possible to use any RPT stop in Prague, 843 municipalities are approachable. However, if it is possible to use only any of the interchange nodes, the number of municipalities drops to 131. Decline is more significant than in the opposite directions and reaches almost 85%. From the map it is evident that even very close municipalities are not approachable from Prague. There is more significant drop in case of Brno too; mainly in the direction to the south and northeast from the city (the number drops to 255 from 647, it means 60% drop). The situation remained the same only in Ostrava where the number dropped from 216 to 119, 45% drop). It was caused mostly by more distant municipalities in Opava and Krnov region.

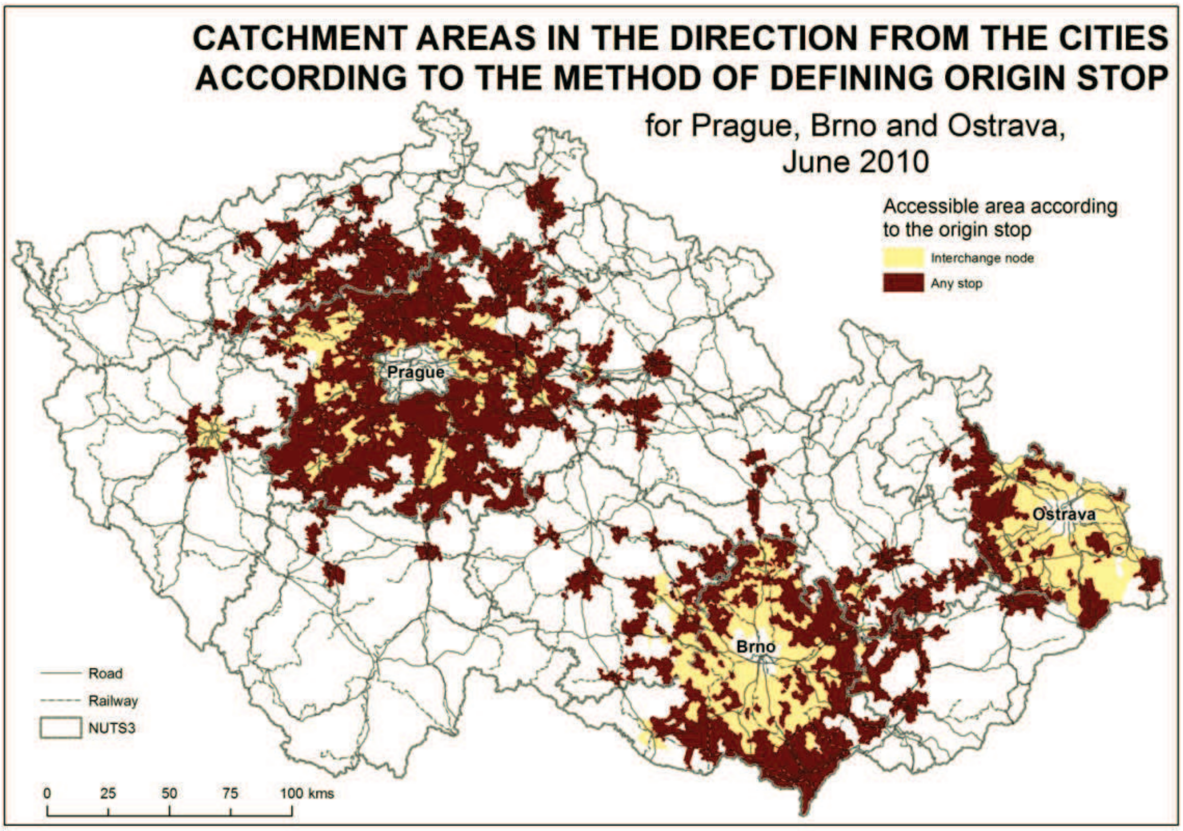

Fig. 4. Catchment areas in the direction from the cities according to the method of defining origin stop

CONCLUSION

The methodology for assessment of the interchange nodes within county capitals in the Czech Republic has been introduced. Based on this methodology; 77 interchange nodes for 8 a.m. commute have been localized. Generally, it is possible to divide cities into three categories according to dominance of train stop use or bus stop use for RPT change. In Prague there are more often used train stations (mostly Masaryk Train Station) and bus stops there often play secondary role. In case of Brno, there has been proved a key role of Central Train Station which is, in vast majority, used as a stop for RPT change. Also in Ostrava there is an important traffic node represented by train station Ostrava-Svinov and close bus stop Svinov, mosty dolní zastávka. In case of other regional cities the situation there is different, some cities rely completely on train stations (Olomouc, Ústí nad Labem etc.), some rely on bus transport

(Jihlava, České Budějovice etc.) and some have similar use of both mode of transport (Pardubice, Hradec Králové etc.). Time stability of these interchange nodes for 2 p.m. and 10 p.m. commute have been investigated on the example of three cities (Prague, Brno and Ostrava). The results of the investigations tend to show similar figures. The number of significant interchange nodes has been falling and the frequency of use of some most significant interchange nodes has been rising. There has been a tendency to raise a number of connections which did not meet the criteria of method (commute time over 90 minutes or later arrival). New interchange nodes (less important due to their frequency of use) have appeared rarely.

These interchange nodes define these cities for the following automated connection search that has been performed for the combination of these three cities. The combination has been defined by any RPT stop or by any stop with the function of interchange node and by all municipalities within 100 km in airline from Prague, Brno and Ostrava. Due to comparison of number of approachable municipalities in the direction from and to the cities, the new methodology could be recommended to use. Number of approachable municipalities has fallen significantly - mainly in the surrounding of Prague by 85%. In case of Brno and Ostrava the drop has not been so significant; however, it has reached almost 50%.

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THE USE OF VIEWSHED ANALYSIS IN CREATION OF MAPS OF POTENTIAL VISUAL EXPOSURE

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Abstract

We have created software tool that helps to determine Visual exposure of landscape potential (VEP). VEP is determining factor of landscape planning and assessment activities with the visual-aesthetic impact on landscape and its visual quality. VEP value is being determined by the area size the concrete landscape point is visually identified from, or by the area size that can be identified from the concrete point. Potential of landscape visual exposure represents potential of each relief surface point to appear visually dominant in comparison with the other points of terrain surface. Relief point being exposed potentially and visually does not represent its real visual prominence. It stands for the ability to improve visual dominance of landscape element value being situated in the concrete point. The most frequently used GIS software does not offer complex solutions in the process of visual quality landscape evaluation. The main attribute of this process is represented by the potential of visual exposure. Software tool in GRASS GIS has been developed to determine VEP. It uses analytical functions of Visibility as well as functions of region adjustment, input map to ASCII format transformation, map and mask import, and data generation. Program being used for map visualisation has been created. It enables complex solution of landscape visual exposure potential. The output is done by data matrix of the selected area in which each cell of matrix stands for Visibility function converted in km^2. The model testing has been realized for the whole Slovak republic and especially for the Nitra town. Visual structure of land and potential visual exposure are considered in the planning and evaluation processes in the theoretical and proposal level, as well. Examples of use of the visual exposure evaluation approach are system of ecological stability of the territory, environmental impact assessment, urban plan documents, and other activities related to the landscape creation and planning.

Keywords: viewshed analysis, visibility, visual exposure of landscape potential, parallel computations

Recommended Citation: JAKAB, I., PETLUŠ, P. (2013) The use viewshed analysis in creation of maps of potential visual exposure. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Definition of main visual landmarks, that mustn't be affected by building-up and at the same time must be visible for citizens mental map to increase readability of urban environment, is necessary for preservation of city's identity. Important aspect in landscaping and city planning is conservation of city skyline, which identifies and makes the city unique. That's why regulations of high-rise buildings, which provide city's historical and aesthetic continuity, are used for this purpose. Equally important is conservation of characteristic landscape panoramas and countryside views, that are signified by the condition of relief and area exposure, but we still don´t have system and regulation for objective assessment. Mentioned landscape panoramas – green skylines are integral aesthetic parts in building green infrastructure and city's environmental image at the same time. But how is it possible to identify this areas? For simple definition of areas with significant visual quality can serve software tool for geographical information system (GIS), that is able to define potentially visually exposed part of landscape. This tool was developed at Constantine the Philosopher University in Nitra and has a wide range of utilization, but especially is usable for land-use, landscape ecology and environmental praxis. This software tool can be practically used for urban planning documentation, especially in green structure plan.

Importance of landscape visual information assessment is associated with landscape planning activities [1] and visual impact on landscape regarding environmental impact assessment. Also current assessments are depending on expertise that measures landscape visual quality subjectively.

We realize that exact and automatic landscape assessment, as visual information source, is impossible with software tools. Our ambition was to create objective assessment platform as source of visual identifiable information. Software solution of landscape visual attributes are close to this issue in works of [2], [3], [4].

Relief is limit factor for visual landscape perception, which defines how every spatial element of landscape is perspective and visible at the same time. This limit is basic starting point for solving issues of landscape visual exposure. We want to create and test model of Visual exposure of landscape potential (VEP), which will be used as objectively measurable platform in case of real or planned activities assessment with visual impact on landscape. This tool will be complement for landscape planning activities.

Visual exposure of landscape potential (VEP) is only hypothetic term, because landscape surface is limited just on relief without landscape structure elements. But reliefs enter like main attribute in process of visual connections determining and assessment. VEP is expressed in values. Value is destined by area size from which we can identify concrete point in landscape (number of points in landscape from which I see one point), or area size which is identifiable from concrete point (number of points in landscape which I see from one point). VEP is main presumption for visual exposure of landscape reality – real part of visual landscape structure. VEP or visual exposure of reality with high values understanding like determining a permanent visual quality factor in landscape planning and visual impact assessment.

Making maps of potential visual exposure of landscape eliminates activities that might have negative impact on perception of urban landscape.

MODELING OF THE VISUAL EXPOSURE

At present, the most common GIS software does not posses a direct tool for the determination of the visual exposure of the area.

It offers viewshed operations which are able to derive a new coverage from the DEM of the area. The newly created coverage shows those areas which are visible from one or more locations and which are coded as a binary image, with 1 indicating those areas which are visible and 0 those which are not [5].

The basic algorithm for generating a viewshed from the DEM is based on the estimation of the elevation difference of intermediate pixels between the viewpoint and the target pixels. The determination whether the target pixels can be seen from the viewpoint is accomplished by examining each of the intermediate pixels between two cells to determine the corresponding 'line-of-sight' (LOS). If the land surface rises above the LOS, the target is invisible. Otherwise, it is visible from the viewpoint. The LOS computation is repeated for all target pixels from a set of viewpoints, and the set of targets which are visible from the viewpoints form a viewshed [6], [7].

The solution of the computations in which all of the points (n) on the terrain are used as viewpoints and targets is partially described by Rana [8]. According to this work, it is the exhaustive but time-consuming Golden Case in which the visibility index computation time is of order O(n2).

The map of the visual exposure can be also considered to be the Golden Case solution. Therefore, each pixel of the input DEM carries a value of the visibility index. The map creation process of the potential visual exposure for a specific area requires a number of time-consuming computations.

The main factors that affect the total time of computation, besides the performance of the computer itself, are the numbers of viewpoints and target points in the viewshed computation. The number of points is influenced by the resolution of the input DEM, size of the investigated area, and maximal distance from the viewpoint inside of which the LOS analysis will be performed.

There are several possibilities for speeding up the Golden Case solution. One approach is described by Rana [8] and Kima et al. [7] as the reduction of the number of observers (viewpoints), targets, or both. Our approach to speed up the process of the visual exposure map creation is based on using parallel computations.

Parallel computations used in formation of PVE map can reduce the computational time approximately as many times as many processor (or processor cores) are involved in computations [9].

The input map is first divided by a user into the required number of segments. The computation of the visibility in the individual segments can be performed by individual processors. This solution leads to an acceleration of the process, depending on the performance of the employed computer – from 2 or 4 processor-containing desktop computers, through computer clusters with dozens of processors, to supercomputers with several hundreds or thousands of processors.

The created segments present groups of viewpoints of approximately the same size. The number of the viewshed computations obtained by the lines-of-sight projecting within a digital model of relief remains the same, but the computations run simultaneously. Each processor can solve the computations in an individual segment, while the computation of the visibility goes beyond the borders of a segment. In other words, the target points, the parts of the computation, are not limited by the borders of segments; therefore, the computation of the visibility exceeds borders of these segments.

In the case of parallel computations, the source of viewpoints can be the created sectors, and the source of target points can be the whole input map or a map which was derived by including the border zone whose size is equal to the maximal distance from the viewpoint. Inside the newly derived border zone the LOS analysis will be performed towards the borders of the individual sectors. Our parallel algorithm is designed for the distributed memory MIMD architecture. In order to maximize the utilization of the processors, the algorithm distributes its data among the processors and allows each processor to process the data asynchronously. This asynchronous operation ensures that each processor processes the data independently of the other processors and as fast as possible [10].

The division of the map into more segments and the application of more processors for the computation can lead to a proportional decrease of the computation time. Thus, the developed toolkit can be easily applied, using multi-core processors, computer grids, computer clusters and supercomputers for the computations of large areas in a high resolution.

FORMATION OF VEP MAP WITH USE OF THE PARALLEL COMPUTATIONS

We developed a GRASS GIS toolkit [9] for solving the Viewshed analysis for a relatively large area, using parallel computations.

The package of our toolkit consists of several modules offering the following functionalities [11]: r.in.gdal, g.region, r.buffer, r.stats, r.out.arc, r.patch, Grass batch job.

The VEP map formation with use of our GRASS toolkit is performed in several steps:

UPLOADING OF INPUT PARAMETERS

The created toolkit runs in a GRASS GIS terminal. The input parameters, necessary for r.los module, are uploaded after starting the run:

- the raster map –An input map containing the elevation data (e.g., Digital model of relief) is transformed into the ASCII grid format using the GRASS GIS (the module r.in.gdal). The size of the raster map which enters to the program algorithm must exceed the borders of the area of interest by the distance of the visibility. This condition is necessary for the visibility computation on the territory borders where calculations take into account the area lying outside the borders.

- obs_elev – the value Height of the observer (in meters) above the viewpoint's elevation,
- max_dist – the maximal distance (in meters) from the viewpoint within which the LOS analysis will be performed.

The VEP maps for the whole area of Slovakia and the cadastre area of Nitra town were the output of the process in our case. We have used the following input parameters to create the final map of the visual exposure potential:

- the raster digital elevation map: the digital map of relief ASTER, transformed from WGS84 to S-JTSK and resampled into resolution of 100 m (in the case of whole Slovak Republic) and 30m (in the case of Nitra town)
- the height above the ground of the viewing location: 1.75 m,
- the maximal distance from the viewpoint: 50 km in the case of whole Slovak Republic, 2,5 km in the case of Nitra town
- MASK: the borders of the Slovak Republic, the cadastre of Nitra town

After start of running the toolkit, the GRASS terminal shows a simple guide for users in the form of questions and answers, leading to the specification of the input parameters, such as the units in which the data is recorded (e.g. the number of pixels that are visible from a set point, the area in square meters, square kilometers, in hectares).

SETTING OF COMPUTATIONAL REGION

Two more questions in a new dialog window are used to provide the specification of the computational region in the GRASS. The first one is for the specification of the output map resolution. The second one is important for the specification of the borders of the computation (the border pixels). The most frequently are defined the borders of the region for the calculation base on the MASK.

If we know the map resolution and the border of the computational region, the program will be able to assess how large area is used in the computation, which is reported as the final number of map pixels in the dialogue window (Figure 1).

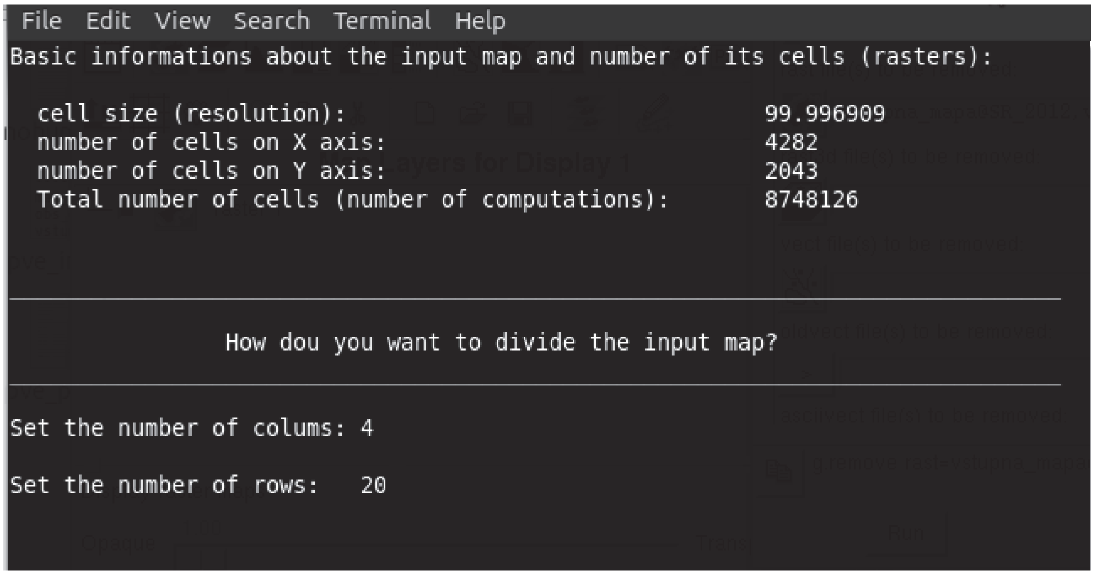

Fig. 1. Segment settings

The report (Figure 1) contains the exact resolution (the cell size), total number of cells, and number of cells on the X and Y axis (the rectangle given by the most outward pixels is taken in account). Whereas the Visibility function has to be performed individually for each pixel, the number of pixels in the computational region is equal to the number of runs of the Visibility function using the r.los module. Therefore, the information from the dialogue window is useful for the users who decide whether they want to use simple or parallel computations of the visual exposure.

FORMATION OF SEGMENTS FOR PARALLEL COMPUTATIONS

If the simple computation is chosen, the sub-program MAP_VPE will run to create the map of visual exposure. When the parallel solution is chosen, it is necessary to divide the input map into smaller parts – segments, and adjust the computation of the visibility for each newly created segment.

The segments present a bordered group of viewpoints, whereas the source of the target points remains the original map DMR. The maximal distance from the viewpoint to the target pixels inside of which the LOS analysis will be performed exceeds the segment borders. In the case of the parallel solution, the user can choose how many segments are necessary to be specified for parallel computations.

We calculated the map of the potential visual exposure using parallel solution. The input map was divided into 20 rows and 4 columns, which led to the creation of 80 individual segments (Figure 1). Creation of VEP map was realized on a computer grid. Number of rows corresponds with a number of computers used and number of columns is adjusted to a number of cores in one computer.

The segments creation produces new input program data saved in external files. The data contain the information about the parameters specified by the user, borders of the individual segments, codes of segments, etc. Therefore, it is important to deal with the organization of the newly created data. Besides the transfer of the data, it is necessary for the parallel computation run to copy the source code and input raster of each segment.

After this question, the above-mentioned data organization is carried out. We then run a further part of the program, leading to the VPE map for the created segments.

RUNNING THE PARALLEL COMPUTATIONS

Running the parallel computations is performed via a Grass Batch Job application. Grass batch job is an alternative method of easily run jobs in the GRASS with a collection of commands in a shell script file. It is possible to apply it to launch the GRASS in the text mode and in a parallel solution of the GRASS jobs [11].

COMPUTATION OF THE VISIBILITY INDEX WITHIN THE INDIVIDUAL SEGMENTS

The computation and map creation start in the left top corner of the map segment. The algorithm of the program solves automatically the Visibility function (the module r.los) for each cell of the area of interest. and the viewing position given by the central point of the cell coordinates. The function Visibility is performed for the point determined by the coordinates of the actual cell center and for the specified values of the height above the ground of the viewing location and maximal distance from the viewpoint.

The module r.los generates a raster output map in which the cells that are visible from the user-specified observer position are marked with a vertical angle (in degrees from the ground) required for the cells' visibility (the viewshed). The value of 0 is shown directly below the specified viewing position, 90 is to the right or left of the position, and 180 is directly above the observer. The angle of the cell containing the viewing position is undefined and set equal to 180 [12], [11].

The creation of the visibility index for a given viewpoint is the next step of the algorithm. The visibility index is obtained by summarizing the results of the r.los module. We use the module r.stats for reporting the area statistics containing the number of the individual cells and the values of their vertical angles.

The following step is the counting of all visible cells with non-zero values. The final number is transformed into the spatial units (chosen by the user during the specification of the input parameters) and written into the output matrix in the corresponding place. It is transferred to the next cell later and the whole cycle is repeated. If the cycle is performed for all cells in the input ASCII grid, the final map in the ASCII grid format is created on the basis of the values in the matrix.

PATCHING OF THE INDIVIDUAL SEGMENTS

The results of the parallel computations – particular maps – can be patched by last part of the program into a final output map.

RESULTS AND DISCUSSIONS

Result of the computation process is a map of the potential visual exposure of the landscape in Slovakia, where each cell of the area matrix possesses a value of the Visibility index transformed into selected spatial units (km^2) and where the value of each cell presents a quantitative expression of the visual exposure potential of the land (which is given by the territory visible from the cell). Computations were done by setting of borders of potential visibility to 50 km for the Slovak republic.

VISUAL EXPOSURE OF SLOVAKIA LANDSCAPE

Visual exposure potential´s digital model is a result of software processing with resultant scale of visual exposure values from 0,09 km2 to 2207,1 km2 (Figure 2). Maximum visually identified area takes 7850 km2. Scale is passing from minimal exposure cell (whites) with initial value only 1.25 km2 of possible visibility to maximal exposure cells (reds) with maximum value up to 2207,1 km2 of possible visibility. Visibility of each point was derivated from area of a circle with a radius of 50 km what presents maximum range of visibility. The highest obtained value presents 28,11 % of total value of visibility. Our results showed that the highest value of possible visibility was achieved for the Babia Hora hill (1725 m a.s.l.) The Babia Hora hill belongs to Oravské Beskydy mountain and it is situated in the contact zone of the Slovac republic and Poland in the northern part of Slovak republic (Figure 2).

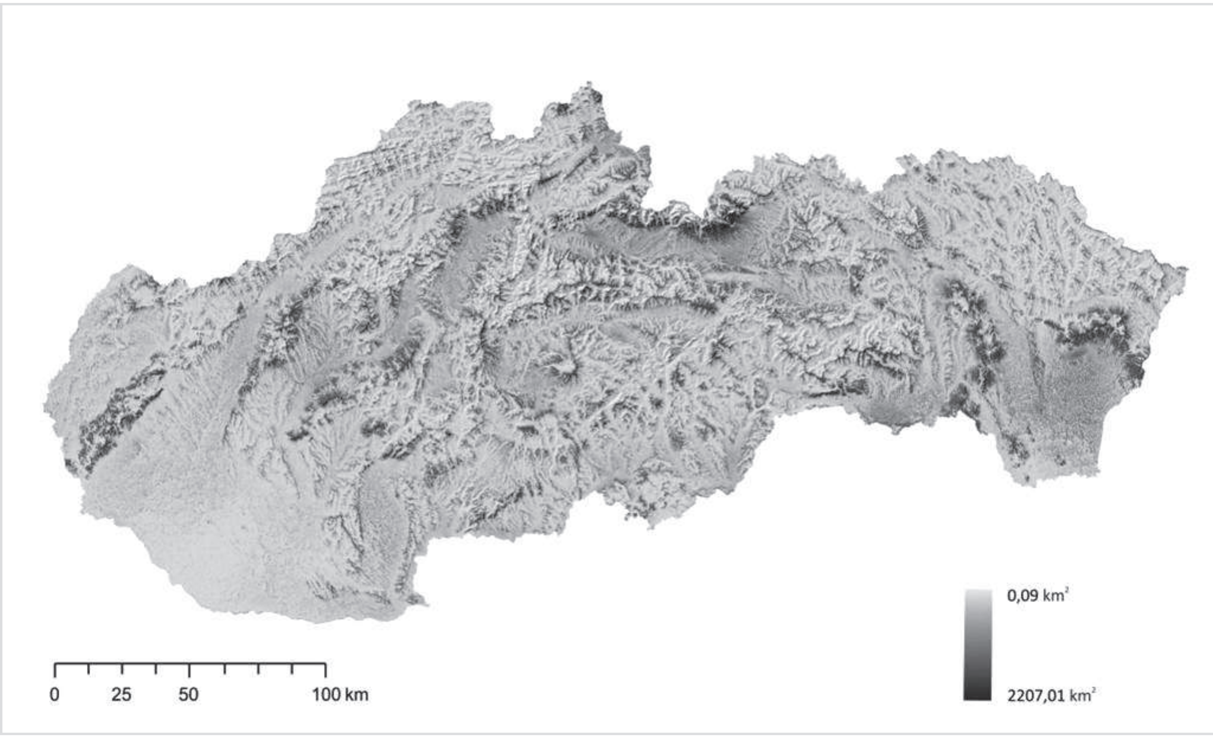

Fig. 2. The potential of the landscape visual exposure of Slovak republic.

These observations are in agreement with our assumptions, because of adjacent lowlands (Podunajská nížina and Záhorská nížina - lowland in the contact with Malé Karpaty on the west and Východoslovenská nížina - lowland in the contact with mountains of Slanské vrchy and

Vihorlatské vrchy on the east of Slovakia). Similarly, Zoborské vrchy with the peaks Zobor (585 m a.s.l.) and Žibrica (617 m a.s.l.) are surrounded by a wide Podunajská pahorkatina – hill land, what enables wide view on the localities. Smaller areas with the relevant value of 25% from possible maximum are scattered over the whole area of Slovakia with culmination on hilly and mountain parts Zoborské vrchy – Zobor (586 m a.s.l.), Štiavnické vrchy – Sitno (1009 m a.s.l.), Pohronský Inovec – Veľký Inovec (901 m a.s.l.), Považský Inovec – Marhát (748 m a.s.l.), Inovec (1042 m a.s.l.), Malá Fatra – Veľká lúka (1476 m a.s.l), Veľký Kriváň (1709 m a.s.l.), Považský Inovec – Marhát (748 m a.s.l.), Nízke tatry – Chopok (2023 m a.s.l.), Kráľova Hoľa (1948 m a.s.l.), Kráľova Hoľa (1948 m a.s.l.), Vysoké Tatry – Gerlachovský štít (2664,4 m a.s.l), Lomnický štít (2632 m a.s.l.), Poľana – Poľana (1458 m a.s.l.), Slánske vrchy – Šimonka (1092 m a.s.l.), Makovica (981 m a.s.l.), and Vihorlatské vrchy – Vihorlat (1076 m a.s.l.).

These localities are identical with the scenic and cultural-historical symbols of Slovakia. Further investigations were focused on identification of localities with relevant value of 25% from possible maximum and we made new visual exposure potential's digital model with good readability of High visual quality (Figure 3). This digital model defines areas with visibility from 25 % to maximum value. By visualization of the data, a map with the most potentially visually exposed areas in Slovakia landscape was created. The mountain areas in Malé Karpaty, Slánske vrchy and Vihorlatské vrchy.

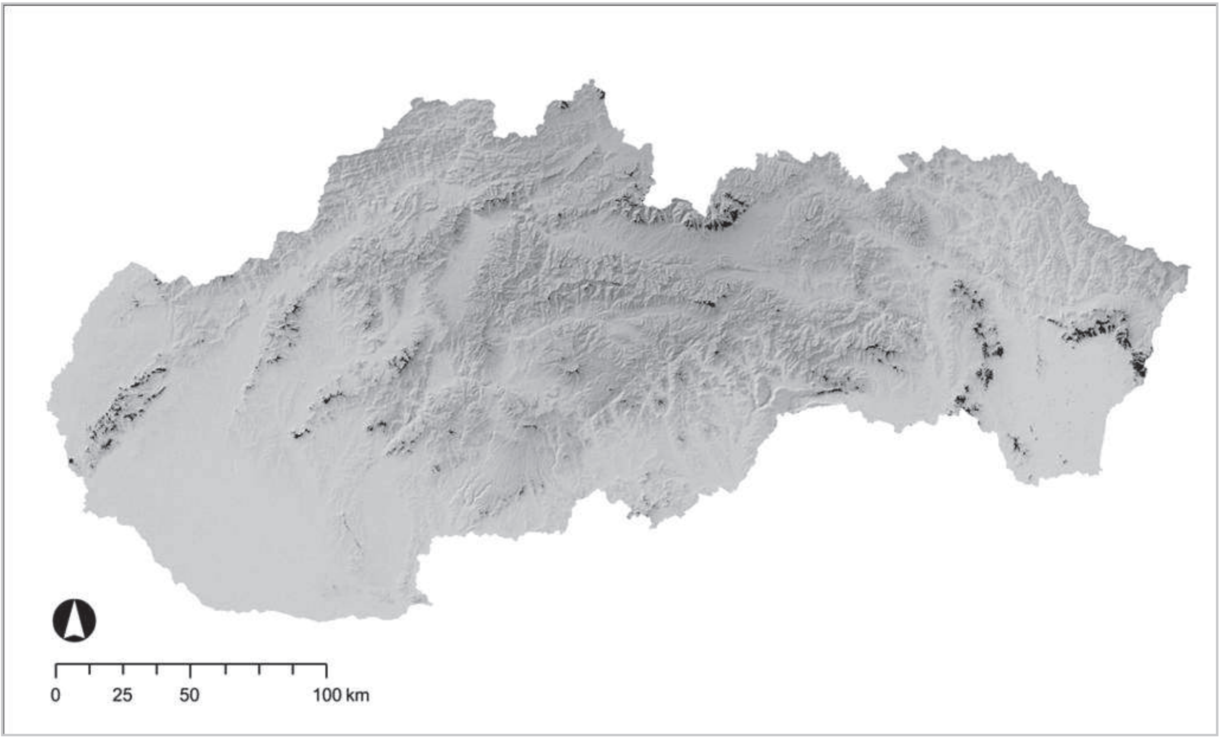

Fig. 3. The identification of the potential visible areas exceeding 25% of the possible maximal area.

USE OF VEP MAP IN URBAL LAND

The town of Nitra was chosen as an area of interest. The input map (ASTER © ERSDAC 2011, http://www.gdem.aster.ersdac.or.jp) with resolution 30 x 30 m was used for computation of visibility with the radius of 2.5 km. Town Nitra is situated on border of Danube plain (in town is the lowest point 138 m a.s.l) and Tribeč mountains (in town is the highest point on top of Zobor hill at 587 m a.s.l.). Landscaping dominants are well readable in field research for these reasons. The old town was established on seven hills like we used to say about Rome. Zobor, Hradný vrch (Castle hill), Kalvária (Calvary), Čermáň, Borina, Vŕšok and Martinský vrch (Martin´s hill) are hills in different heights but most dominant is massif of Zobor. Visual exposure potential´s digital model is a result of software processing with resultant scale of visual exposure values from 0.1 km^2 to 14.6 km^2.

Reclassification of Nitra city VEP was performed for identification of the most visual exposed areas in the city. The scale of five grades for VEP was set based on how large area can be identified from the each point of terrain. We divided the area into the categories of visibility as followed: category 1 (0-15%), category 2 (15 – 30%), category 3 (30– 45%), category 4 (45– 60%), category 5 (60 – 75%), category 6 (over 75%, this category was not observed in the area of interest), Table 1., Table 2., Figure 4.

Table 1. Area of individual category of visual landscape exposure

Category of visual landscape exposure	Area in square meters	Number of pixels
1	52,926,648.119034	58,795
2	41,435,727.747613	46,030
3	6,086,181.953113	6,761
4	205,243.231077	228
5	7,201.516880	8

Table 2. Univariate statistics of the non-null cells

n	111822
minimum	22
maximum	16245
range	16223
mean	3349.77
standard deviation	1941.13
median (even number of cells)	3133

The urban plan defines the primary dominants, which have importance in identification and orientation. These dominants are usually buildings. We propose an universal platform, based on relief, which creates potential of visual exposure.

We have prepared the model of VEP of Nitra town with good readability of high visual exposure. Figure 4 shows dominants of relief. This digital model defines areas with visibility from 25 % to 74.6 % (maximum value – Table 2).

We can say that results from this digital model and field research are same, but digital model points directly at results on exposure areas, which are the most sensitive places on interventions.

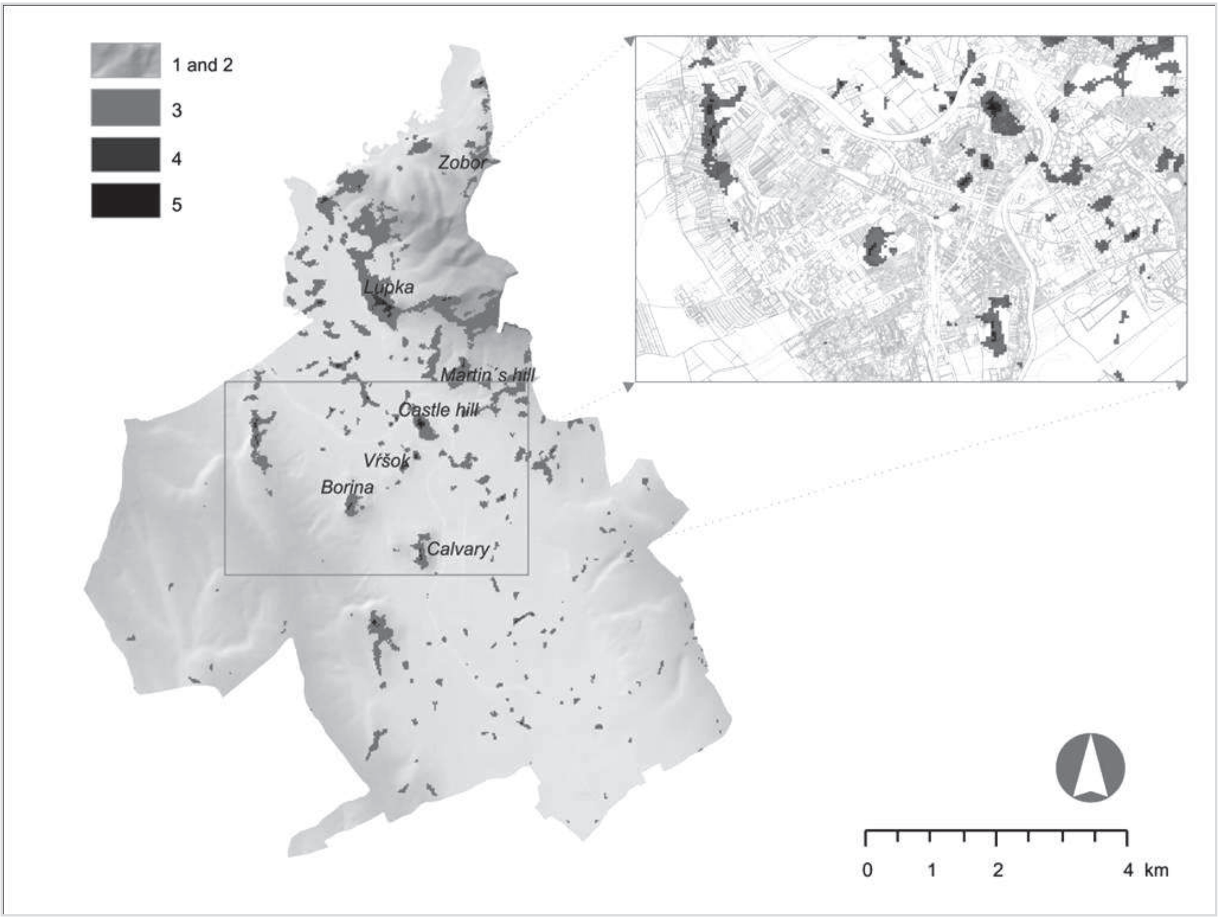

Fig. 4. Category of visual exposure of landscape potential in Nitra town. 1 and 2 – without significance, 3 – less significant, 4 – more significant, 5 – the most significant.

CONCLUSIONS

Our contribution was aimed at the use of the GIS software to develop a toolkit for modeling the visual exposure of landscape. The output of the process is a map of the visual exposure in which each pixel of the raster map carries information on the visibility index. The importance of the landscape visual information assessment is associated with the landscape planning activities and a visual impact on landscape. The current assessments depend on expertise which evaluates the landscape visual quality subjectively.

We wanted to create and test the model which would be used as an objectively measurable platform in the case of the assessment of real or planned activities with a visual impact on landscape. This would be a complementary tool for landscape planning activities. This method is applicable in landscape planning documents, in our conditions in green structure plan of residences. Software GIS solution is good choice for urban landscape visual quality assessment and making green horizons core for traditional urban landscape character of towns.

ACKNOWLEDGEMENTS

The work has been prepared with the support of grant projects KEGA 030UKF-4/2011 The visual quality in study of landscaping and landscape-ecological planning.

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USING VIRTUAL 3-D CITY MODELS IN TEMPORAL ANALYSIS OF URBAN TRANSFORMATIONS

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Abstract

Assessing dynamics of urban areas requires sophisticated methods and tools to better understand the processes affecting the on-going changes in the city structure (morphological, functional, social, etc.). Recent developments in geospatial technology have brought new methods for 3-D data collection (LiDAR, digital photogrammetry) that enabled greater availability of virtual 3-D city models that can be effectively used in such analyses. The 3-D city models provide new possibilities to analyse specific issues related to spatial relationships and processes in urban areas, such as morphological changes of urban areas including the vertical dimension, 3-D cadastral information, multi-layer functional use of buildings and various environmental issues having impact on people living and working in the city. In this paper we present a temporal analysis of the Sekčov area within the city of Prešov, Slovakia. This area has changed from agricultural and semi natural swamp to the biggest residential area in the city with more than 30,000 inhabitants. Recently, the area has also experienced rapid development of new shopping and entertainment facilities that strongly changed the appearance and free spaces in the zone. Therefore, we have developed series of 3-D city models from the 1970 period up to the current state and we demonstrate the visual, morphological and functional changes in this part of the city. We also demonstrate the application of 3-D city models in various 3-D environmental analyses, such as visibility, light and noise pollution.

Keywords: 3-D city model, transformation, Prešov, spatial analyses

Recommended Citation: KAŇUK, J., HOFIERKA, J., GALLAY, M. (2013) Using virval 3-D city models in temporal analysis of urban transformations. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Accessibility and production of 3D geodata for virtual 3D city modelling rapidly advanced in the last five years. The main reasons relate to the progress in methods of spatial data acquisition and means of sharing and visualising the 3D geoinformation such as Google Earth or Microsoft Bing Maps (Virtual Earth). The applications are very successful in providing publicly accessible effective visualisation of the earth surface and three-dimensional objects such as buildings, roads, or specific features of technical infrastructure. The data used for producing virtual 3D city models can be collected via a wide range of techniques. The airborne remote sensing techniques such as photogrammetry, synthetic aperture radar, and laser scanning (i.e. LiDAR) are the most applicable especially for larger urban areas. Remote sensing from mobile terrestrial platforms allows for highly detailed modelling of urban structures [1]. However, smaller areas can be more effectively mapped using direct ground based measurement with tachymetry or global satellite navigation systems.

The virtual 3D city models which include also the close surroundings of the city provide a realistic approximation of the urban environment which is more effective than the 2D analysis [1], [2]. 3D visualisation and virtualisation of a landscape intensifies the spatial impression and view of the users. Further, it increases the visual accuracy thus a more realistic portrayal of the landscape. Hence, the virtual 3D city models serve as input data for simulation of geospatial processes in which the third dimension (height) is essential. Ranzinger and Gleixner [3] summarised the main data sources, approaches and application realms for virtual 3D city models. Kolbe et al. [4] introduced several potential uses of the models for hazard management, including examining effects of floods on building storeys under a range of scenarios. Hofierka and Kaňuk [5] analysed distribution of solar radiation within the city of Bardejov using a simple 3D model. Law et al. [6] demonstrated noise modelling in an urban model of Hong-Kong considering the elevation of buildings and the presence of noise barriers. Thill et al. [7] demonstrated the feasibility of using three dimensional urban models for novel forms of route planning and optimal placement of facilities within the buildings considering vertical movements of individuals within buildings as well as between them. Yasumoto et al. [8] evaluated scenic amenity in a case study of the Kyoto city. Guney et al. [9] explored the use of 3D virtual city model for assessing the city skyline form different viewpoints. By this means they also identified maximal height of buildings in order to keep the aesthetic look of the skyline. Guo et al. [10] showed how 3D cadastre can be designed on virtual 3D city model. Wu et al. [11] discussed technical issues of developing a virtual globe-based 3D visualization framework for publicizing urban planning information using Web Services. At present, there is a wide range of software tools for creation of 3D city models based on CAD, VRML, or other architecture which is interoperable also with GIS software [12]. However, only few GIS tools exists enabling true 3D spatial analysis [13].

The outlined applications of virtual 3D city models are abundant but the potential of the 3D city models remains rather unexplored in studying the city dynamics and transformations. One of the pioneer works is presented by Acevedo and Masuoka [14] who visualised urban transformation of the Baltimore-Washington area via a time-series animation of 2D urban landscape features draped over a digital elevation model which was viewed from a 3D perspective. Construction of virtual 3D city models as time series going back several decades into the past is challenging as it narrows the available data sources to 2D data sources such as technical documentation, historical maps or photographs. However, issues related to uncertainty arise when using historical geospatial data [15]. Pacina et al. [16], [17] used similar types of historical data to generate a dynamic virtual 2.5D model of an open-cast mining area in GIS for studying the landscape change. Applications of time series of virtual 3D city models are rare but examples either based on a series of 2D historical geodata are abundant [18].

The aim of this paper is the 3D reconstruction of a part of a city for different time periods. In particular, the focus is on methodology for creation and use of virtual 3D city models in studying dynamics of urban landscape using a wide range of historical data. The methodology will be applied to the urban area of Prešov, Slovakia leading to series of 3D city models representing various stages of urban growth and development. Moreover, the 3D city models will be also used in 3D spatial analysis in order to show vast application areas of the technology.

METHODS AND DATA

The production of the virtual 3D city models for particular time period is central to the scope of the paper. In order to generate the models a retrospective approach was applied. The main idea is described in the following section. The proposed methodology for temporal analysis of urban areas using virtual 3D city models consists of three main steps: (i) production of virtual 3D city models for particular time periods as time-series, (ii) performing spatial analyses with the model time-series, (iii) identification of major factors affecting spatio-temporal changes in the urban area.

A retrospective approach to build a dynamic 3D geodatabase

Generating a digital database for 3D landscape modelling in high level of detail is a complex task. From the methodological point of view, creating the geodatabase for the current stage of landscape is relatively straightforward for great abundance and availability of relevant data sources. Performing similar task for the earlier stages of the landscape is more challenging as the range of applicable data sources becomes smaller. Historical maps are one of the most important data sources for modelling temporal snapshots of the landscape. However, generalisation, map scale and measurement accuracy limit the displayable level of detail as is discussed in Jenny and Hurni [15] or James et al. [19]. The real landscape features are eliminated, reduced or represented by cartographic symbols which do not hold the exact location and spatial extent of the features. For example, symbol of urban fabric with gardens supposes presence of trees but the symbol does not allow for exact location and number of the trees. The maps are schematized 2D models of landscape which are to be used for extraction of 3D geographic data. In this case study, a retrospective approach was adopted to achieve this task. The main idea is based on reconstructing the earlier stages of the landscape from the virtual 3D city model of the current stage which provides the highest fidelity. The current geographic objects recorded in the 3D geodatabes are eliminated or modified depending on their existence in the historical records. The adopted approach provides advantages to digitizing floor plans of the buildings directly from historical maps. Elimination of buildings and other man-made structures from current vector data avoids introduction of uncertainty associated with the measurement and georeferencing accuracy of scanned maps, or technical plans. There were other approaches proposed, e.g. Laycock et al. [20], where a semi-automatic approach was used to align historical maps with a current vector database. The approach applied in the paper assumes continuous evolution of the landscape reflecting the genius loci. In this way, the character of the landscape can be reliably modelled but there are limitations in expressing the absolute location, size, and number of particular objects. However, the ability to analyse spatial processes is preserved and that was important for the aim of this case study. For example, the series of 3D landscape models can be effectively used to analyse the change of skyline from a particular location. Another application is in reconstruction of the distribution of solar irradiation which relates to the changes in the quality of the environment (shadowing, heat, scenic amenity).

Study area

The research presented in this case study is based on production of a series of virtual 3D city models for the Sekčov area which is an integral part of the city of Prešov, Slovakia (Fig. 1). There are over 96 000 inhabitants living in the city in the northeastern part of Slovakia. The current stage of the Prešov City centre has been formed since 12th century but a marked morphological growth occurred in the 20th century. The change was related to industrialisation of the area which lagged behind the main stream of the former Czechoslovakia due to marginal position of the city with respect to main transportation routes, railways especially. Political and economic circumstances after the World War 2 were influenced by the Soviet Union and determined the most striking morphological expansion of the Prešov urban area. There had been a five folded increase of urban fabric since 1945 up to present. Progressively, several industrial estates were located in Prešov mainly machinery, electronics, metalworking, clothing, food and polygraphic industries. The industrialization naturally induced development of the third sector activities, transportation infrastructure, and urbanization in general. The population growth stimulated increase in housing construction focused on settlements of blocks of flats. Clusters of individual detached houses were also built.

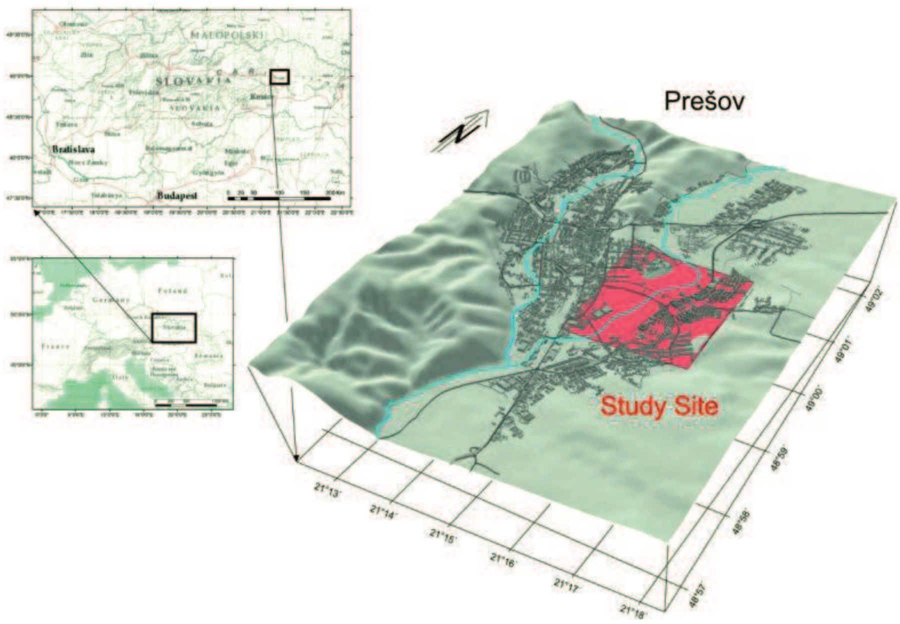

Fig. 1. Location of the study area (red square).

The approach for 3D city reconstruction is presented on the the area of the Sekčov urban settlement which is now the biggest residential area within Prešov providing home for more than 30,000 people. Originally swampy meadows on the alluvial plain of the river Sekčov were selected for their close vicinity to the city centre. The landscape was completely transformed. This process started in 1969 and construction of the first blocks of flats began in 1978. Beside the massive blocks, the construction involved public facilities for education, health care, and entertainment, small shops, hypermarkets, restaurants, etc. Construction of such facilities continues until present but the original plan was not fully achieved for political-economic changes after 1989. The original terrain parameters required specific preparation works. The river Sekčov was relocated into an artificial channel of 5 kilometres length. Its bottom is based about 2.5 meters deeper below the original terrain. The original channel was filled up. The swampy areas were meliorated and intermittent water streams were diverted into the main stream of Sekčov. These changes also affected the original land cover and other landscape features, such as hydrologic regimes, soil and microclimate.

The development of the residential area had 3 major stages: It started in the southern part of the area in 1978 and finished in 1989. The next stage (1989-1999) included blocks of flats with a complete technical infrastructure such as gas, power and water supply, sewerage, roads). Since 2000 the area has been filled-up with various commerce objects such as shops, services, etc. Currently, the new development is concentrated in new, previously empty zones.

The period of the mentioned landscape transformation is well recorded by geospatial data sources. Hence, it was possible to reconstruct particular stages of the Sekčov area as a series of virtual 3D city models of the present and its earlier stages. The models enabled dynamic modelling of selected geographic phenomena. The virtual 3D city model of the Sekčov area consists of three main feature types: digital elevation model, 3D model of buildings, and land cover model. The origin and use of data sources is further described with respect to the particular feature types. All data were measured or supplied as georeferenced in the national grid system SJTSK (EPSG: 5514, http://www.epsg-registry.org/).

Digital elevation model

The current terrain surface of the area was modelled from the ground surveyed points heights and contour lines (valid to 2010) supplied by the Municipal Office of Prešov. The Sekčov area has not experienced marked changes of the georelief in general. The parts where some changes occurred were not large enough to be represented by topographic height symbology just graphic symbols for features as (road cuts, embankments). Therefore in such circumstances, the terrain was estimated and designedly modified. For example, the area of a road embankment was elevated by 2 metres.

3D model of buildings

Current stage of the buildings was reconstructed from the data measured with electronic tachymetry supplied as a technical 2D geodatabase supplied by the Municipal Office of the city of Prešov. It was the most accurately measured data set used in the study (subcentimeter accuracy). The vertical dimension of the buildings and related facilities (e.g. chimneys, towers) was measured with a laser distance meter (submeter accuracy). The main objective was to capture the third level of detail [21]. In this way, the virtual 3D city model of the Sekčov area was generated and it comprised almost 1000 3D objects. The model represented the current/last stage of landscape analysed in the study valid to the end of year 2010. Modelling the dynamics of the case study area was based on the knowledge of its landscape evolution. As it was mentioned above, the area used to be mainly agricultural and comprised only few buildings before 1950. For that reason, it was possible to reconstruct the earlier stages from the current stage of the landscape for which the retrospective approach was used. The 3D building models for particular time period were eliminated from the virtual 3D city model of the current stage depending on their existence in the historical records. The attributes such as function, height, date of construction were assigned to each 3D building model. The exact date of building construction was ascertained from the date of building approval recorded in the archive data, Kohlmayer [22] and Matlovič [23]. Modifications, destruction or changes of general shape of the buildings was not identified in the historical records for the area.

Land cover model

The models of land cover were based on polygon representation generated using the 2D technical geodatabase of the city of Prešov, and by manual interpretation and vectorization of orthophotomaps (years 2002, 2009, spatial resolution 0.5 meter) and historical maps (scale 1 : 25 000 for period 1952-57, scale 1 : 10 000 valid to 1990). The land cover was classified into the following categories: permanent grass land, arable soil, forests, gardens, roads, railways, water streams, continuous urban fabric. It should be emphasized that the main aim was to express the landscape character for which trees make a significant 3D appearance. Hence, trees were treated separately as point objects with defined tree type and height. The current stage of land cover was reconstructed with regards to the highest possible accuracy using the high detail orthophotomaps and the technical geodatabase. By this means, individual trees were exactly located while for continuous areas of trees the trees were randomly located in order to portray the landscape character. Earlier stages of the land cover were reconstructed from historical maps aided by ground level photographs (from 1950 - present) and interviewed local inhabitants. Due to generalisation and map scale issues, many features were represented as symbols (e.g. roads) in the historical maps while their spatial extent was reproducible only from the most current geodatabase and orthophotomaps. In such cases the existence of the feature was important and the spatial extent was estimated. In other case, some features were not displayed due the same cartographic reasons and we assumed their presence in the landscape as, for example, shrubs along the river or trees in the urban areas (parks, gardens, etc.).

Dynamic virtual 3D city model

The individual models for particular stages of the study area represented a chronological sequence of landscape snap shots. The dynamic model of the area is represented as animation generated by integrating the time-series into a single model. In order to ensure a smooth transition between the landscape stages the snapshots were artificially densified. It improved the perception of the landscape changes especially for cases of rapid change from arable soil to urban fabric. The inter-stages were produced by modelling the transition from stage A to stage B by estimating the change of the height and character of the land cover.

Spatial analyses

Time series of 3D city models provide a valuable dataset that can be used for various spatial and temporal analyses. While standard GIS packages provide a plenty of 2D functionality in this area, sophisticated 3D tools are still rather sparse. Most of current 3D GIS tools are limited mostly to visualization and simple data handling [24]. It is clear that more work has to be done to develop a comprehensive toolbox of spatial operations applicable to 3D data. To demonstrate a wider applicability of our approach, we have selected 3 application areas with relatively simple methods and tools readily available within GRASS GIS and ArcGIS software packages.

Solar radiation modelling in urban areas has become quite popular in solar energy applications because many solar energy systems can be installed in built-up areas, on roof-tops or even facades. This however, requires a complex spatial database with 3-D data representing buildings or other features within the area. Hofierka and Kaňuk [5] have presented a new approach to assess the solar resource potential in urban areas using solar radiation tools such as PVGIS or r.sun of GRASS GIS. Recently, Hofierka and Zlocha [13] have presented the extension of the r.sun module to 3D using a combined raster-vector approach. This work also includes several application examples from the Prešov urban area represented by a simple box model.

Flood-risk analysis is another common application of 3D city models . This is due to a relatively easy comparison of water table height to buildings height or other landscape features. In our study area we have a river that can pose a risk to built-up areas. To demonstrate the flooding event we have applied a simple operation. The flood level was modelled as a linear trend surface of the water table of the river Sekčov. The planar surface was raised 2.5 meters above the river level valid to the particular time period which simulates a flood wave of 2.5 metres height.

The traditional 2D parcel maps are poorly applicable to the complex urban features, such as multi-stage buildings with many owners, tunnels, underground constructions, etc. The natural solution for urban areas is a 3D cadastre. It is a discrete division of 3D urban area to 3D cadastral entities representing volumetric parcels and buildings. Using 3D cadastre we can analyse spatial relationships among volumetric parcels and parts of the building. The cadastral data can be also used to identify various functions of the cadastral entities within the building. This especially valuable as a particular building does not have a unique function, it could have several functions, for example, residential as well as commercial use of blocks of flats are quite common in Slovakia. To develop a 3D cadastre information, we need a detailed data about the building and internal structures defining cadastral entities.

RESULTS AND DISCUSSION

Using the suggested methodology and data described above, we have created 3D city models for 6 time horizons representing distinctive periods of development in the Sekčov area. Fig. 2 shows the situation before the start of development. The area has dominantly an agricultural and seminatural character. In 1969, the development started with new buildings in the older parts of the city (Fig. 3). The massive construction of the new residential houses started in 1978 along with some buildings with non-residential function (Fig. 4). This period also affected some seminatural features of the area, such as relocation of the river and terrain changes. These changes had also a very important effect on other spatial processes, such as flooding and land cover changes. Period starting in 1989 shows almost a complete residential development (Fig. 5). This period is closely related to the social changes in the Slovak republic with a major impact on economic and social situation of many inhabitants of this area. A former state-sponsored development was halted and former renters of flats were allowed to buy flats and become owners. The period of economic prosperity brought renewed interest in the development of new blocks of flats and construction of some new non-residential buildings mostly with a commercial function. After heavy construction in previous decades we can see also changes in land cover with gradual increase of shrub and tree vegetation (Fig. 6). The most recent stage of the area is associated with a rapid development of new commercial facilities, especially large-area shops (Fig. 7).

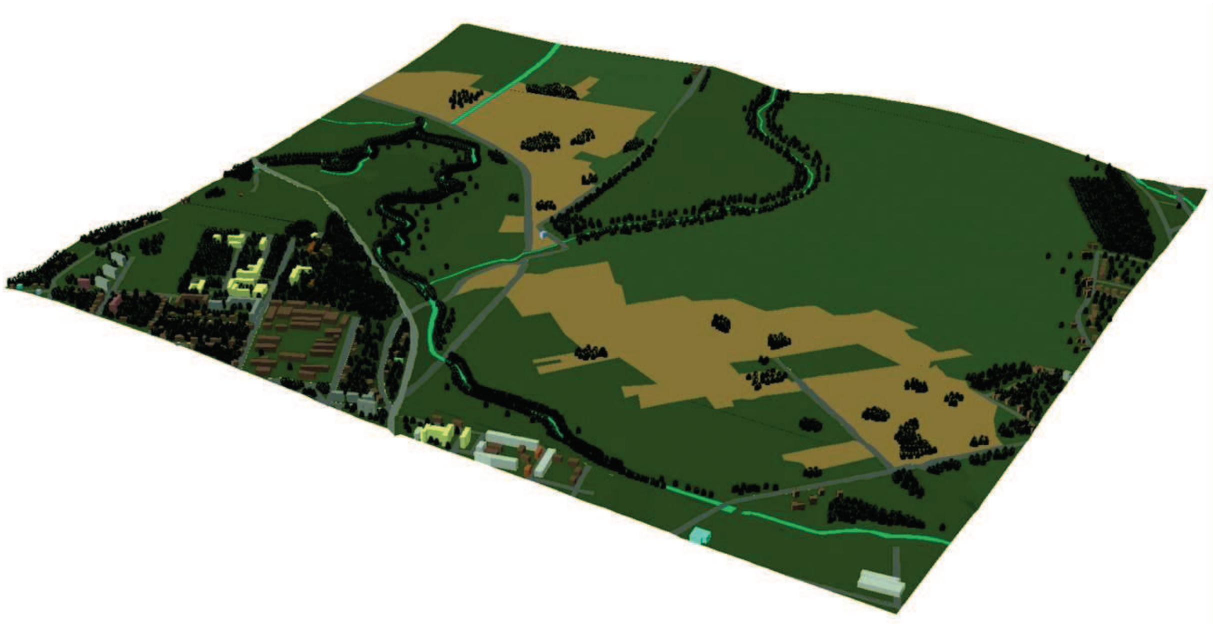

Fig. 2. 3D city model representing the Sekcov area in 1959

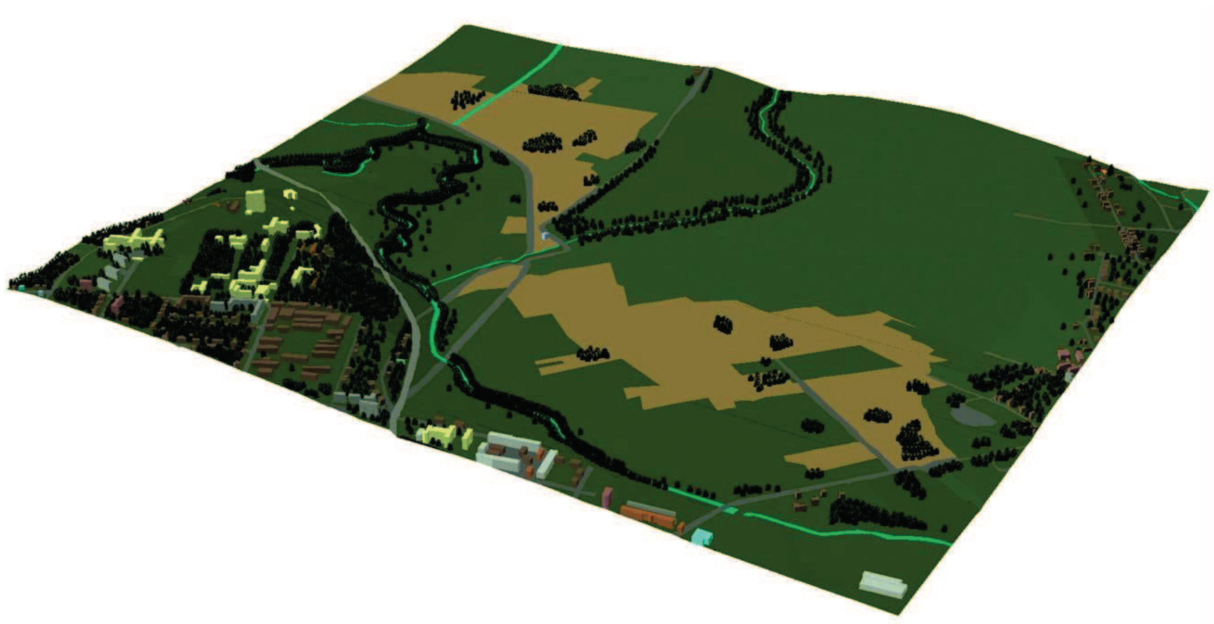

Fig. 3. 3D city model representing the Sekcov area in 1969

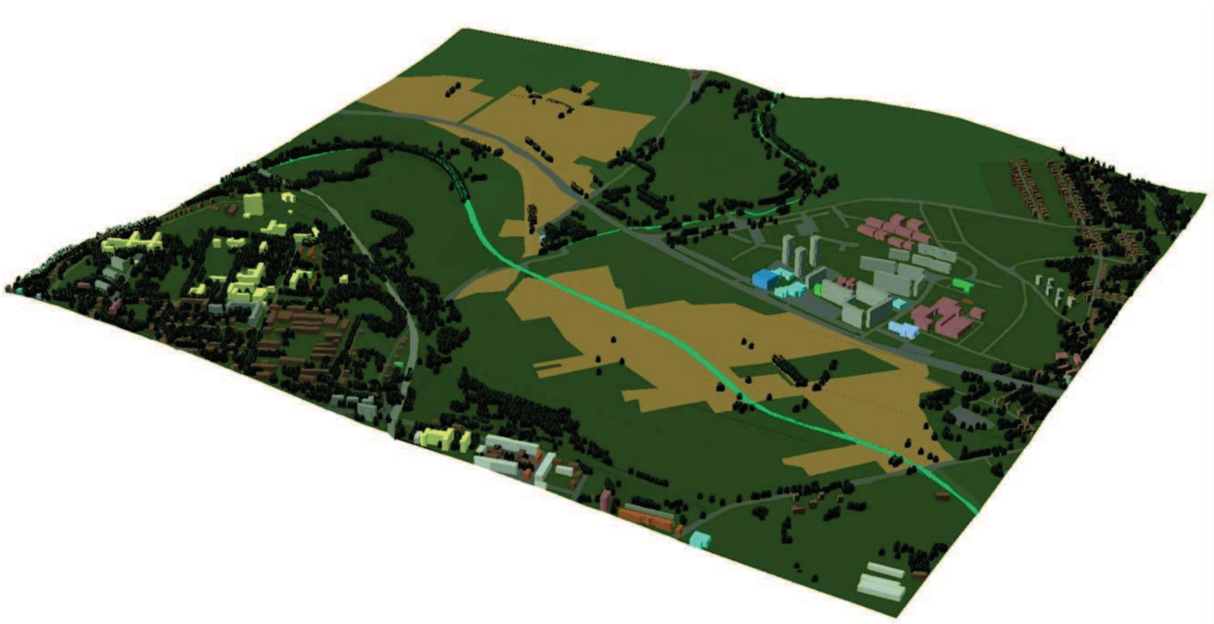

Fig. 4. 3D city model representing the Sekcov area in 1979

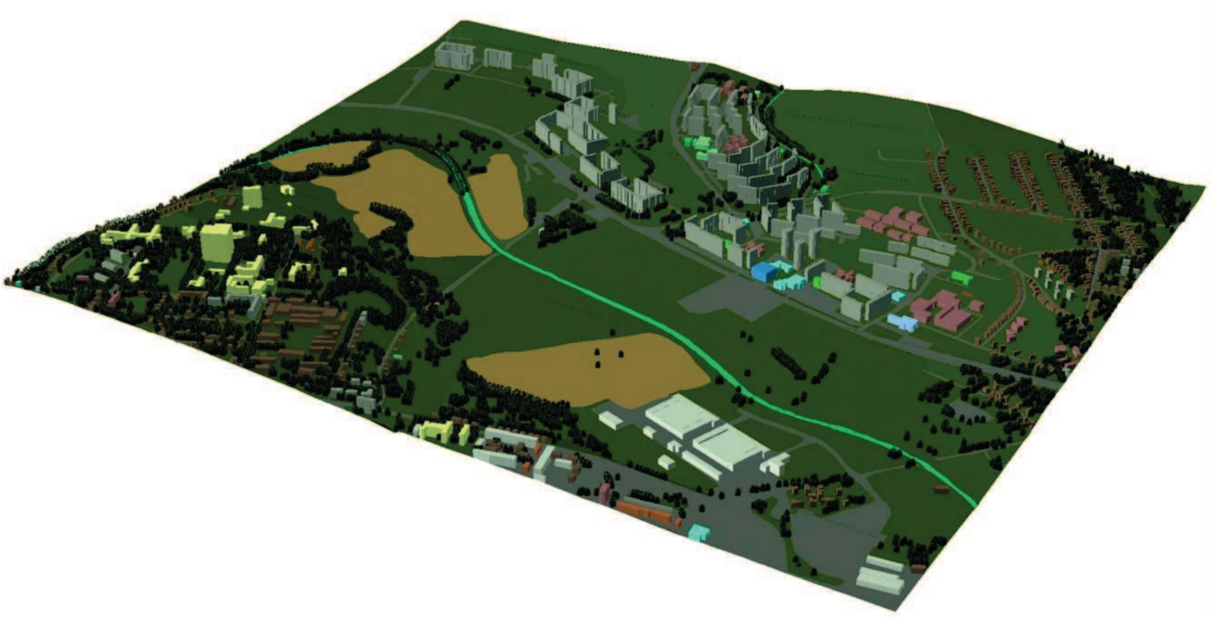

Fig. 5. 3D city model representing the Sekcov area in 1989

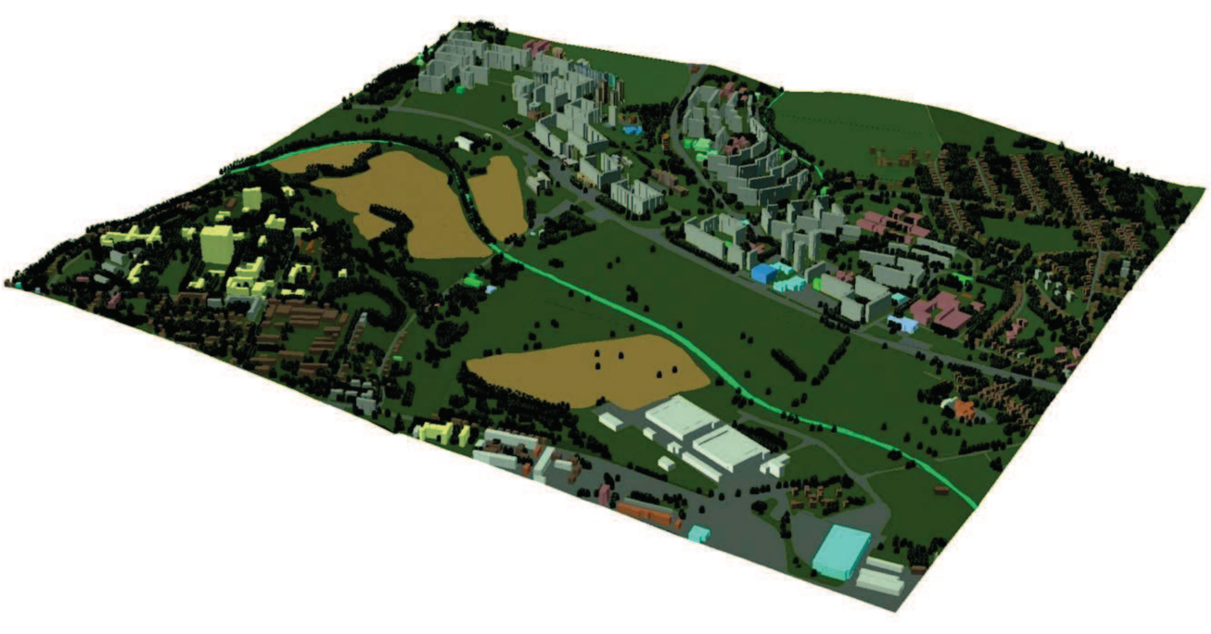

Fig. 6. 3D city model representing a development of the Sekcov area in 1999

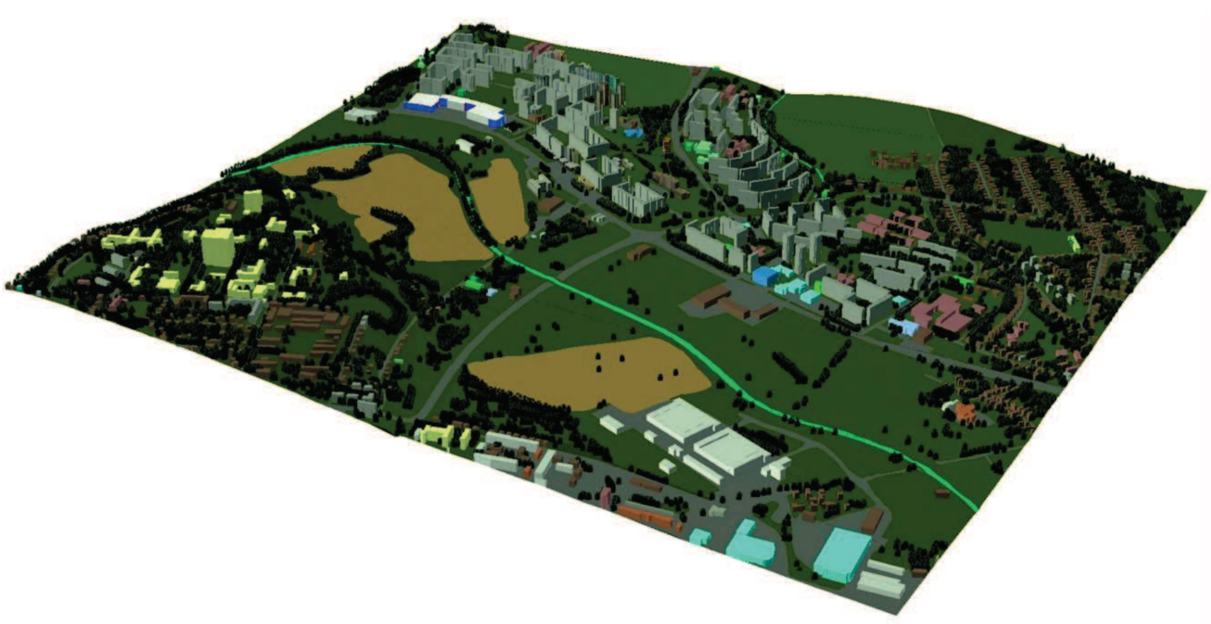

Fig. 7. 3D city model representing a development of the Sekcov area in 2012

To demonstrate a wider applicability of temporal series of 3D city models, we applied a simple flood-risk analysis to our study area with different time horizons. Figure 8 displays the scenario before any major changes in the landscape occured. The flood level is set to be 2.5 meters above the Sekčov river table at that time. Figure 9 shows the scenario valid for the current stage of the landscape after melioration works and relocation of the river into an artificial channel which was cut ca. 2 meters deeper into the ground than the original channel. The flood level is set 2.5 meters above the river level in 2010 and the flood risk was clearly reduced. This demonstrates how spatial-temporal changes of landscape influence the flooding hazard a risk to human activities. The third dimension of the model allows not only for identification a building flooded but also up to which floor it is likely to be flooded.

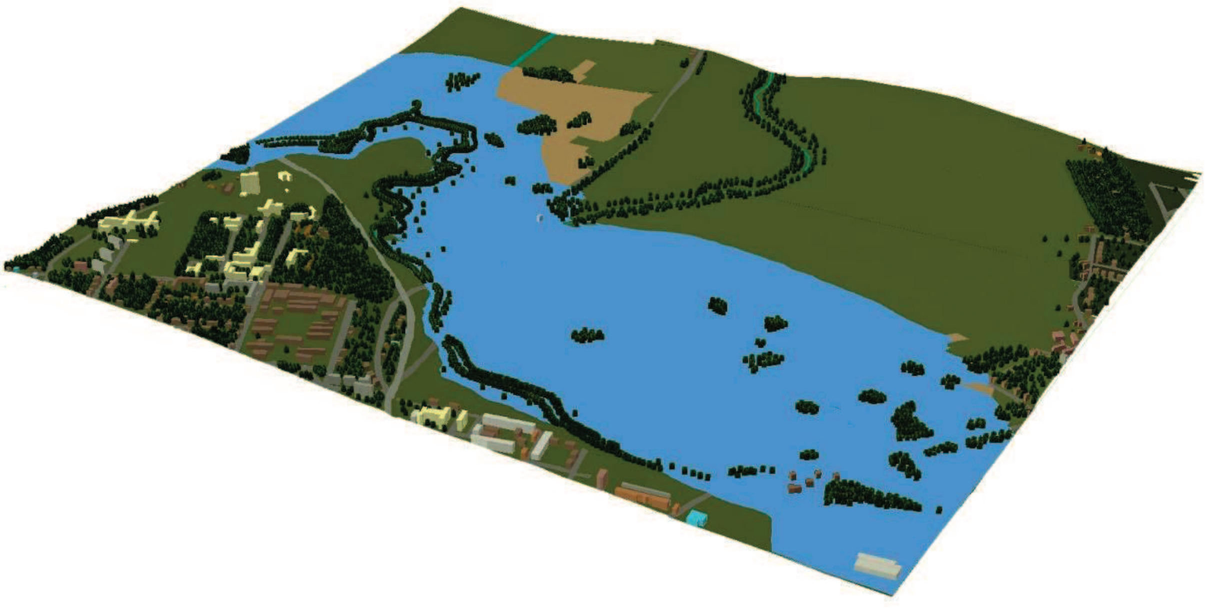

Fig. 8. Estimated flood impacts in 1959

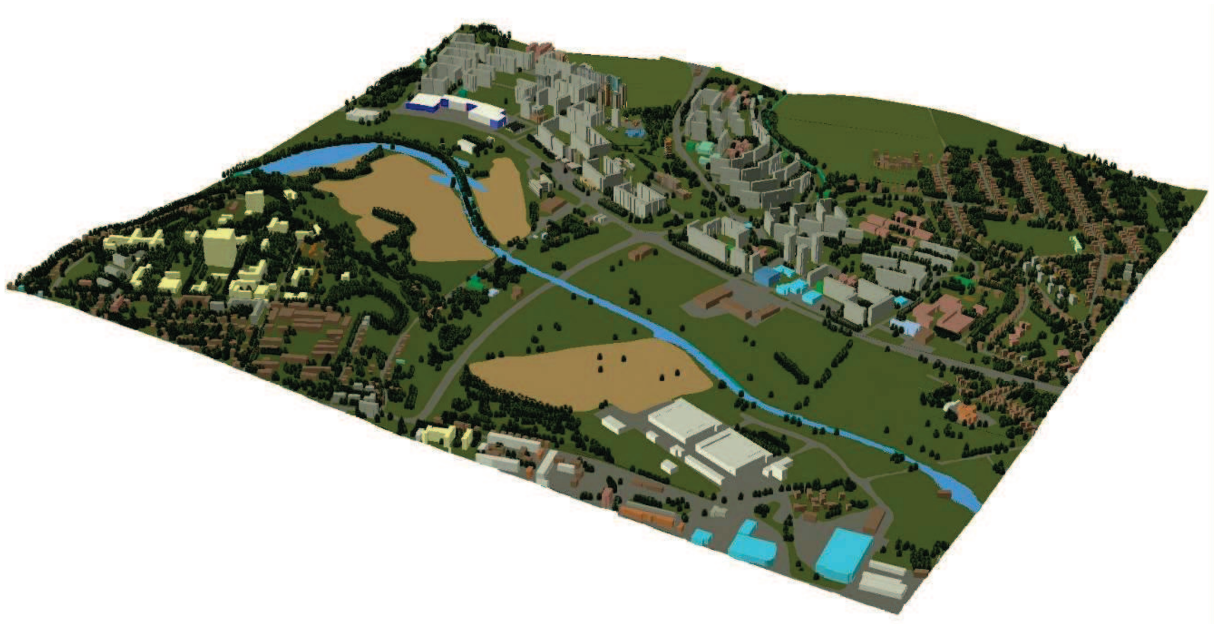

Fig. 9. Estimated flood impacts in 2012

Over the last 5 decades our study area experienced rapid changes in many landscape featues. These morphological changes are clearly visible only using 3D city models. However, thanks to profound societal changes that started in 1989, we can found also very important functional changes in several buildings. Many residential buildings were state-owned, later former renters were allowed to buy flats and become owners. Moreover, some part of these blocks of flats lost a purely residential function and became polyfunctional buildings (Fig. 10). Without 3D city modelling it would be very difficult to express in a GIS database all spatial context and relations. This information is also needed for 3D cadaster that is planned to be implemented in Slovakia.

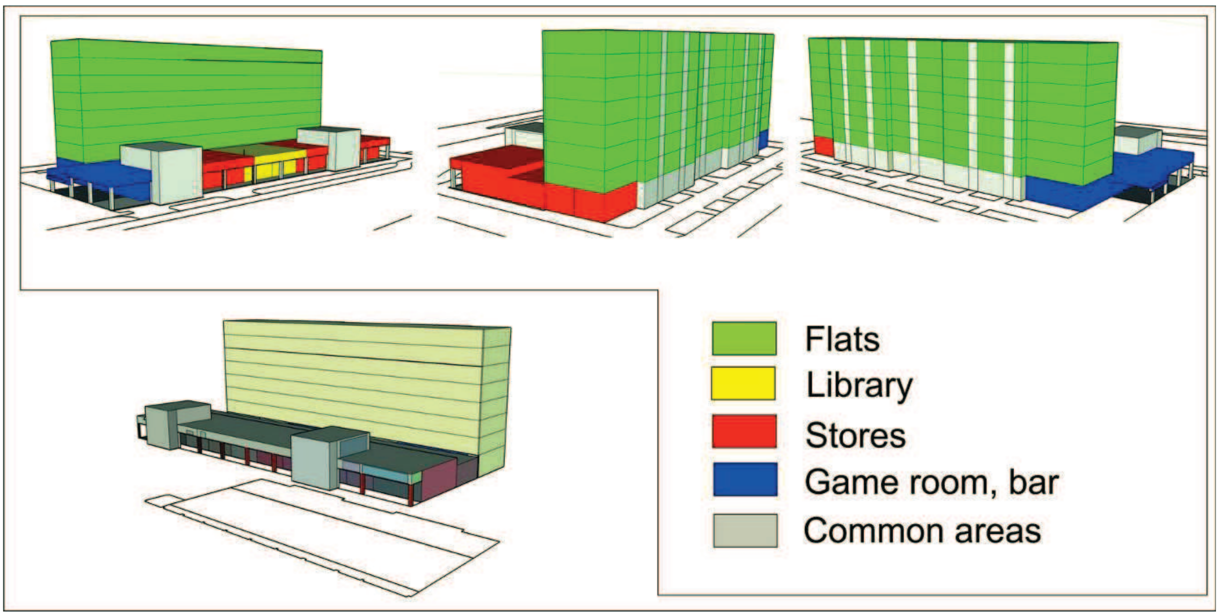

Fig. 10. Data from a multipurpose 3D cadaster show different functions of the building

The reliability of the generated 3D city models depends on the character of the reconstructed landscape features. The spatial location and geometry of buildings is the most reliable as the most accurately measured data were used for their reconstruction and also for buildings being the most stable features in the study area in terms of their change in time. Current stage of land cover features is also highly reliable because it is based on the current and accurate data. The reliability of the 3D model decreases proceeding back to past. The reason is that the older stages are modelled mainly from 2D maps which portray just the general character of landscape relatively reliably. Due to cartographic generalization it is not possible to judge the exact location, account and height of land cover features. From the methodological point of view, the 3D reconstruction of an urban landscape as a time series is in fact an approximation of the past reality. It depends on understanding the landscape and knowledge on the landscape of the particular expert. Hence, it is difficult to automate the generation of the 3D model although it is possible into some extent. A database comprising the dates of building approval (construction finished) allows for dynamic rendering of particular time stages. Succession of vegetation could also be automatically rendered by estimating the ratio, density and height of trees, scrubs and grass species.

CONCLUSIONS

A greater availability of virtual 3D city models has brought new possibilities in research of dynamics and spatial changes in current cities. In this paper, we have presented a simple methodology for creation and use of virtual 3D city models derived from various data sources including old historical maps. Virtual 3D city models provide a unique new tool to better understand the morphological changes in built-up areas, considering the vertical dimension. This has profound implications for urban growth research and analysis, as well as many other application areas. In comparison with a traditional 2D visualisation, the 3D models provide improved perception of the landscape which is more natural for human understanding and can not be achieved with 2D maps.

Using the case study of the Sekčov area of Prešov, Slovakia, we have shown rapid changes in this segment of the city that included not only buildings but also georelief and land cover. The dynamic virtual 3D city model consists of a sequence of digital models representing important landscape features, such as georelief, buildings, land cover or other city features having impact on the further development. Using a temporal analysis of this model the researcher can assess trends and various implications for future development of the area. New 3D spatial analysis tools present very important part of the methodological equipment for any researcher dealing with urban areas. These methods can identify critical spots or segments of the area that need a more targeted planning or different development plans. We have explored 3 application areas of spatial analysis using 3D city models to identify possible problems in our study area: solar radiation modelling, flood-risk analysis and analysis of 3D cadastre situation to demonstrate the applicability of the adopted approach. The presented reconstruction was undertaken for a city part constructed on a green field. If the historical evolution of the modelled area is more complex (e.g. construction, demolition, and new construction of buildings) additional approaches should be also explored. The presented methodology can be applied for other types of urban landscape bearing in mind that relatively accurate and diverse data are available.

ACKNOWLEDGEMENT

This work has been carried out within the scientific project VEGA No. 1/0272/12 "Spatial analyses and modelling for a 3-D GIS" funded by the Ministry of Education of the Slovak Republic.

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SELF-ORGANIZING MAP ALGORITHMS TO IDENTIFY SUSTAINABLE NEIGHBOURHOODS WITH AN EXAMPLE OF SZEGED (HUNGARY)

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Abstract

The housing market involves substantial diversity over space and product categories as it develops across localized city units. Especially amidst city transformations taking place in the Central and Eastern European (CEE) context such processes are dynamic. The paper analyses such localized housing market outcomes and sustainable development in Szeged, Hungary, during the period 2000-2009. The aim is to see to what extent these two patterns overlap. Housing market outcomes comprise data on averaged house prices and sales volumes. Sustainable development is defined in terms of environmental, social, cultural and economic features of the built environment.

The analysis is mainly descriptive and based on interview, field inspection and house price modelling using the self-organizing map (SOM) and the method of fixed time-windows. The analysis replicates prior analysis of Budapest. The results point to a rather heterogeneous urban housing context, which much involves green and mixed settings, often with accessible public transportation. These findings are by definition elements of urban sustainability. The conclusions furthermore suggest that a relatively well-developing regional city such as Szeged might be more successful in generating sustainable urban housing market locations and micro-environment than a capital city such as Budapest.

Keywords: housing market, sustainable development, built environment, the self-organizing map (SOM)

Recommended Citation: KAUKO, T. (2013) Self-organizing map algorithms to identify sustainable neighbourhoods with an example of Szeged (Hungary). In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

When investigating the changes taking place in urban environments, housing market analysis at the local level is for long time already seen as a relevant research topic. In urban housing economic theory a longstanding issue of interest concerns the various determinants of relative house prices within a city. In the seminal works carried out already in the 1970s large variations in significant factors were found across urban areas: in some cases accessibility to city centre was the key whereas in others the environmental and social factors had a stronger influence on price levels [1], [2]. Since the 1990s the research gained more momentum due to contributions that accepted a more dynamic and complex mechanism of house price development than the hedonic approach in its simplest form (Hedonic pricing is an increasingly popular method aimed at establishing an equation between the price and the characteristics (descriptors) of a consumer good – in this case the home. Using multiple regression analysis techniques, actual market transaction records and large datasets of the descriptor values, the model can be 'parametricized', and, partial prices for each descriptor isolated. The method is well established since the 1970s) [3], [4]. Localized price developments and market activities provide signals of how a city is diversifying in a more or less organic sense as some areas are showing growing and others declining tendencies in their economic fortunes when patterns of housing market change is observed. On top of the price development target urban sustainability is more recently being incorporated as a more qualitative target of evaluation [5].

This study follows such research traditions as the aim is to compare the price development with various sustainability aspects across a variety of locations and typical market segments. This demonstration uses house price and turnover data on Szeged and follows the research design of a prior study on Budapest (the capital of Hungary). The data sets for the years 2000-2009 are run with a quasi-dynamic modelling approach based on the self-organizing map (SOM) and fixed time-windows. The interviewed experts represent real estate business, local government and NGO sectors. Finally, field inspection is carried out. This paper documents some preliminary results of work in progress.

URBAN HOUSING MARKET ANALYSIS

Intra-urban spatial house price differentials and their development in time are interlinked with various locational influences. Among such factors, the physical environment is always important, because it changes slowly. Furthermore, institutions and socio-demographics are growing in importance, when looking at the generic categories of spatial housing market features. In this literature, typically, American, British and Australian cities are covered – relatively little is conducted from mainland Europe, and even less so from the Central and Eastern European (CEE) circumstances. This research is based on traditions of urban economics (pricing, supply, demand) or urban geography (mobility) in their standard forms, that is to say, assuming some form of equilibrium in outcomes [6].

Since the 1990s the emphasis on urban housing market analyse has been diverted on behavioural factors, feedback mechanisms and complexity. In this framework an certain area may experience an upward or downward development in value, depending on the time of development and its current image. The investment will either enhance the potential of that location, thereby attracting further investment, which increases the value further, or lead to dilapidation, a loss in potential, absence of investment and a further decrease in price-level. The trend may however be reversed in the area in question. Such processes are temporally and spatially specific, and lead to a mosaic of various price-segments with different degrees of substitutability among them. The questions to answer are how physical, socio-demographic, financial and administrative factors shape the housing choices of individual households and this way the urban form. Again, the CEE context here offers a special interest element due to the quick pace, comprehensive nature and large spatial scale of such changes in the urban mosaic [6].

SUSTAINABILITY ASPECTS RELEVANT FOR URBAN DEVELOPMENT

Within the widespread sustainability discourse buildings and land use issues occupy a core position from c. year 2000 onwards. In the physical sense land and buildings are increasingly subject to monetary sustainability evaluations along environmental, social, cultural and economic dimensions. This is evident in the discourse surrounding certification of relevant sustainability features or the lack thereof [7], [8], [9], [10], [11]. For operational purposes related to such evaluation, I have picked twelve broad issues surrounding the urban land use and real estate sustainability agenda. These are listed as follows, starting from the most localised to the widest scale, based on literature:

1. Energy efficiency in buildings (during their life cycles)
2. Use of renewable energy in buildings (during their life cycles)
3. Pollution control in building (during their life cycles)
4. Real estate quality
5. Real estate affordability
6. Real estate diversity
7. Optimal density for a block/neighbourhood
8. Public transportation availability (functional issue)
9. Traffic pollution (ecologic issue)
10. Social cohesion in the neighbourhood/city/region (including favouring local products and labour)
11. Communicativeness in local/regional planning (governance transparency)
12. Innovativeness of the region (economic sustainability, including financial transparency of corporations).

In the present study the emphasis is on the factors 4, 6, 7, 8 and 9, due to their relatively easy identification during field inspections.

METHODOLOGY

While the sufficiently accurate linear hedonic regression modelling of the housing market has proved successful, alternative approaches allow researchers to capture the complex nature of the housing market relationships. The self-organizing map (SOM, [12]) is a type of unsupervised neural network technique with a competitive network architecture (The neural network is such a sophisticated statistical method that captures nonlinear, but regular associations (i.e. patterns) within a data set without a pre-defined model). The SOM is best defined as a mapping from a high-dimensional data space onto, a (usually) two-dimensional lattice of points. This way disordered information is profiled into visual patterns, forming a landscape of the phenomenon described by the data set. The SOM produces a feature map of nodes, each of which represents a characteristic combination of attribute levels. In the training procedure of the algorithm the matching is usually determined by the smallest Euclidean distance between observation and response. The results are strongly dependent on the data – all necessary guidance to the analyses is obtained from the sample we feed the network and from the compulsory network parameters. A label is assigned for recognising, for instance a symbol for a particular area, where the particular combination of characteristics is typical (street name in this case).

Thus the output nodes receive 'hits' by one or more observations with strong resemblance in terms of the input variables. This technique works in three steps. First, to predefine the surface in terms of the number of potential clusters (nodes) and the parameters for adjustment of this map-like surface (feature map). Second, to train the map using a dataset of m observations (cases) measured as n variables (map layers). Third, to examine the resulting feature map in terms of similarities between nodes and intensities of any nodes with respect to a given map layer. The similarity and intensity of any nodes can also be identified across all map layers when the location of a given node is fixed across these layers by definition. The figures 1 and 3 to 12 illustrate the outcome of this projection, clustering and discrimination process. Here each node (i.e. circle with shading) represents a certain type of observation, its shade denotes the intensity of a given indicator (e.g. price) and its the position notes similarity and difference to other types of observations. AS for the reliability of these clusterings, it depends on the number of 'hits' per node, which in turn depends on the data quality and quantity.

The main principle of functioning in the SOM could be described as 'the winner takes all'. The winner is the node with shortest distance to the observation vector, and its weights are adapted towards the observation. This goes on until all observations are used for training – usually more than once. Neighbouring nodes on the map are being similarly adapted towards the observation, but the extent of this depends on the selected parameters. During the training procedure each node obtains a multidimensional numeric value where the dimensions correspond to input variables. The variation in numeric values across one input variable can be shown visually as a map-layer (see Fig. 1). Here are two important notions: *the similarity* between units within the structure, and *the typical properties* of a given unit with respect to the input dimensions.

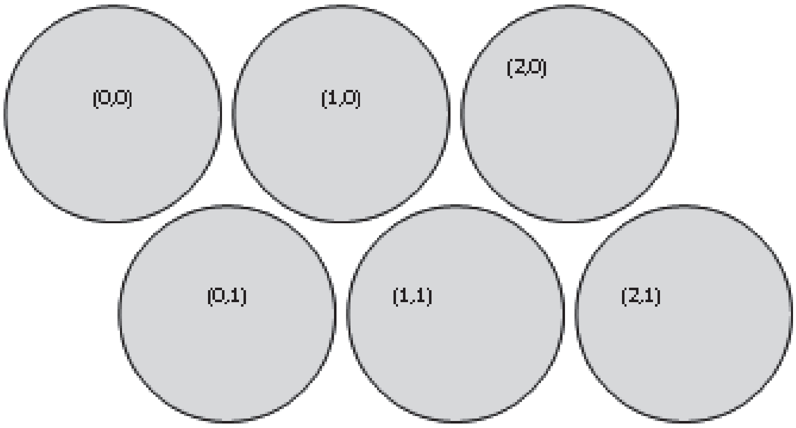

Fig. 1. The situation of the nodes in a three-by-two (3x2) map.

This technique has the following advantages:

- It comprises a holistic, pragmatic and fuzzy method.
- It enables incorporating a qualitative element beyond number crunching.
- It enables detection of combined effects of the input variables together with non-linearity and diversified effects

Unfortunately it also has some caveats that limit its use:

- It requires a *priori* selection of the number of nodes and other parameters.
- It is a ‘black box’.
- Any changes that take place between two points in time (i.e. snapshot) are not captured as the time-windows sequence is merely ‘quasi-dynamic (see below).

The real challenge for an analysis of price data based on the SOM is to incorporate the dynamic dimension. If time is one variable among others, then the rigid map cannot adapt new observations. However, a solution for this problem is to use fixed time-windows [13]. Using the fixed time-window method by, the procedure is to run cross-sections for each year and from the resulting feature maps identify changes in the trend of a given variable on the one hand, and in the fundamentals of this variable on the other.

To sum up the methodology, the SOM was used as a tool for reduction of dimensions of the input data, and subsequently for clustering of the observations based on these reduced dimensions. Here the time windows technique enabled incorporating temporal dynamics too (albeit in a quasi-dynamic manner). This modelling method was subsequently applied together with more qualitative research strategies (see earlier work on Budapest [14]).

MORPHOLOGY OF SZEGED

Szeged is a regional city of c. 170,000 inhabitants (thus one tenth of the population of Budapest). While it has a critical mass and universities, it is not being part of a particularly well performing region. Szeged in itself is however a growing city much thanks to having managed to attract EU funding. This also can be seen in the physical structure which in recent years has improved significantly, in particularly in the inner city areas. On the other hand, we are talking about a historical city with vial position in the Austro-Hungarian monarchy. Compared to its size the urban structure is remarkably dense. The city structure of Szeged much is determined by the comprehensive planning and rebuilding that resulted after the great flood in 1879. As seen in Fig. 2, the ring structure is much reminiscent of that of Budapest (but without the elevation of Buda side).

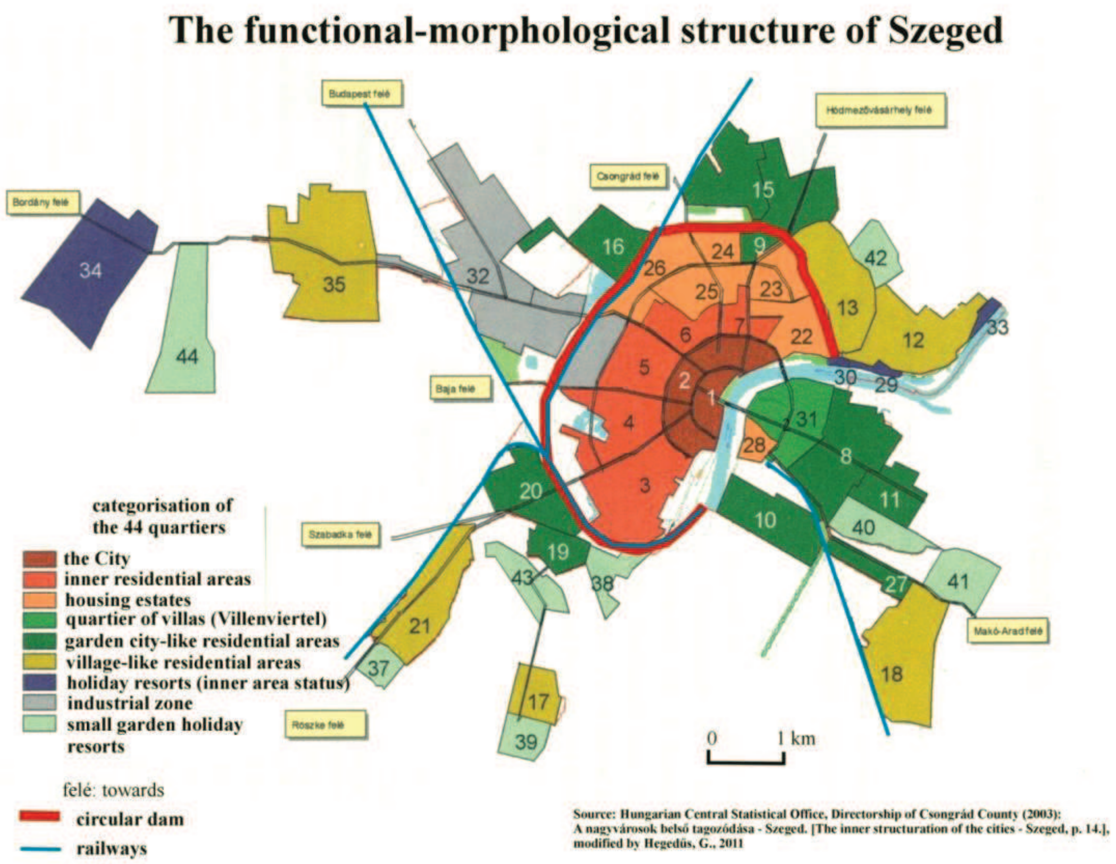

Fig. 2. The city structure of Szeged

In today's circumstances the city development proceeds as follows:

- The inner areas are being filled in rather than the outer expanded.
- Not much row houses since the 80s when it was a popular building type (applies for the whole country).
- The best area (in the sense of having the most expensive property prices) in Szeged:
    - The most expensive plot values: District 2, the Jewish quarters: Belső Városrész (inner parts of the city);
    - The most expensive building values: District 11, Marostő, single family area in Ujszeged.

- The worst area: Dorozsma (district 35): medieval infrastructure, dangerous, used to be a village but now very bad Roma ghetto; the worst in the inner city: Cserepesi sor – Roma neighbourhood with social housing (LKV) in District 4.
- Alsovaros (district 3) and Moravaros (district 4) have undergone gentrification – this has led to dominance of condos instead of peasant housing.
    - Refurbishing.
    - Demolishing and new built.
- Ujszeged (the part west of the river Tisza) is less densely built and thereby does not have so bad areas.
- In Szeged an active mayor Laszlo Botka (socialist party) with a strong lobby got large amount of EU funds. In fact, Szeged received most funds of all Hungarian cities. As a result Szeged is vibrant. (It is speculated that the voting base of the socialists corresponds to the housing areas 26, 25, 24, 23, 6 and 7 – the 'Red Belt' in the northern parts of Szeged. (These are housing estates, except districts 6 and 7 which are inner city residential areas.)
- Only a few new projects have been launched in recent years:
    - *Arkad* shopping center at the edge of the Jewish Quarter in the inner city (district 2); it is already functional at the time of writing.
    - Due to the expensiveness of plots, residential developments take place outside the inner city: notably some gated communities in districts 22 (*Tiszapalotai*, *Tisza Palace*, a mixed new office and residential block close to and with view over the river Tisza); 25 (*The French Hill*, open condo) and 4 (*Vadaspark*, Zoo); obs: the last of these is amazingly very close to Cserepesi sór.

DATA

Static and dynamic analysis uses data on sales prices and volumes for a ten year period 2000-2009. The data is obtained from the Ingatlanadattar CD-rom, compiled by KSH (Hungarian Statistical Office). Three qualifications are to be observed when evaluating the data:

a) Street names refer to the municipality of Szeged. Some of the outskirts of Szeged belong to autonomous municipalities (such as Domaszek, Deszk and Sándorfalva), but are not included in this analysis.

b) Three standard building types are used: single-family, condominium and panel, as well as a total figure comprising a weighted mean of the price and the sum of transactions. (OBS: gated communities can be both single-family and condo types).

c) The figures comprise the mean price per sqm and volume of sales from the stamp duty calculations. While unreliable as absolute values, these indicators are reliable to compare in relative terms (across space and time).

ANALYSIS WITH THE SOM

The variables comprise a set of indicators which was readily available from KSH (in their annual CD-Rom of house price data). Data is recorded on mean sales prices per sqm and sales volumes aggregated on street and district levels. Both indicators are split onto four variables: single-family, condos, panel, and total figures. This way eight input variables are generated for the analysis with each variable enabling a market related interpretation. As explained above, the aim is to look at particular areas that form clusters on the SOM surface (feature map). In this way a quasi-dynamic approach is afforded through the time windows method.

The feature maps were generated using the following parameters: Software: *SOMPAK*, 12x8 map dimensions, bubble neighbourhood type, hexagonal topology, running length in basic run and fine-tuning 5,000 and 50,000 respectively, alpha (sensitivity parameter) 0.03 and 0.01, radius 10 and 3, and calibration based on street name. Some of the map layers are shown in the figures 3 to 12 (over). These display the variation in total price levels, and are selected intuitively for pedagogic purposes. All map layers are obtainable from the author upon request. (The total number of comparable map layers is 80 = 10 years x 8 variables; on top of these graphs many others could be shown too, for example a distribution of the number of 'hits' per node for a whole map). To interpret the position of the nodes and the grey-shade variations the key is that light colour indicates high price or turnover for a particular group of relatively similar observations, when the similarity between nodes means closeness within the map surface. Here it is to note that the position of a given node remains fixed across all map layers in a one year surface.

FINDINGS FROM THE SOM ANALYSIS

The interpretation of the map layers is based on intensities of the shading, distances between the nodes and the labels (although special letters such as é and á are replaced by other symbols). Basically two kinds of cases are interesting for this study: (1) assumed niche markets where price is high but turnover low in relative terms; and (2) upper or upper-average markets where both price and turnover is high in relative terms. The locations with exceptionally high price but relatively low turnover are not particularly many for each cross-section. However, they are found everywhere except the northern and south-western neighbourhoods (and obviously the most western part, Doroszma). The more average priced locations with high turnovers in turn are even more spread over the city, which is logical due to their higher number. Thus in Szeged all areas contain cases that are relatively high priced and cases with high turnover, even the northern and south-western parts (and one is even found in Doroszma, the worst neighbourhood). To compare, in Budapest both types of locations were found in very specific places. This is a big difference between the two cities based on these analyses.

It is likely that all the cases that show up with light colour (high prices or turnovers) in the map layers were built at a time when no sustainability or green considerations existed in Hungary. Nevertheless, from each cross-sectional analysis above certain street-addresses were picked for further investigation (in October 2012). In order to follow consistently on the SOM analysis above the further aim was to focus on the two segments namely (1) highest price where turnover is low; and (2) average or above average price where turn-over is high. For reason of convenience, only the most accessible locations were subject to field inspection. The remaining locations were evaluated based on interviews and maps. The next aim was to see why the areas have a higher than average price level, and if there is any kind of logic related to sustainability aspects.

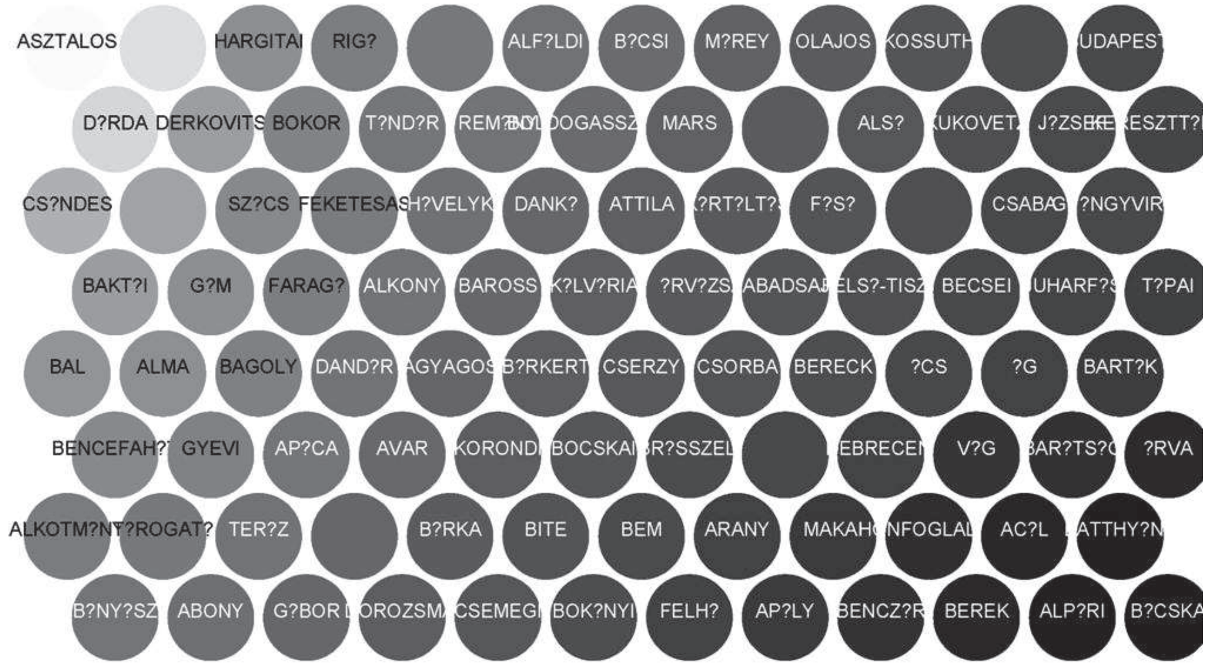

Fig. 3. Map layer: year 2000, total price per sqm.

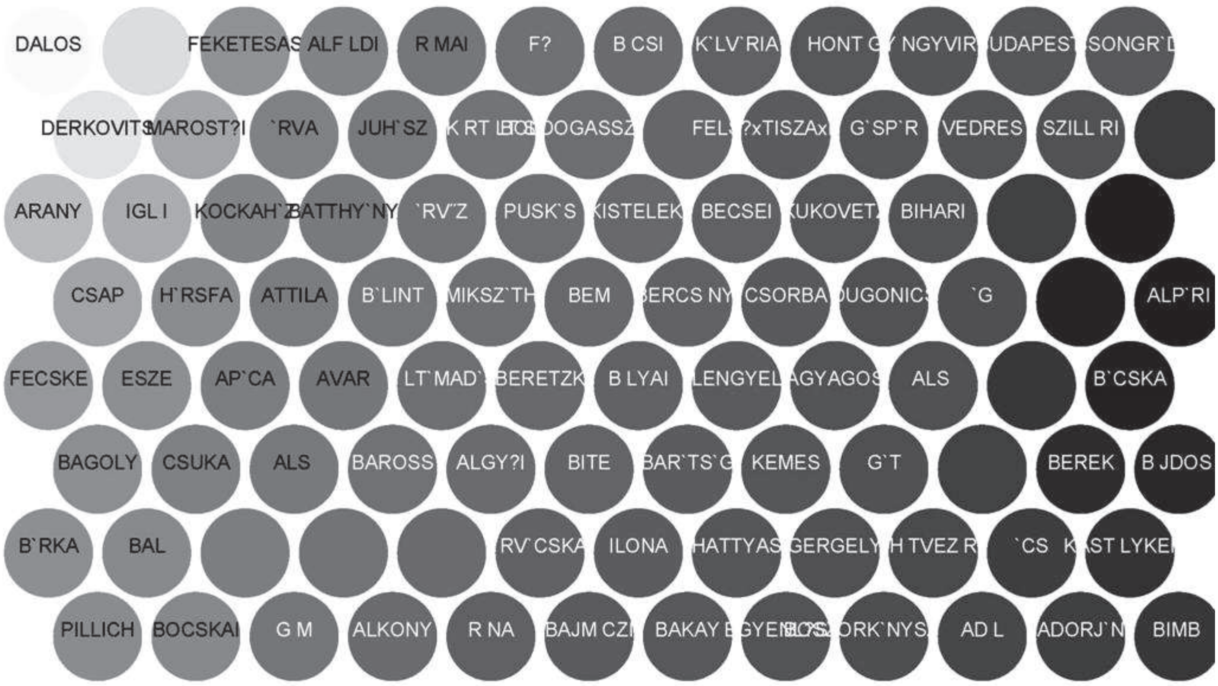

Fig. 4. Map layer: year 2001, total price per sqm.

Fig. 5. Map layer: year 2002, total price per sqm.

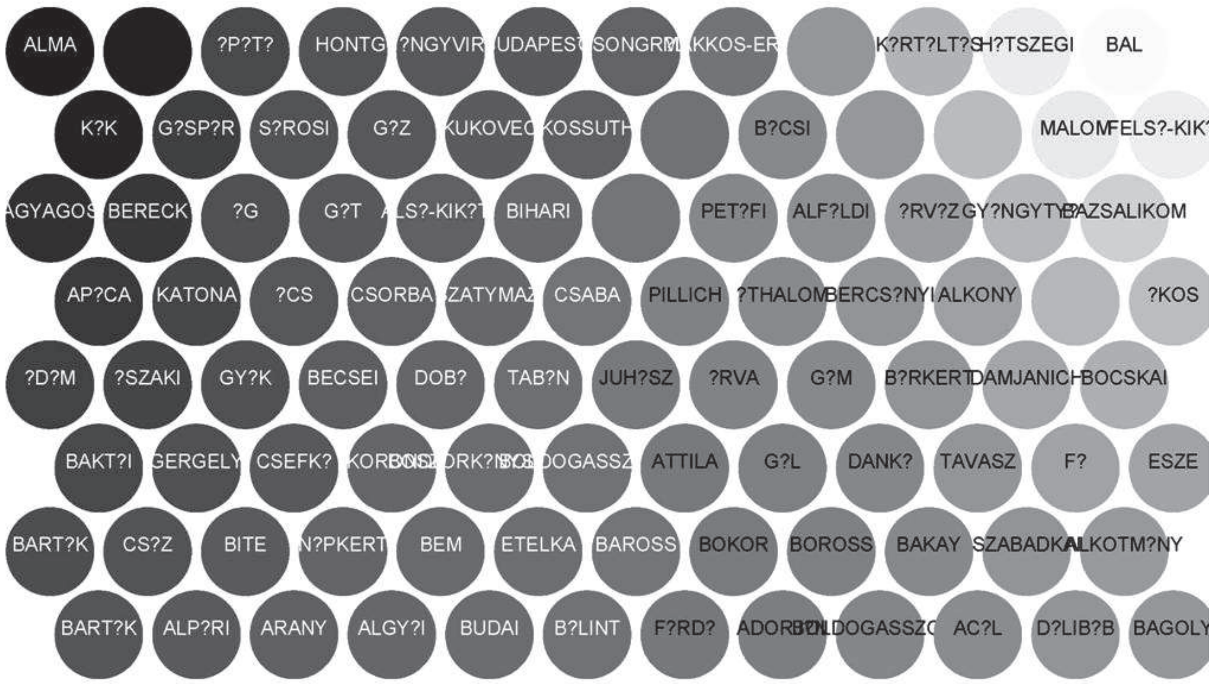

Fig. 6. Map layer: year 2003, total price per sqm.

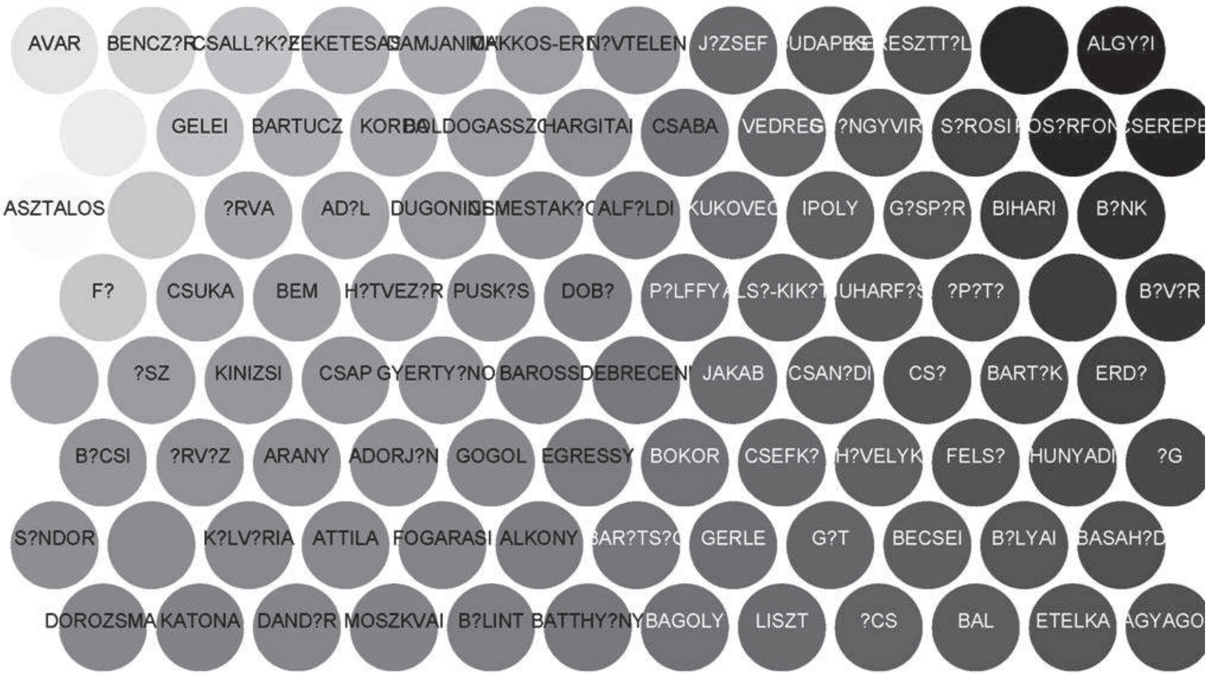

Fig. 7. Map layer: year 2004, total price per sqm.

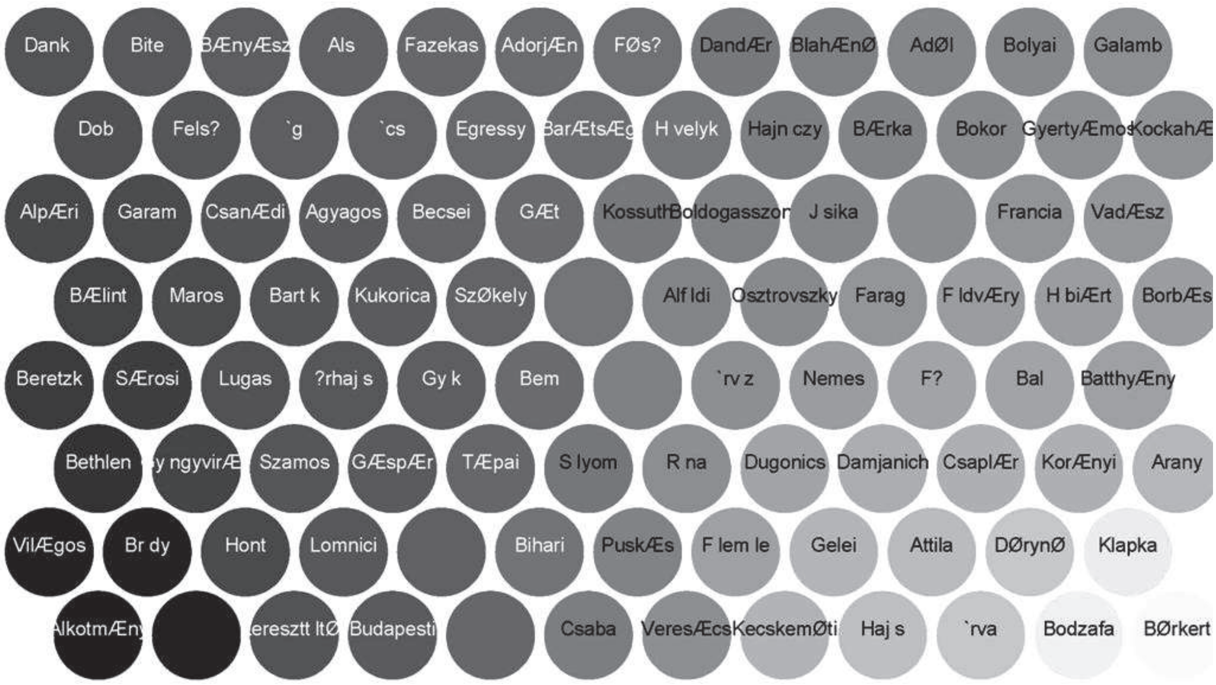

Fig. 8. Map layer: year 2005, total price per sqm.

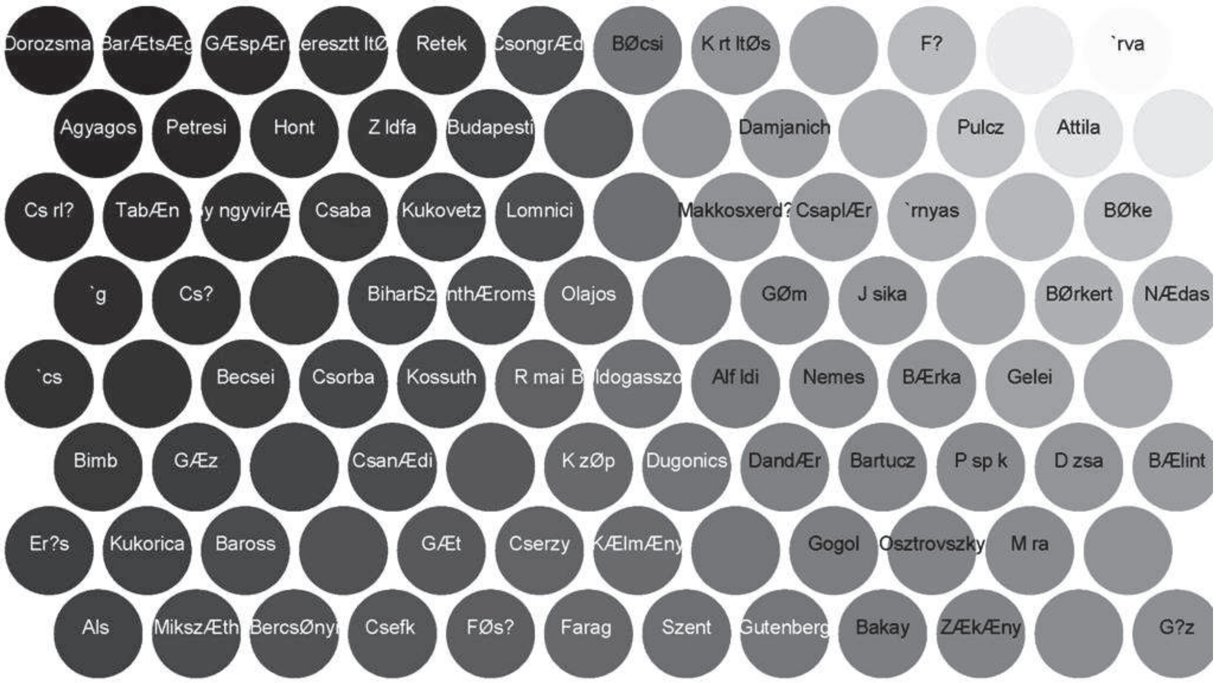

Fig. 9. Map layer: year 2006, total price per sqm.

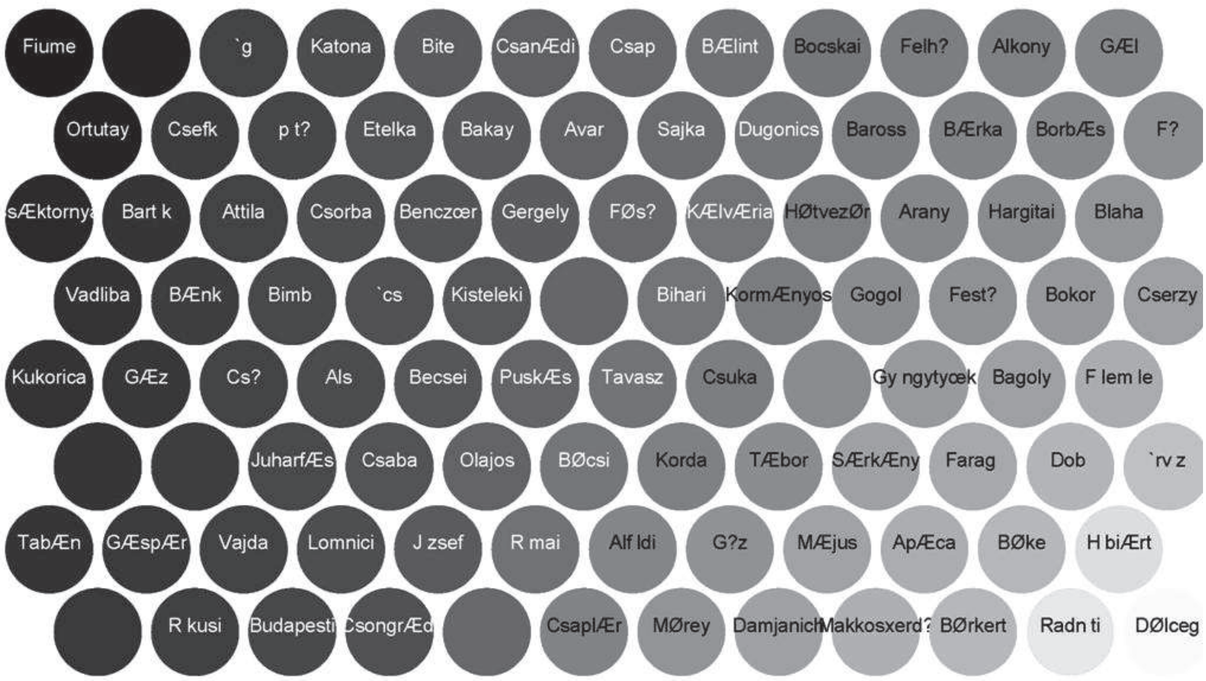

Fig. 10. Map layer: year 2007, total price per sqm.

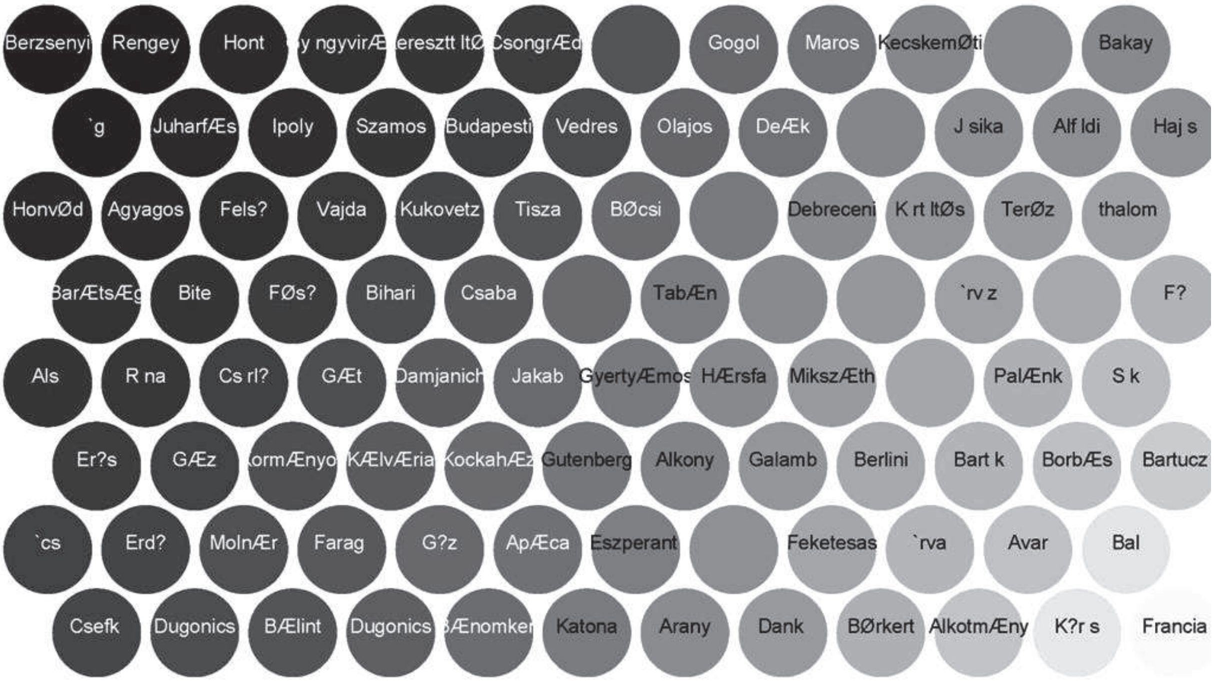

Fig. 11. Map layer: year 2008, total price per sqm.

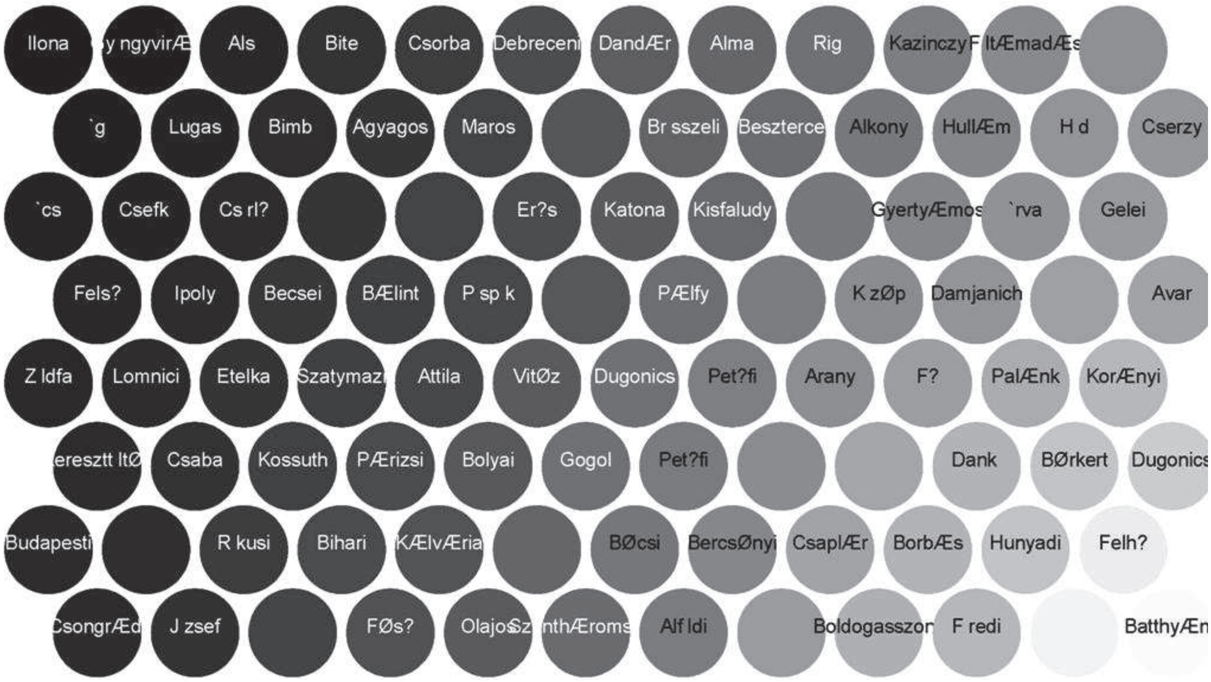

Fig. 12. Map layer: year 2009, total price per sqm.

FINDINGS FROM THE FIELD INSPECTION

Field inspections were carried out for 97 of the total 130 (street and property type specific) cases that showed up in the analyses (75%) with the SOM.

When compared to the corresponding study on Budapest, a number of relationships can be picked up:

1. Mixed areas (1960s housing estate, modest ‘residential parks’ (i.e. gated communities), cultural heritage buildings, converted farmhouses, various types of urban infill, empty plots and so forth) can be found in close proximity, often within one and the same segment of a given street.
2. Residential areas are green, pollution-free and well-maintained.
3. Residential areas have good accessibility and due to the compact city structure the distances are short everywhere. The exception is the area on the eastern side of the river Tisza known as Ujbuda, it is substantially less accessible with public transportation than the rest of the city.
4. Obviously, closer to the centre the structure is more dense (i.e. higher plot efficiency) and the facades better maintained than in the outskirts. The boundaries between the areas are not however as sharp as in Budapest.
5. Only in the ‘red belt’ of the housing estates in the northern segment of the city the areas are internally rather homogeneous and separated from the rest of the urban structure.

The field inspection confirmed furthermore that the following elements command a price premium:

- river proximity (e.g. Tiszapalotai),
- cultural heritage or neotraditional buildings, but in any case ’interesting design’, and
- more middle class neighbourhoods (relative terms).

This both corresponds with findings from Budaepst and text book urban economics theory. Lastly, from a sustainability perspective some positive developments could be verified:

- plenty of row houses (especially in Ujszeged), rather than high rise (which is socially unsustainable) or single-family/villa areas (environmentally unsustainable)
- bicycle friendly size and design of the city (at least its inner parts).

CONCLUDING DISCUSSION

Depending on the selection of data/variables it is possible to illustrate differences in urban structure using the SOM. However, while it is relatively easy to illustrate price premiums it is far more difficult to relate them to any sustainability factors such as cultural heritage, public transport accessibility, walkability, green areas, mixed stock, energy savings or maintenance of communal areas. This paper has documented a SOM-based study on Szeged, a middle-sized city. The field inspection confirms that there is premium for river proximity, heritage buildings and more middle class neighbourhoods (relative terms). This is however still within standard NC urban economics theory rather than any explicit urban sustainability conceptualizations.

From a sustainability perspective some positive developments include plenty of row houses and bicycle friendly city size and design. In a prior study on Budapest, using the same method and data, the analysis suggests that only the cultural dimension is strongly present in the Budapest context of sustainable housing development and housing market [15]. In that respect, the contrast to the analysis of this smaller city is amazing. Namely, that most of the city comprises residential areas that are green, clean and of mixed character, often also with good public transport. These features add up to a picture that is sustainable by definition. The broader significance of this findings might be that in a CEE context big/capital cities have fewer sustainable residential areas than middle-sized/regional cities, using the particular definitions of this study. In fact, the argument of places with fewer inhabitants being more walkable – and thereby more sustainable with respect to this criterion – than larger places was recently backed by Rauterkus and colleagues [16]. In the current paper a caveat is in order however: the analysis has not picked other than upper and upper average housing market areas and segments; furthermore, not even all of these are followed up with field inspection as the study is yet work in progress.

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INDICATOR-BASED ENVIRONMENTAL ASSESSMENT OF SPATIAL PLANNING WITH THE USE OF COMMUNITYVIZ

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Abstract

Rapid land use transformation caused by human activity make it necessary to create indicator-based assessment to measure those changes. Assessment should be established in a form of mechanism which is possible to implement on any area. One of main issues which should be measured is environmental group. Considerations made in this paper examine the possibility to use for this purpose tool called CommunityViz. Research was taken on a local spatial plan and spatial polices for communes, prepared for area from Wroclaw Larger Urban Zone. Calculation include demographical, environmental and vehicle-journey factors. Research has shown that the application Scenario360 can support environmental impact assessment.

Keywords: environmental changes, indicator-based assessment, CommunityViz, Scenario360

Recommended Citation: KAZAK, J., SZEWRAŃSKI, S. (2013) Indicator-based environmental assessment of spatial planning with the use of CommunityViz. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

This paper presents an attempt to use the geoinformation system – CommunityViz for forecasting environmental burdens caused by spatial planning and development. Research area was a local spatial plan and spatial polices for communes from Wroclaw Large Urban Zone. This paper presents the principles of spatial calculations, based on parametric assumptions on the local level and use of the decision support system for environmental issues. CommunityViz system makes it possible to define the elements in system-assessment by the user, and the ability to modify the calculation assumptions.

INDICATOR-BASED ASSESSMENT

The need of monitoring changes in the environment, as a complementary component of a comprehensive assessment of local development, has been discussed for many years. "Report on the status and conditions of work-tangent planners in municipalities at the end of 2007," [1] prepared by Institute of Geography and Spatial Organization from Polish Academy of Sciences pointed to the escalating intense of the spatial conflicts caused by urbanization process. It concerns mainly on natural, residential, tourism and communication functions.

The report highlighted the fact that local governments are not able to forecast or monitor these conflicts effectively. The lack of consistent and a comprehensive system of monitoring the investment processes and space transformation at the local level was found. It is a serious obstacle in the assessment of actual risks arising from land development. Moreover, one of the main conclusions defined in the scientific discussion on the phenomenon of urbanization, is urgent necessity to develop techniques which allow precise and clear as possible assess the scale of the phenomenon of urban sprawl. This is considered by the experts of the European Union as a "priority task of the Member States of the Union" [2]. European Parliament resolution of 8 June 2011 on "Beyond GDP – The Need for New Measures of Progress" [3] emphasizes the needs of the measurement of change and development, not only in economic and social terms, but also in environmental and planning. It is proposed to complement the GDP including the environmental load index, illustrating aspects such as climate change and energy use, nature and biodiversity, air pollution and health impacts, water use and water pollution or waste generation and resource use.

In order to investigate the possibility of measuring indicators with the use of geoinformation systems, analysis focused on the current state of knowledge and reliable indicators selected. As noted Czochanski [4] indicators used in monitoring, should be simple (one-dimensional), relational and synthesizing (showing wider background of phenomena and relationships with other elements) and context (showing the relationships between different areas or variants of phenomena). Based on the analysis of the final report "Criteria development of ecoabsorbency in spatial planning" [5], and public statistical data, three groups of measures were defined: demographic factors (A), resources-use indicators (B) and automobile traffic indicators (C).

Geoinformation systems which support decision making can be based on two different types of graphics. These are vector or raster graphics. The choice of graphics dictates including spatial coverage of the analyzed area. Raster graphic is used more often for larger areas and geoinformation are more generalized. Examples of operations on raster data is to study the soil changes made in the evaluation process of the environmental effects caused by urban sprawl on the example of the Warsaw agglomeration. In this case, the terrain resolution pixel used in the study was 1 kilometer [6]. These systems are based on the idea of cellular automata, and are designed primarily for making changes in the spatial projection. Vector graphics, compared to raster, makes it possible to faithfully reflect the topology of the area. Given the size of the selected area of study, in these trials have been used with vector graphic.

System used for forecasting and assessing the environmental effects in this article is CommunityViz. It is an extension of the basic functionality of ArcGIS Desktop. The two main components are CommunityViz Scenario360 and Scenario3D. For research the first component was used. It was designed as a tool to assist decision-making by stakeholders in the planning process. It allows the prediction of future traits that define the area and the factors that affect the local community. It can be used to carry out experiments with hypothetical scenarios, perform parametric evaluations, modify spatial calculation assumptions, present visual effects of the proposed action, make decisions based on comprehensive information and connect your work with three-dimensional visualization variants. U.S. experience shows that the system CommunityViz with skilful use and cooperative society can be an effective tool to support decision-making [7]. CommunityViz case study from Boston named “Supporting Youth in Designing Sustainable Neighborhoods” have shown that complexity of this software is really low. It can be successfully used for helping social participation even during work with laymen, people who are not specialists [8].

The intention of the authors is an attempt to use the system CommunityViz in predicting and assessing environmental influence of spatial planning changes on the example of local spatial plan from Wroclaw LUZ. The essential thing is proper interpretation of principles for the formulation of indicators, public parameterized data distributor for advice on the local level, and results visualization of spatial calculations.

METHODOLOGY AND RESEARCH AREA

Research was taken on local spatial plan from Siechnice area and spatial polices for Czernica, Kobierzyce and Kostomloty communes located in the suburbia of Wroclaw. It was a basis for forecasting future environmental effects of development polices and plans. Information about changes in population, consumption of natural resources, energy and waste production was presented in variants. It was generated as well as information about the approximate load of the road network by setting an indicative number of cars and daily trips. To define these indicators and determine their value system CommunityViz was used.

The article presents the possibilities of use of the application as a tool to support investment decision-making process related to land development. In order to determine the assumptions used in the calculations of space was used, inter alia, the provisions of the Study of Conditions and Directions of Development of the Siechnice commune from 2010 and statistical data from the Central Statistical Office (GUS).

RESEARCH RESULTS

First part of research is focused on the development of the elements of the environmental effects of the provisions of the local spatial plan for the section Siechnice – Center (Fig. 1).

Fig. 1. Local spatial plan for part of the area: Siechnice – Center [9]

To calculate values in CommunityViz, system was provided with geoinformation describing the topological characteristics of the terrain and objectives defined by the operator of the program. Because the system used in the study is a framework to ArcGIS, it was benefited in the electronic format tailored to the vector spatial data. Assumptions values were set freely and they are modifiable in the CommunityViz interface. Data assumptions should come from external databases (available in parametric form) or they should come from operator's expertise (Fig. 2).

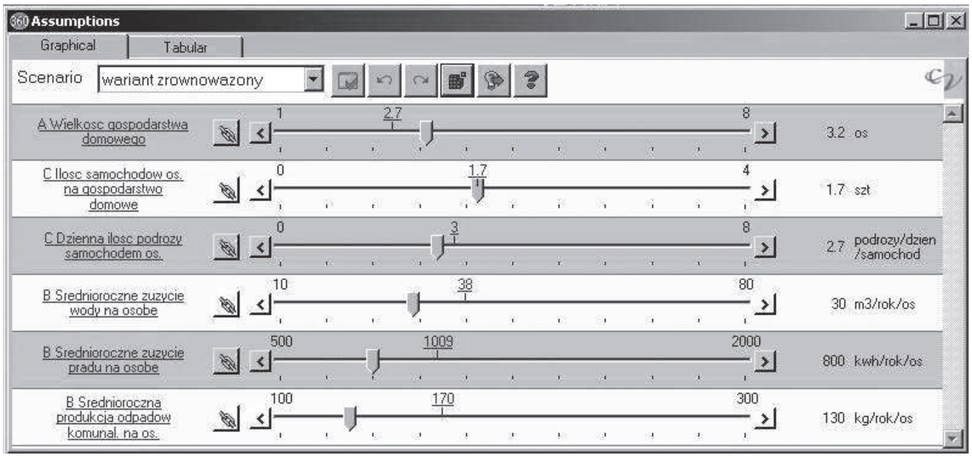

Fig. 2. The appearance of the interface – changes in the values of the assumptions (source: own study with the use of CommunityViz)

CommunityViz may calculate values of any indicators to predict future changes found from the local plan, if it is supported with data prepared in this form. During the study it was defined seven indicators describing the demographic changes, natural resources and energy consumption, waste production and increase the indicative amount of cars and the number of their daily trips. Values can be obtained in the form of tabular and graphics.

A major advantage of the system is possibility to create variants and analyze results from each scenario. For this purpose, in addition to the basic variant, were generate an additional two scenarios. To demonstrate the technical feasibility calculations based on very different assumptions and presentation of the span-values results two other variants were created: a sustainable variant and a variant of consumption growth. The values of the assumptions used in the calculations in various scenarios are shown in the table (tab. 1). Results of the calculations can be presented in tabular form (tab. 2) and in graphical form (will be present in a second part of this research).

Table 1. Values of assumptions in scenarios

Assumption	Basic scenario	Sustainable scenario	Consumption growth scenario	Units
A Quantity of households	2.7	3.2	2.7	people
B Average year waste production	170	130	200	kg/year/person
B Average year energy consumption	1,009	800	1,300	kWh/year/person
B Average year water consumption	38	30	50	m3/year/person
C Daily trips per citizen	3.0	2.7	4.0	trips/day/car
C Number of cars per household	1.7	1.7	2.0	cars

Source: own study with the use of statistical data from GUS and CommunityViz

Table 2. Values of indicators in scenarios

Indicators	Basic scenario	Sustainable scenario	High consumption scenario	Units
A1 Number of households	103	103	103	households
A2 Number of citizens	278	330	278	people
B1 Average year water consumption	10,578	9,898	13,919	m^3/year
B2 Average year energy consumption	280,877	263,938	361,883	kWh/year
B3 Average year waste production	47,323	42,890	55,674	kg/year
C1 Number of cars	175	175	206	cars
C2 Number of daily trips by car	309	278	412	trips/day

Source: own study with the use of CommunityViz

Assumptions about the environmental issues, which are primarily focused in this discussion, adopted in the variants are based on data from the Central Statistical Office resources. They show that the average water consumption per person in the community Siechnice in recent years hovers around 38 m^3. The annual production of commune waste per capita by Siechnice averages 170.5 kg. Due to the lack of available data about consumption of electricity at the commune level, the value was used for group of communes from Wroclaw LUZ. It is 1,008.6 kWh.

Second part of this research are focused on spatial polices for selected communes. To this calculations only one indicator was chosen to examine possibility of those calculations for larger area. Communes which were chosen in different directions of development were analyzed. Different assumptions for each commune come from GUS data. Calculations were taken on Kobierzyce which had highest rate of water use, Czernica with average level and Kostomloty where use of water was the lowest. The bottom map shows area of Wroclaw and surrounding communes (fig. 3). To the west of Wroclaw is located Kostomloty, to the south Kobierzyce and to the right of it is Czernica. Central city is strapped and selected communes are marked darker grey colour.

Fig. 3. The map of Wroclaw Larger Urban Zone (source: Local spatial policy documents)

Only residential development was analyzed. It follows that those three communes vary in way of development. Significant part of Kostomloty was intended for agricultural production, marked light gray (fig. 4. A). The different situation is in Kobierzyce where the northern part adjacent to Wroclaw predominates industry – checkered (fig. 4. B). Czernica is intended mostly for residential development, marked dark gray (fig. 4. C). It is typical example of 'bedroom of the city'. In water use calculations only housing areas were taken into consideration, that is why communes which intended areas for over uses may be underestimated, like Kobierzyce where predominates industry.

Fig. 4. Development of Kostomloty (A), Kobierzyce (B) and Czernica (C) (source: Local spatial policy documents)

The table below (tab. 3) shows assumptions which were used to the further calculations. Density of households and their quantity is stable for all communes. Data allows calculate what the annual water use per inhabitant is in chosen communes.

Table 3. Values of assumptions

Assumption	**Local spatial policy**	**Units**
Households per ha	15	households/ha
Quantity of household	3	people/ household
Czenica – average use of water per citizen per year	38	m³/year
Kobierzyce - average use of water per citizen per year	44	m³/year
Kostomloty- average use of water per citizen per year	26	m³/year

source: own work with use of CommunityViz

Results are visible in table below (tab. 4) and it follows from it that commune which has the highest water use, that is almost 5 million m³ per year is Kobierzyce. Kostomloty – the only commune which retained rural character, has the lowest water consumption.

Table. 4. Values of calculated indicators

Indicator	Local spatial policy	Units
Czernica – number of citizens	107,937	people
Czernica- predictable water demand per year	4,101,602	m³/year
Kobierzyce- number of citizens	113,603	people
Kobierzyce - predictable water demand per year	4,998,517	m³/year
Kostomloty- number of citizens	60,144	people
Kostomloty- predictable water demand per year	1,563,737	m³/year

source: own work with use of CommunityViz

Below are data in form of bar chart (fig. 5) which concern population in chosen communes and use of water per year. It shows relation between water use and number of inhabitants in selected communes. Worth noting is that although Kobierzyce has nearly two times more inhabitants than Kostomloty, water use in this commune is more than three times higher what shows that Kostomloty is environmental friendly commune. Despite of similar amount of citizens between Kobierzyce and Czernica, difference in water consumption is much more visible.

Those calculations are not added to table of attributes, that is why cartograms are not able to generate by this function. Charts are the only option to visualize those values, when this mechanism is used. Cartograms would be possible to create by making the calculations on dynamic layers, which is not a part matter of this paper.

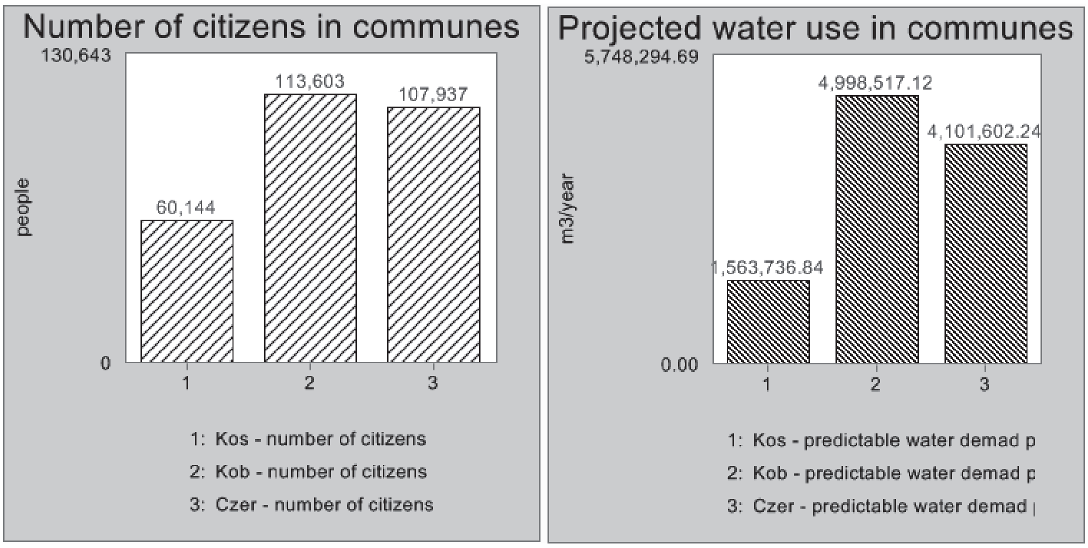

Fig. 5. Number of citizens in communes and projected water use (source: own work with use of CommunityViz)

CONCLUSIONS

Forecasting and assessing the impact caused by spatial planning can be carried out by using multiple techniques and tools. One of these instruments is CommunityViz. This system enables the assessment of the effects in parametric values, based on statistical assumptions. On the basis of the availability of local variables, the system can reliably and efficiently support the forecast, assessment and monitoring spatial transformations. CommunityViz is a clearly understandable tool for customers, clearly outlining the results of the planned activities. The scenarios generated by the application Scenario360 illustrate the effects of spatial polices and plans and their impact on the eco-capacity of the space before making a final decision on changes to the functional areas. The system allows to estimate the future potential media consumption, waste production, estimated load of the road network and many other features of the freely-defined demographic trends. A major advantage of the system is the ability to define individual indicators based on any combination of geoinformation and defined assumptions. Very important fact is that all calculations and results' visualizations react at the same time when assumptions are modified. That is why CommunityViz can be useful not only during time-consuming research but also in discussion with society. Scenario360 can effectively support the prediction and assessment of the environmental impact of planning and zoning as well as decision-making process.

ACKNOWLEDGMENTS

Badania zrealizowano w ramach projektu badawczego MNiSW Nr N N305 384838 pt. „Wskaźnikowe oceny zmian środowiskowych powodowanych niezrównoważonym rozprzestrzenianiem się dużych miast".

The study was carried out in the framework of the research project MNiSW No. N N305 384838 "Indicative assessment of environmental changes caused by unsustainable sprawl of large cities."

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PEDESTRIAN NETWORK DESIGN AND OPTIMISATION BASED ON PEDESTRIAN SHORTCUTS AND NEEDS

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Abstract

We have designed a new approach to build an optimal pedestrian network. Modelling and building optimal walkway network is a big challenge. It is a complex task, which generally get more complicated with increased functionality and size of a city. In this study is walkway network considered as optimal, when no shortcuts are used by pedestrians to reach their target location. Pedestrian shortcuts are also understood as a tool for walkway network optimisation. Optimisation of walkway network also includes simplification and shaping. There have been investigated shortcuts in cities Olomouc and Ostrava. Focus has been taken on the surrounding environment of shortcuts and proportion of the initial and shortened distance. We found that there are regularly taken shortcuts by pedestrian when at least 18% of the original walkway distance is shortened. Also we found that there are two exceptions. Firstly, at the edges of the rectangular parts and at the right angles of the network are made short paths. Secondly, at time depending through-flows, such as zebra crossing, public transport, bus or railway stations, are the shortened distanced even smaller. In this case is important to consider the direct visibility of the target location (station, traffic lights etc.). The first problem can be solved with changing the shape of paths. In the second case is needed an optimisation process. Furthermore in this study was considered the proportion and density of the walkway network in the city and surface of the network and its aesthetic perception.

Keywords: pedestrian network, optimisation, shortcut, distance, human perception, walkability

Recommended Citation: MUDROŇ, I., PACHTA, M. (2013) Pedestrian network design and optimisation based on pedestrián shortcuts and needs. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Since ages, the people move from one place to another. Walking is the most natural and oldest human type of movement. The purpose, ways and speed of motion have changed over the past centuries, but walking still stays most common. This is based on the observation that most people travel only short distances, while a few regularly move over hundreds of kilometres [1]. Even if a person is taking a different way of transportation, it has to walk to the starting point of that particular locomotion. For example the passenger has to walk to the parking lot before taking distance using a car. Pedestrian trajectories are often approximated with various random walk or diffusion models [2], [3]. But none of them fully satisfies the reality. The behaviour of human motion in space is close to the properties of Lévy motion (flight). But in contrast with the random trajectories predicted by the prevailing Lévy flight and simulated random walk models, human trajectories are showing a high degree of spatial and temporal regularity. Each individual is being characterized by a time independent characteristic travel distance and a significant probability to return to a few highly frequented locations [1]. In the real world few long distances are often made in a single step. But they are mostly done by other ways of transport. Thus we focus on small distances and walkability in cities, what is important for development and design of pedestrian networks. Pedestrian can choose the route to move according to its perception of the environment and its goals [4]. The movement patterns generated by purposive and by random walkers are the same [5]. Walker is moving fully autonomous with its personal needs and attributes in mind. Walkability of a particular area is a property of environment-human system. It can be properly modelled only when interweaving environmental and human properties [6]. The literature on urban design and walking has often emphasized more macro-scale features of environment system, such as block length and number of intersections, which are easier to measure using remote sensing and GIS [7], [8], [9], [10]. Urban designers, in contrast, emphasize the importance of micro-scale features [11], [12]. Such micro-scale features are including the presence of street trees, pathway width, the presence of abandoned buildings etc. [13]. It is necessary to involve both types of features. Concerning human environmental perception in general, when people are looking at objects, they perceive their action-related properties, rather than their physical attributes [14]. These properties, also termed affordances, are determining whether the person is walking or not [13]. Hierarchically ordered walking needs are feasibility (lowest resp. basic need), accessibility, safety, comfort and pleasurability (highest one). First the basic needs have to be fulfilled, before higher level needs are even considered. For example, if a walkway in park provides pleasurable and comfortable walking or running but lack of safety, it will not be considered as usable by pedestrians. In order to have effective walkway network it is essential to build the network with regard to aforementioned concept of hierarchical needs.

PEDESTRIAN NETWORK

Optimal pedestrian network planning and design is challenging problem, which is keeping attention of urban planners, architects, geographers, psychologists and others. The understanding of basic laws governing human motion remains limited owing to the lack of tools to monitor the time-resolved location of individuals [1]. A proper investigation and monitoring of movement would also violate against human rights. Many aspects of walking are difficult to experiment within the real world and can be reliably explored through computer models [15]. High-fidelity representation of human walking behaviour is required and model-builders often use agent-based models as a mechanism for representing individual agency in simulation, but in many cases they specify the models with coarse, abstract representations of movement [16]. Crowds of pedestrians represent a complex system: the overall behaviour of the system can only be defined in terms of the actions of the individuals that compose it, and the decisions of the individuals are influenced by the previous actions of other pedestrians sharing the same space. Despite the substantial amount of studies and effort of researcher, we are far from complete understanding this complex system [4]. Because of the lack of knowledge, inability to truly reconstruct the behaviour of pedestrian motion, difficulty with deriving rules for agent walking behaviour, reliability of associated movement paths with the human reasons and complexity of the system, we decided to base our pedestrian network on different approach (Fig 1.), but relying on aforementioned facts and results. The human perspective has been neglected in both public space design and management. Places are proposed, built and assessed with goals of space managers, space designers and its clients instead of address people's needs [11]. In this article, we introduce a scheme to resolve this problem by adopting the pedestrian network to pedestrian needs rather than vice versa. Pedestrian environment has to be adapted to pedestrians too. More or less pedestrian friendly environment will rise or decrease the walkability of city and thus control pedestrian flows if needed. In the first place it has to build a basic framework connecting all nodes of network (bus stations, schools, housing units, parking lots etc.) using minimal number and length of walkways. Material used to build this basic frame of network has to be easily removable and less expensive because of the high probable change or removal. This first step will make all nodes accessible, but the network will not be optimal yet. Optimisation will be done in a cycle, in which the pedestrians will choose their own pathway. Their pathways will turn into pedestrian walkways according to frequency of usage and distances they cut and shorten. The optimisation is done until no new pathways (shortcuts) are generated and meanwhile all of them are regularly used by pedestrians. After every cycle, the environment of network has to be reconditioned. So there will be no shortcuts between the nodes and edges of the pedestrian network (e.g. grassing or any other land cover change to reset conditions). The influence of pedestrians using older variant of the network has to be eliminated, so the old shortcuts have to vanish. This is an important step, because new shortcuts should appear according to the upgraded network and human's experiences using it. This is based on the fact, that a person moving through a transportation network (by any kind of transport) perceives its walkability as an affordance that comprises different qualities and satisfactions. So he can later on choose an alternative way of movement. This change of environment by tracking out a shortcut can result into change in pedestrian network. Other changes of environment such as building a new building, communication, zebra crossing etc. are leading also to changes in pedestrian network. On the other side a particular walkway can be changed back to another type of land cover, if not used by pedestrians anymore. Pedestrian network is a dynamic system, which develops continuously with its environment and users. Fig. 1 depicts the optimisation process, where the changes of human-environment system (box change in environment) determine the change of pedestrian network (box change in pedestrian network) or its surroundings (box reset of environment) or both of them.

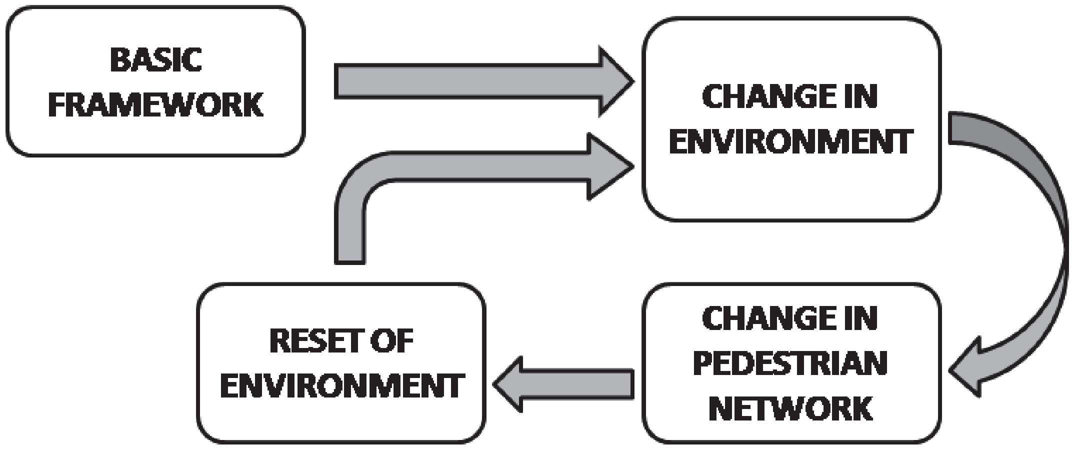


Fig. 1. Outline of pedestrian network optimisation.

SHORTCUT BASED OPTIMISATION

The aforementioned pedestrian network development is based on theory of ant colony optimisation. However the human perception of a world and expectations in life are more sophisticated. Theorems used in this article are changed according to the purpose of walkway network. The goal is to achieve a pedestrian network with properties, which would satisfy almost all pedestrians. The social interaction between ants (or insects, animals) is often established through indirect stimulation, which is also called stigmergy [17]. Ants deposit pheromones on the ground in order to mark paths, which should be followed by the other members of same colony [18]. The trace left in the environment can be understood as a form of communication between agents. On the other side pedestrians are more intelligent agents and have a good memory. A particular shortcut in the pedestrian network can be understood as a trace left in the environment by other agents. When pedestrian is approaching shortcut (or crossroad), he perceives the environment and its walkability. Finally pedestrian makes decision and continues in walking. Passing through an unknown area pedestrian evaluates the chosen and optional opportunities for passing towards its target location. Pedestrian finds the optimal solution comparing previous experience or observation of the alternatives with the chosen way in the area. Thus the risk of taking twice or more times wrong route is significantly decreased. Another big challenge is the purpose of walking. The purpose of walking determines the selected route (e.g. to crown a dog, shopping, work etc.). Also the environment of walkway takes an important place. Many people take a pleasure passing through or next to a notable or comfortable place (touristic attraction, park, fountain, crowded localities, etc.). So they can walk longer distance, even when they are aware of doing it. Comparing to swarm intelligence (shortest distance) is the problem of building optimal pedestrian network more complicated and complex (hierarchical needs, different purpose). Deficiencies of pedestrian networks are leading pedestrians to walk outside the network. So shortcuts are representations of human needs to reach their goals.

CASE STUDIES AND RESULTS

In our study we analysed 163 shortcuts in cities Olomouc and Ostrava. We tried to deduce generalities from the analyses of gathered attributes and so provide useful guidelines to planers and researchers. As expected; the shortcuts are mostly located in more populated residential areas. Shortcuts occurred most frequently in residential district Nové Sady in Olomouc. Shortcuts are abundant in public space, alongside communications, when pedestrian network ignores natural and artificial barriers (Fig. 2). Next ones are connected with poor planning or optimisation of pedestrian network, such as missing edges, unconnected nodes of pedestrian network, small capacity, wrong placement of zebra crossing etc. (Fig. 3). Short pathways are also tracked out at the edges of the rectangular parts and at the right angles of the network. It can be eliminated with appropriate shaping. These localities are the most crucial for pedestrian network optimisation.

Fig. 2. Left: Shortcut as a result of outlet between barriers made of two blocks of flats. Middle: Green urban space with shortcuts in residential district Nové Sady. Right: Shortcut along the railway just next to Railway station in Olomouc (Source: Martin Pachta).

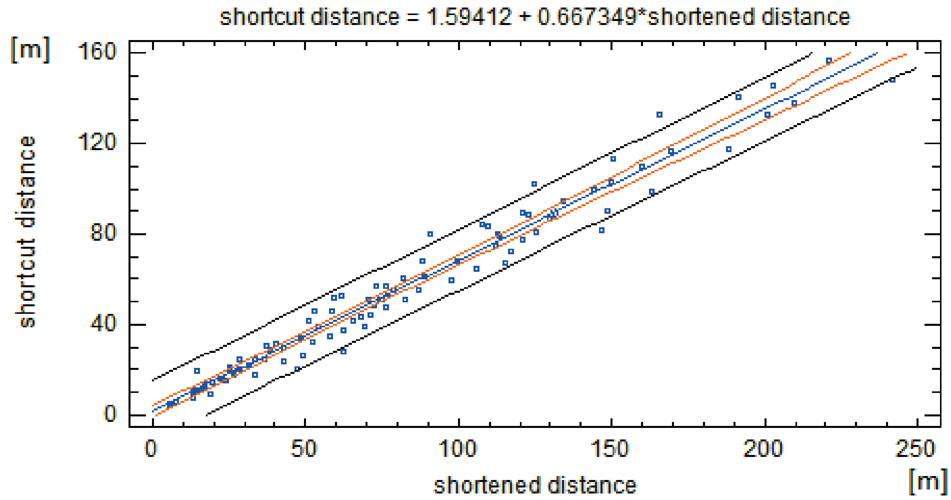
Fig. 3. Left: Maximal pedestrian flow overreaches the capacity of the cobblestone pavement. It caused shortcut in residential district Nové Sady. Middle up: Wrong placement of zebra crossing leaded to two shortcuts and unused cobblestone pavement in Moravská Ostrava. Middle down: Missing sidewalk around the park force pedestrian walk through the street or shortcut in Poruba part of Ostrava. Right: Playground is not connected with the pedestrian network, thus four shortcuts have been tracked out. (Source: Ivan Mudroň)

All analysed shortcuts are located in urban areas. Average length of analysed shortcuts is 42.8 meters, median 31.4 meters. Shorter shortcuts occurred more often than longer ones. Most frequently in the interval of 15-20 meters in length. The width varied from 15 cm to 120 cm. The measurement was made with 50m long measuring tape. The lengths were measured along the centre line of walkways. We analysed two dependencies. The measured lengths were rounded off to one decimal place. First, it was investigated the dependence of shortcut distance on proportion of the initial and shortened distance. The proportion shows the percentage of saved distance by taking particular shortcut. We investigated if length of a shortcut has an influence on optimisation (using simple regression), viz. longer shortcuts save more percentage of initial length and shorter ones less percents or vice versa. In the analyses we were not able to find any dependence. We have also used various types of models. The best R-squared value has Reciprocal-X model (Table 1), but it represents poor estimate (17 percent of variation of the data explained by the fitted line). So we can state, that long shortcuts as well as short ones have statistically the same optimisation effect according to distances.

Table1. Comparison of R-squared values of alternative models used to explain the empirical data.

Model	Correlation	R-Squared	Model	Correlation	R-Squared
Reciprocal-X	-0.0416	17%	Exponential	<no fit>	-
Logaritmic-X	0.0381	15%	Double square root	<no fit>	-
Squared-X	0.0350	12%	Multiplicative	<no fit>	-
Square root-X	0.0343	12%	Reciprocal-Y sq. root-X	<no fit>	-
Linear	0.0322	10%	Logarithmic-Y sq. root-X	<no fit>	-
Reciprocal-Y	<no fit>	-	Squared-Y sq. root-X	<no fit>	-
Logaritmic-Y	<no fit>	-	Sq. root-Y logarithmic-X	<no fit>	-
Squared-Y	<no fit>	-	Reciprocal-Y logarithmic-X	<no fit>	-
Square root-Y	<no fit>	-	Squared-Y logarithmic-X	<no fit>	-

Second analyses investigated the dependence of shortcut length on initial shortened distance. We wanted to found the relation between the aforementioned distances. Linear model will underline the previous analyses. As expected, there is a strong linear dependence of shortcut length on initial shortened distance (Fig. 4.). The linear model fitted almost perfectly (Fig. 4, R^2 96%). We found that the variance of shortcut distance values is increased with increase in shortened distance. According to this model if a pedestrian is taking shortcuts in total length of 200 meters on the way home, he is saving 96 meters or 1 minute and 9 seconds (speed 5 km/h, circa 1.4 m/s).



Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Multiplicative	0.9841	96.84%
Double square root	0.9827	96.57%
Double reciprocal	0.9825	96.53%
Linear	0.9803	96.10%
Double squared	0.9731	94.70%
Square root-X	0.9625	92.63%
Logarithmic-Y square root-X	0.9599	92.14%

Fig. 4. The output shows the results of fitting a linear model to describe the relationship between shortcut distance and shortened distance. Table shows the results of fitting several curvilinear models to the data. Of the models fitted, the double square root model yields the highest R-Squared value with 96.8% because of the higher variance of larger values.

We found that there are regularly taken shortcuts by pedestrian when at least 18% of the original walkway distance is shortened. The average saved distance (when walking through a shortcut between two locations connected to pedestrian network instead of taking the pedestrian network) is 29.7% of the distance taken through the pedestrian network. Corresponding to topology and environment we evaluated the density, neighbourhood and connections of shortcuts. Most of the shortcuts are in high populated areas and in poorly connected nodes. Focus has been taken on the surrounding environment of shortcuts, but we were not able to gather enough data according to complexity of the problem. Poorly connected (up to three walkways) nodes, which are daily visited by a large number of pedestrians (hospital, school, administrative departments, psychological office, etc.), are associated with higher number of shortcuts. At time depending through-flows, such as zebra crossing, public transport, bus or railway stations, are the saved distances smaller than the average aforementioned value. The direct visibility of the target location is influential in this case. Most of the shortcuts are connecting the edges and creating triangles in the pedestrian network. They represent shorter ways of node connections. But shortcuts (6% in our study area), which are creating quadrilateral, pentagonal or polygons with more sides are revealing missing edges (or curves) of the network. In the study area are common pentagons, hexagons and also one heptagon in Nový Svet district of Olomouc. It is necessary to gather more information to make reliable conclusions about other functional structures. For example in the case of commercial or shopping zones shortcuts are following different rules. It seems to be interconnected entrances with each other (whatever with pavement or shortcut). This phenomena should be deeper studied. The last but not least was studied the aesthetic component of the problem. Shortcuts do not fit into the cities. There is a notable group of people, who does not agree with usage of shortcuts. They see it like violation against public order. Shaping and design of new paths in the cities is very important. Surfaces as bulk gravel for open space or cobblestones for sidewalks of communications and historical city centres fit better into the environment. Colour and shape is important too. Bulk gravel is the easiest removable and nature-friendly material. It fits in the fringes of cities and parks more than traditional surfaces (asphalt, concrete, etc.). It is also good to use this material in downtown green areas, where is high proportion of artificial material all around. In planning, design and building new parts of pedestrian network should not be skipped any aforementioned aspect, because pedestrians perceive the environment as a whole system. Only when this system will be build according to pedestrian needs, they start to fully use it. Only then the network starts to fulfil more purposes than just a simple medium of movement (relaxation, social interaction, pleasure, etc.).

CONCLUSIONS AND DISCUSSION

In this paper, the outlines of a new concept for modelling and design of pedestrian network is presented. The concept is based on shortcuts made by pedestrians according to their needs. Following the results, the pedestrians have evidently found a faster way of movement through the urban environment in our study area. As reported in results these shortcuts are found in specific locations, which are prone to tracking out new shortcuts. This is notable in other cities too (using aerial images, maps.google.com, terrain research in Magymaros and Budapest). It seems that the reasons taking the shortcuts are the same. People are living in hectic time, where every second counts. Some others are indolent to walk longer distances. This makes a call for fast and walkable environment, especially in the cities. Recent urban areas, especially in the industrial areas (such as Ostrava), are facing various problems such as air pollution. Due to high level of motorized transportation is this problem worsened. Modern strategy of sustainable transportation planning set a goal to increase the relative share of non-motorized transport such as cycling or walking. A precondition for this is to improve the pedestrian network in existing cities and plan optimal networks in the new parts of cities, town districts or cities [19]. One of the solutions is to improve the walkability of city, the level at which is the city suitable for walking. Shortcuts are indicating the problems. It is important first to understand the reason why places are ignored or used by pedestrians. Building the network according to pedestrians can be later on studied and it can show reasonable answers for building and modelling pedestrian networks by traditional methods. It should be gathered more information and also use different resources. It would be useful to interview anonymously the pedestrians, who are using shortcuts. Count the number of pedestrians. It should be done twice: before and after change in environment or pedestrian network. Some weather conditions, e.g. fresh snow, can reveal the patterns of pedestrian movements. Optimal pedestrian network also decreases the number of traffic accidents. It increases the number of pedestrians. Physical activity of walkers is a key to maintaining their health.

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PINdex + 4: A SPATIAL IDENTIFICATION SYSTEM FOR POINTS OF INTEREST IN INDIAN CITIES

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Abstract

Location addressing system in India is associated with drawbacks that limit the scope of geocoding the points of interest and subsequently carrying out spatial related analyses. In this paper, we present the details of a map mashup called *PINdex+4* spatial identification system that is proposed to overcome the shortcomings of the existing location addressing system in geocoding the points of interest and contribute to conducting business analyses more effectively. The proposed system leverages on an existing web mapping service to accurately locate a point of interest. Further, a spatial code called *PINdex+4* is generated for each point of interest by appending four digits to the corresponding postal index number (PIN) of the point of interest. The authors suggest that the *PINdex+4* code can serve as a spatial tag for the points of interest, which can be integrated with other business information and enable the organizations to conduct business analyses and generate business reports at different spatial levels including within the PIN code regions. The paper concludes with a brief discussion on the practical implications and limitations of the proposed system.

Keywords: geocoding, spatial Database, GIS Data, PIN code, map mashup

Recommended Citation: NANDI, S., NICHOLS, P., NANDI, M. L. (2013) PINdex + 4: A spatial identification systém for points of interest in Indian cities. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Information has long been one of the important resources used by the organizations to deliver their services [1]. Developments in information technology (IT) and the computer based information systems (CBIS) in the past three decades have changed the ways, in which organizations operate in the markets. Firms are increasingly relying on IT and CBIS to enhance their operational efficiencies and service effectiveness. Geographic information systems (GIS) are one such CBIS that has the potential to improve the efficiency of transaction systems and support organizations in making their business related decisions [2]. Availability of the location data with offerings such as Google Earth and Microsoft Virtual Earth has opened up many possibilities of integrating location data with the business data in the business decision processes [3]. The applications of GIS in business related analyses encompass asset management, route planning, service planning, customer profiling, and sales planning. Despite the advancements in GIS and related technologies, organizations in developing nations such as India, Pakistan, Phillipines and other nations are still struggling to reap the potential advantages of the GIS, when compared to their counterparts in developed nations. The problems hindering the potential use of GIS in the organizations include lack of consistent and accurate source data to generate the digital GIS data and lack of consistent location and demographic information [4]. This paper focuses on the difficulties faced by the organizations in India in geocoding their points of interest to carry out various analyses such as customer profiling, asset management, and route planning. The paper further proposes a spatial identification system called *PINdex+4* spatial identification system that can enable the organizations to overcome the difficulties associated with geocoding the points of interest (POIs) and facilitate different business analyses.

GEOCODING THE POINTS OF INTEREST IN INDIA

Geocoding of the points of interest involves processing their textual addresses to add the positional co-ordinates that usually are the latitude and longitude of the location, to each address. These coordinates are then indexed to enable the addresses to be searched geographically [5]. There are several

methods to add the positional coordinates of the POIs. Positional coordinates of POIs could be derived physically using global positioning system (GPS) devices and integrating them with the address information. This process however, can be cumbersome and expensive, when there are huge numbers of POIs. Another method of geocoding the POIs is by plotting them manually, using the textual address information and the GIS data layers. Accuracy of the geocoded location however, is a problem with this method, especially when the user does not have a first-hand knowledge of the POI location.

Lack of urban planning and standardized location addressing system in the Indian cities make it difficult to incorporate standard logics for geocoding POIs. An address for a location in an Indian city typically consists of the building number or plot number followed by the nearest landmark, the area name, the city name, and the postal index number. Building numbers and plot numbers are allotted by the local Government entities that is, municipal corporations, following different methods. These numbers are not necessarily sequential and are not easily comprehensible for general usage. Landmarks and area names cannot be technically used as an input for geocoding the POIs. Landmark reference to a POI usually is associated with phrases such as “besides”, “near”, “behind” and so on, which are difficult to interpret. A similar difficulty in locating the addresses was pointed out by Razzak et al. [6] in the context of locating the addresses of the road crash sites from medico-legal records in Pakistan. Concerning the area names, no definitive information is available on the area names and their corresponding boundaries, and hence serve as a loose reference to the location. Postal index number otherwise referred to as PIN code is the only available standardized and reliable resource for finding the geographical location of a POI till date. PIN code however, encompasses a larger geographical area. In the background of these difficulties associated with geocoding the POIs, many organizations are settling in for the business analyses at the PIN code level. The present paper proposes *PINdex+4* spatial identification system that allows users to graphically identify the address on a map while providing the addresses. The system further generates spatial codes called *PINdex+4* codes for the addresses of the POI, that can serve as spatial tags for the POIs in carrying out the business related analyses. Details of the proposed spatial identification system are discussed in the following sections of the paper.

PINdex+4 SPATIAL IDENTIFICATION SYSTEM

System Architecture

The *PINdex+4* spatial identification system consists of a web application that is integrated with a spatial database, *PINdex+4* grid maps, and a web mapping service application such as Google maps, Bing maps, and Open street maps. In web development terminology, the proposed system can be called as a map mashup. A map mashup is a web application based on web 2.0 that uses and combines at least one map data source with added information to create a new map or a spatial database [7], [8], [9]. The general architecture of the mashup as shown in Figure 1 consists of three levels. The first level in the bottom contains data sources and services to be used in the mashup. The access to data sources and services is achieved through using the corresponding set of application program interfaces (API). In the case of *PINdex+4* spatial identification system, the first level consists of a set of map APIs from Google, Bing, or Open Street Maps, the *PINdex+4* grid database, and a spatial database. The spatial database is a database that supports storing and querying of spatial elements such as points, lines and polygons. The second level of the mashup holds the mashup applications, which are typically software routines. The mashup applications enable communication between the mashup components and bring the data sources and services together for a set of logics and functions the mashup provides. Last level on the top of the mashup architecture has the web user interfaces required to access the mashup sites [9].

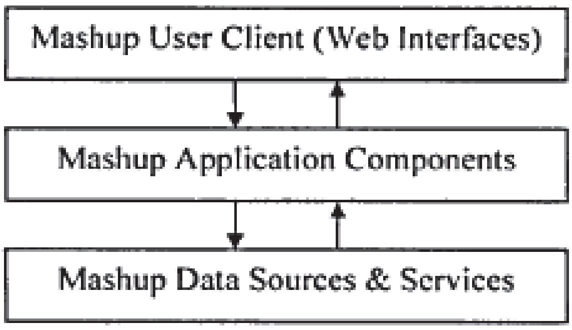

Fig. 1. General mashup architecture (*Source: Gong, 2007)*

Functionality

While several functionalities can be integrated with the *PINdex+4* spatial identification system, the main functionality that potentially can help in overcoming the geocoding of the POIs in India is discussed in detail in this paper. The user interface essentially consists of a frame to enter the address information of the point of interest and other POI related information and map interface that displays the location of the POI. When the user enters the address information, a system software program retrieves and processes the state, city, and area information and sends a location search request to the mapping service application using the corresponding API. The map with an approximate location of the POI from the mapping service application is presented to the user. The user checks for the accuracy of the POI location, makes a correction if needed and approves the location. After the user approves the accuracy of the POI location, the *PINdex+4* code is generated by the system and stored in the spatial database along with the other information of the POI. The *PINdex+4* code serves as a spatial tag and the dataset can be used for different analyses at different spatial levels including regions within the PIN code.

Generation of PINdex+4 code

A PIN code in India consists of a six-digit number indicating the region, sub-region, revenue district, and the delivery post-office [10]. For instance, in the PIN code 110006, the first digit that is, 1 refers to the northern zone, the second digit that is, 1 refers to the region of Delhi within the Northern zone, the third digit refers to the Delhi revenue district and the last three digits that is, 006 refer to the post office numbers in that PIN code boundary. The *PINdex+4* spatial identification system, appends four digits to the corresponding PIN codes of the POIs by recursively decomposing the rectangular grid generated from the extents of the PIN code boundary. The PIN code boundary grid is divided into four equal rectangular grids. The first digit following the PIN code of the POI corresponds to its location within these four grids. The digit is assigned in a clockwise direction starting from the upper-left grid, that is, the upper-left grid is numbered as 1, the upper-right grid is numbered as 2 followed by lower-right and lower-left as 3 and 4 respectively. This step is repeated for each of the constituent grids in which the POI is located, until four digits are achieved. An example for the procedure is shown in Figure 4, where the *PINDEX+4* code of 110006-2113 generated for a POI in Delhi. The logic behind the appending additional four digits to the PIN code can be compared to the point region quadtree data structures, which are generally used to store the vertices of polygon map data [11].

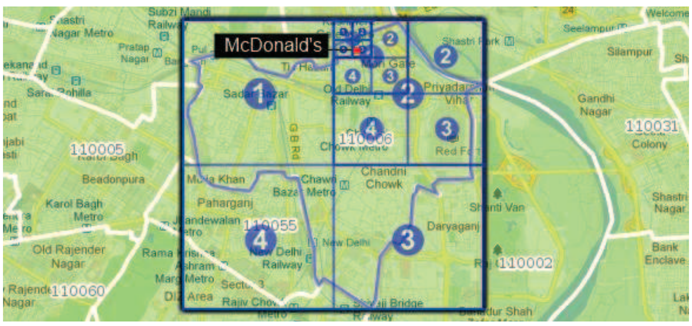

Fig. 2. Generation of PINdex+4 code

DESIGN AND DEPLOYMENT

The architecture of the proposed spatial identification system is shown in Figure 3. Presently, the system is in a conceptual stage. The authors intend to build a prototype of the proposed system and conduct a pilot case study with a direct broadcast satellite service provider in India. Initially the *PINdex+4* is planned to be deployed as a mashup for the use of enterprises catering to their specific business planning needs. In the later stages, when the system stabilizes, the *PINdex+4* code generation tool along with some analytic tools are planned to be hosted for general public use.

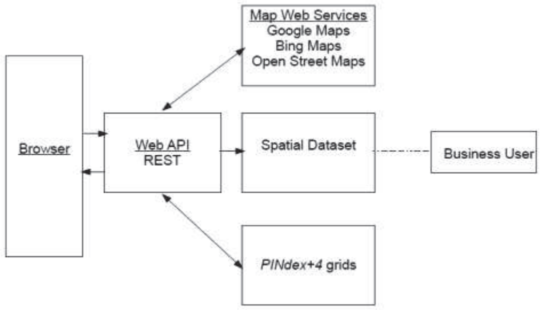

Fig. 3. *PINdex+4* spatial identification system architecture

PRACTICAL IMPLICATIONS

Firstly, the *PINdex+4* spatial identification system enables geocoding of the POIs and generation of a spatial database for the POIs with a simple additional step in the address information entry at the user level. These *PINdex+4* codes can simply be integrated with other enterprise applications and enable conducting business analyses and generating reports at different spatial levels independent of any GIS software platform. With *PINdex+4* codes, the level of business analysis can be enhanced to spatial levels within the PIN code regions. This feature is especially important to telecom and direct broadcasting satellite service providers to manage their assets and service outlets based on the customer profiles within the PIN code regions. Similarly, enterprises in the banking sector can plan their all time money (ATM) machine installations and design targeted promotions based on the customer profiles within the PIN code region. At a later stage when the system stabilizes, the general public users can communicate their address with the *PINdex+4* code, rather than the existing address system, which in most cases is lengthy.

LIMITATIONS

An important limitation of the *PINdex+4* spatial identification system is that the *PINdex+4* codes are generated from the PIN code boundaries. With changing political situations, such as addition of a new states and districts, PIN code boundaries change. For instance, new states have been added consistently until as recently as 2000 in India. These situations can have negative implications on the standardization of the *PINdex+4* codes. Also, the level of accuracy of locating a POI is dependent on the size of the PIN code boundary. Consequently, there is a possibility of having the same PINdex+code as a spatial identifier for multiple POIs. Therefore, it needs to be noted that the *PINdex+4* code can serve as an approximate location reference to a POI and not as its unique reference. Moreover, the accuracy of the POI location in the proposed system is subjective to the users' input and cannot be compared to the geocoding accuracy using the GPS survey method. Lastly, it is possible that different software providers can come up with different logics for geocoding that can potentially result in a conflict and hinder in creating a standardized spatial identification system. While this can be considered as a negative implication to the proposed system, it still could be a positive indication to addressing the geocoding problem that is persistently hindering the potential benefits that could be reaped from the GIS applications by the organizations.

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THE BRATISLAVA PUBLIC TRANSPORT IN NETWORK ANALYSIS

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Abstract

This paper explores network approach possibilities to urban environment. Since the subject is too complex and difficult to cover in global, we keep focused on a selected sample of real-world spatially embedded network. Public transport is a likely candidate, due to increasing significance indicated in literature. First, we use the most relevant statistical properties of public transport network for the purpose of description. We are interested in whether edge weights have any significant effect on topology, or topology contains complete information on network; how the existence of transport hubs affects scaling behaviour; and if a specific topology creates artificial barriers within the city. We review and illustrate the analytical methods potentially valuable further. Second, we try to design a simple simulation, purpose of which is to estimate the strength of influence of basic distance based variables on the network topology, generated throughout decades on an evolutionary basis. Empirically, we use the multimodal Bratislava public transport system.

Keywords: public transport, network analysis, simulation, Bratislava

Recommended Citation: ONDOŠ, S., PAULOVIČOVÁ, I., BELUŠÁK, L., KUSENDOVÁ, D. (2013) The Bratislava public transport in network analysis. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Many real world complex systems can be described as networks with individuals in the real system represented by vertices and interrelationships among individuals represented by edges. Modelling of transport systems becomes important not only in large cities around the world. Public transport, being one of the spatial networks, consists of two basic elements, routes and stations. A route is formed along a number of stations. Under normal circumstances, passengers can travel from station A to station B along a certain route, and also travel from station B to station A along the same route in opposite direction. Therefore, public transport networks are usually treated as undirected graphs [1].

Public transport network is a result of a long-term evolution in a typical city. It reflects, similar to urban morphology, the history of built environment and current functional structure both in the same time. The information enclosed in the network topology itself seems to be richer than only documenting transport possibilities for everyday life of metropolitan inhabitants and visitors, despite services operated crucially depend on their transportation demands. Otherwise, transportation network would be inefficiently wasting public resources, which to some extent still can be the case. Our intention is to explore selected analytical possibilities concerning the network architecture built in public transport network and to find research paths leading potentially towards future topology improvements helping to make the network serving better than the network in its current evolution stage.

Traditional literature of transportation network is abundant. During the past few years, several public transport systems have been investigated using various concepts of complex networks. Most of previous studies have analyzed specific sub-networks of public transport networks in various large cities and in different parts of world. For instance, subway network analyzes of Boston by Latora and Marchiori [2], [3] who defined measures of local and global network efficiencies. They notably found that the small-world behaviors existed in that system. Seaton and Hackett [4] calculated the clustering coefficient, path length and average degree vertex of the rail systems in Boston, US and Vienna, Austria. Also, Musso and Vuchic [5] (1988), Vuchic and Musso [6] focused on evolution and characteristics of subway networks. Sienkiewicz and Holyst [7] have analyzed the bus and tram networks of Polish cities finding that some systems appeared to show a scale-free behavior, with scaling factors. A very similar analysis was offered by Xu et al. [8] focusing the complexity of several bus networks in China. However, as far as the bus, subway, or tram sub-networks are not closed systems, the inclusion of additional sub-networks has significant impact on the overall network properties as has been shown for the subway and bus networks of Boston [9], [3]. Von Ferber et al. [10] used complex network concepts to analyze the statistical properties of public transport networks of several large cities, looking at all technologies and accounting for the overlapping property of transit systems, notably finding a harness effect. They also attempted to model system based on number of stations and lines.

To understand the network topology we employ on one hand state-of-the-art description techniques, presented in the first part of the text, as well as an attempt to lay foundations of simulation capable of informing us on principles hidden beyond pure topological properties of the network, shown in the second part of the paper. Motivation for our research is in limited understanding of how a public transport network in our case in a moderate size city can be built and operating most efficiently with a specific heritage of historical infrastructure unlikely to be transformed too radically from technical or financial reasons. Tightening public budgets over latest period only support relevance for this research motivation.

DESCRIPTION OF DATA

In the first part of this paper we will focus on the real data. We will perform our study according to the following scheme: first choosing public transportation system for analysis, second collecting the data, then representing them and finally calculating chosen basic statistics.

Choosing and collection of data

The first step was choosing a public transport network. We will be interested in various characteristics of chosen network. Therefore to allow general properties of a network structure to manifest themselves, the network analyzed should be large enough in terms of numbers of nodes and edges. The results presented below are based on an analysis of public transport network of Bratislava with 584 stations and 1502 lines of 94 different public transportation routes. Bratislava as the biggest and the fastest growing city in the Slovakia has sufficiently developed public transport network. In our assumptions the public transport in Bratislava suffers from inappropriate structure based on historical background and is highly influenced by natural conditions. Thus we have chosen this, not completely efficient public transportation network.

We want to use minimum input information possible, in form of the list of currently existing service lines provided. These are easily transformed into a directed graph alternatively weighted by time needed to cover specific distance between two adjacent stations. Bratislava is covered by a web of 1502 directed station dyads, which means that only 0.44% of all 340,472 potential links are operated by the service provider, formally leaving us with a sparse network problem. Even further generalization is possible in form of simplification into a non-directed graph where to a large extent double entered information is discarded since majority of services run symmetrically in both directions between adjacent stations.

The second step towards analysing public transport in Bratislava is therefore to collect the data by the given way. This is typically done with the aim to represent the network as a graph with nodes/vertices and links/edges. By having stations/stops all linked by lines, public transport system are in fact physical networks. Nevertheless, there exists several ways to define them as graphs. For this analysis is important each station and line, not only in the city area, bud also station which are located outside of the city (in the case of Bratislava they are located in Hainburg (Austria) and Rajka (Hungary)). The schedules of public transport for Bratislava were downloaded from the provider. We used data publicly available from webpage of “Dopravný podnik Bratislava” [11]. Consequently, obtained data was brought into appropriate format to construct the ordered lists of stations serviced by each line from schedules (hereafter we do not make any differences between bus, electric trolleybus or tram public transport lines). From consecutive stations of routes where built directed edges according to real accessibility. These serve as a background for the network structure analysis. At last, we added the shortest time needed to travel from one station to next to every edge.

Representation

As presented in Barthélemy [12], there are many possible ways of representing public transportation system as a network. For the aim of this paper we used the space-of-stops or the L-space representation as defined in von Ferber et al. [13]. Each station is represented in this graph by a node and an edge between two nodes indicates that these are consecutive stations of at least one route. As follows from previous, neighbours of a node are only those stations, which can be reached from it within single station trip. For purpose of this analysis we use directed graph so it better reflects real conditions of selected PTN. As weights we use inverse travel time between stations.

Public transportation network statistics

From all existing network analysis we have chosen identifying communities and modularity as characteristics shown in this paper. In our expectation, identified communities in the real network will be visible also in the simulation, as they there will be more links inside them as between them.

There are many possible algorithms for identifying communities in networks. The fastest way uses greedy algorithm for optimizing modularity [14] which can lead to producing super-communities. Another way is by using simulated annealing [15]. We used algorithm presented in Blondel et al. [16] (2008) consisting of two passes repeating iteratively until modularity cannot be further increased. Each pass is represented by one phase, where modularity is optimized by local changes, and second phase, where new composition of communities is made by aggregation. For better outcome, more measures were introduced to algorithm using structural as well as dynamical properties [17]. Modularity of a partition in a weighted network is calculated as [16]:

$$Q = \frac{1}{2*m}\sum_{i,j}\left[A_{ij} - \frac{k_i * k_j}{2*m}\right]\delta(c_i, c_j) \tag{1}$$

where m is half of the sum of all weights; A_{ij} is the weight of edge between i and j; k_i is sum of weights of the edges connected to i; $\delta(u,v)$ is 1 if $u = v$ and 0 otherwise; c_i is community to which node i belongs. Modularity compares the density of links inside communities to links between them and can acquire values between -1 and 1.

Using last described algorithm on directed weighted representation of real network resulted in 57 communities shown in figure 1 with only two hierarchical levels with modularity 0,885. 22 larger communities, bordered by a line, correspond to continuously urbanized fragments of Bratislava.

All the calculations and visualizations provided in this chapter were made in an open source interactive platform called Gephi [18], version 0.8.1-beta. For geographical layout was used plugin Geo Layout. The information about positions of stations in geographical space was downloaded from Open Street Map [19].

SIMULATION

The simulation exercise is based on a direct analogy with frequently used generalized linear modeling of raster represented urban land [20]. One way of extracting hidden regularities, offering itself in our situation, but not commonly used is binomial logistic regression model predicting occurrence of transport service independently for each oriented dyad, irregularly spread across the urbanized territory of the city as a single input. The model actually predicts the probability of connection between theoretical boundaries 0.00 and 1.00, instead of occurrence itself, only based on a few theoretically relevant predictors. To some extent our exercise finds inspiration in Koenig and Bauriedel [21].

Fig. 1. Communities in PTN presented as nodes in shades of grey with boundaries of bigger communuties.

We start from a set of localized stations defined by the geographic coordinates extracted from Open Street Map database, reflecting the location of transport service users and their transport destinations. This allows us to assume that location of stations plus their mutual location include also a relevant information on the purpose of their existence, which is the movement along unknown service lines running across unknown network drawn among already given locations. A preceding step of the more mature future analysis could be estimating the location for each station endogenously. Actual spatial distribution of locations is far from random. They appear in spatial clusters, linked together by strips of stations between clusters. They also reflect topography of the area since we deal with a city spread on both sides of Danube, one of the largest European rivers, meeting Carpathian mountain slopes, ending in a systematic spatial structure.

The purpose of any transport service is to remove the effect of geographical separation of distance by means of movement across space. Therefore, first driving force considered seems to be logically distance between two stations itself. Increasing length is expected to decrease the probability of connection. We employ log value of distance. Since point locations are scattered across a plane we also consider neighborhood relationships among them. The space between stations can be easily divided in zones of land, from which only one location is preferred on a distance basis. The points which do not prefer any location form borders between these zones. Geography then enters our consideration in an additional way. The Thiessen polygons constructed upon Delaunay principle allow us to construct the spatial contiguity matrix identifying neighbors from the universe of all possible connections. The resulting dummy predictor is expected to influence probability in positive direction. Being neighbors in space should increase probability of connection between these regions. This factor is related, but not necessarily the same as distance itself. The linear model will attempt to estimate how the two differ in effect on actual links distribution. The third factor considered is inspired by market potential constructed as an average distance to all other stations of the system increasing probability of connections distributed under expectations with a higher density in central city decreasing towards peripheries. Each dyad then gets average log value of two connected potentials, both directions same.

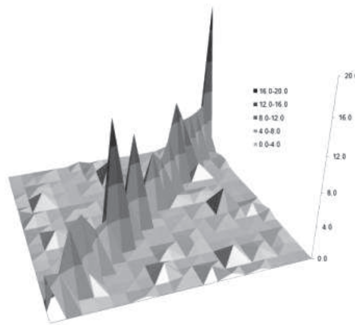
The estimation of a three-variable model allows to document direction, magnitude and significance of assumed linear effects on links distribution in empirical network. All of them have expected signs, more distant stations are less likely to be connected, neighbors are more likely to be connected, and central connections tend to be more likely than peripheral. So far logistic model based simulation works fine. But resulting network distribution uncovers limited applicability at this stage with only 738 dyads simulated correctly pointing at 49.13% success. The comparison between a real and a simulated network topology reveals that the model gives many dense disconnected clusters of very short links. Naturally, such a network is not a functional one, but it suggests how the regularities considered shape a real world network. In an extreme way it articulates the principle given already in our introductory description of point pattern in the data. To get closer to real world network one must find opposite directed influences capable of dispersing links out of dense clusters and of connecting them in one single network instead. Model might clearly benefit from inclusion of additional factors aiming at neighborhoods of individual locations.

Table 1. Coefficient estimates for three logistic model versions.

Model I	**B**	**S. E.**	**t**	**Sig.**	**Exp(B)**
Intercept	-7.949	0.593	-13.407	0.000	0.000
Log distance	-2.481	0.058	-42.488	0.000	0.084
Neighbors	1.559	0.095	16.441	0.000	4.756
Log potential	-0.086	0.191	-0.448	0.654	0.918
Log neighbors count	-0.399	0.251	-1.590	0.112	0.671
Log local potential	1.355	0.090	15.004	0.000	3.876
Model II	**B**	**S. E.**	**t**	**Sig.**	**Exp(B)**
Intercept	-7.927	0.591	-13.420	0.000	0.000
Log distance	-2.479	0.058	-42.628	0.000	0.084
Neighbors	1.557	0.095	16.451	0.000	4.744
Log neighbors count	-0.360	0.236	-1.530	0.126	0.697
Log local potential	1.328	0.068	19.512	0.000	3.774
Model III	**B**	**S. E.**	**t**	**Sig.**	**Exp(B)**
Intercept	-8.718	0.289	-30.173	0.000	0.000
Log distance	-2.493	0.058	-43.331	0.000	0.083
Neighbors	1.530	0.093	16.493	0.000	4.620
Log local potential	1.310	0.067	19.524	0.000	3.707

Offering itself as a generalization of previous forces automatically is an average distance towards neighbors instead of all remaining locations in the network. This having positive additional effect could help in dispersion of linkages out of dense clusters, giving better chance of missing connections between clusters to appear among 1,502 most probable links. The number of neighbors is another potentially helpful predictor, which can prefer connecting points with smaller number of neighbouring locations. These seem to be again those out of dense clusters of points. Five explanatory variables version (Model I) basically repeats regularities known from the previous, but there are some differences among the effects. Positive significant effect of log potential is lost in expense of positive significant local potential version. Also, size of the location neighborhood proves to be an insignificant predictor. This model version improves prediction to 778 correctly simulated links, giving a 51.80% success. The Figure 2 enclosed suggest that more sophisticated driving forces must be employed in further versions to redirect remaining links from dense clusters in space linking them into one connected network.

(a)



(b) (c) (d)

Fig. 2. Probability surface illustrating 5,000 most probable links in the network (a) and real network (c) to simulated (b) comparison. Distribution of average probabilities of connections among network communities including prominent internal connections on matrix diagonal.

Full model containing five variables on the right hand side of the equation is in the first section of the table, followed by two generalized versions (Model II) removing the least significant log potential, and then (Model III) removing log count of neighbors in third section. Second one has improved performance correctly simulating 780 links as our most successful, third version performs slightly worse giving 774 correct predictions. The Figure 2 illustrates how probability surface translates into a disconnected web of short linkages missing most of longer network elements. The contrast between Figure 2b and Figure 2d reflects clearly the space left for improvements in a more mature future modelling attempt. The Figure 2d documents a conceptual connection of the results from our simulation exercise with the descriptive network community detection approached in final part of this analytical section.

The remaining question is, whether distribution of probability values connects somehow to modularity-based network communities used so far for descriptive purposes. The answer can be found in average probability values constructed for all possible inter-community connections appearing in the matrix. Given all theoretical connections, the diagonal elements (7.57%) appear 53-times bigger than the non-diagonal elements (0.14%). Focusing now Delaunay neighbours only, the diagonal elements (40.39%) still appear 8-times bigger than the non-diagonal elements (5.29%). This means that our logistic model correctly assigns much more probability to the linkages falling inside different network communities found by Louvain method than those between them. Whether this contrast is a significant one requires a specific regression test, which would have to take into account spatial network autocorrelation present in our problem.

CONCLUSIONS

This paper describes and explores a public transport network in a typical, moderate size European city. The sparse network of service linkages among 584 stations scattered across the urbanized territory offers an exciting research problem. Public transport network is only a sample of spatial interaction networks that city offers as a documentation of its real-world functioning, potentially with a promise of efficiency focusing performance improvements in the future. Former part of the paper identifies hierarchy and barriers existing in the network topology. We have discovered a small number of prominent vertices, one of which serves as a hub. Their distribution corresponds perfectly with natural settings and barriers: mountain slopes, country borders, and river dividing the area in two. Unfortunately, those few nodes, including the most important "Račianske mýto", reflect more a path-dependent topology than correspondence with requirements of current Bratislava.

The modeling exercise in the later part tests the importance of several driving forces hidden behind specific topology of the network. Three predictors prove to be significantly changing probability of connection between two stations, namely geographic distance between them, neighbourhood status of a candidate connection, and an average distance to the station neighbours. Presented findings in their best alternative reach 51.93% success of simulation, pointing at about one half of network architecture inherited from basic distance based spatial relationships, but in the same time one half remaining unknown. Heterogeneous clustering of stations in space seems to be a concept worth further attention, especially knowing about a clear connection with the outcome of network communities detection.

ACKNOWLEDGEMENTS

This research was supported by VEGA grant 1/0562/12 with the name "New demographical analysis and prognosis of the population of Slovakia and its regions by using of progressive geographical applications".

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MULTI-LEVEL OBJECT-BASED URBAN MAPPING FROM REMOTE SENSING AND GIS DATA

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Abstract

Evolution of urban structure is very often related to population growth and socio-economic changes in large metropolitan areas. The availability and integration of spatial data such as imagery, airborne laser scanner (ALS) and database information is a potential source for mapping urban structure along the time. A multi-level object-based classification approach applied to the city of Valencia (Spain) is presented here, and its potential application in urban studies discussed. At first level, a classification of cadastral plots in seventeen land uses is obtained based on the automated extraction of multiple descriptive attributes from aerial images, airborne laser scanning (ALS) data and a cadastral database, providing information about the spectral, structural, shape, 3D metrics, internal and external spatial context of each plot in the city. Then, a second level classification in nine urban structural typologies at block level is achieved from another set of spectral, structural and 3D attributes at this broader scale, combined with the proportion of land uses per block obtained in the first level classification. The overall accuracies obtained for the two levels are above 80%, and can be improved reconsidering the classes. Analyzing the results and maps by administrative neighbours some structural differences are noticed, providing useful information for urban managers. The potential of the methods proposed is discussed for mapping the fragmentation of metropolitan areas, their dynamics in land uses and structural changes, and the relationship of these variables extracted from geospatial data to socio-economic changes. As a preliminary example, the total volume extracted from ALS data restricted to residential land use cadastral plots allows for the prediction of the population by neighbourhoods with a coefficient of determination r^2=0.78. In the future, these data and techniques could be used to improve and validate urban structure models based on socio-economic statistical data.

Keywords: urban structure, object-based mapping, land use, LiDAR, high-resolution imagery

Recommended Citation: HERMOSILLA, T., RUIZ L. A., GIL-YEPES, J. L., RECIO, J. A., PARDO-PASCUAL, J. E. (2013) Multi-level object-based urban mapping from remote sensing and GIS data. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

The urban spatial structure is a physical reflection of various processes during the evolution of a city [1], so urban districts constructed in different time periods show significant difference in building density and structures [2]. The geometrical shape and topological relationships of open spaces and built-up areas significantly determine the appearance of urban environments, defining local particularities related to a spatial identity [3]. Consequently, the urban structural typologies can be depicted by describing their properties, such as the dimensions, shape, spatial arrangement and context of the buildings and diverse land covers that compose them. Although remote sensing is a real opportunity and a very relevant data source in this domain [4], the structural description of a city using remote sensing data is dependent on the data used [5]. Remote sensing devices allow for a massive data acquisition. Multi-spectral imagery, collected from satellites or airborne sensors, provides valuable information to analyze the territory. Additionally, three-dimensional information is currently acquired using airborne laser scanning systems (ALS). These systems obtain point clouds representing the height distribution of the observed terrain and the aboveground elements.

The precise characterisation of complex intra-urban patterns using remotely sensed data is a highly complex task, and commonly two stage approximation methods are used [6]. Initially, the main land-cover types or significant elements in the image are identified, and then this information is analysed in a spatial context to define metrics that enable to discriminate land uses and structural typologies. According to Yoshida and Omae [7], in analysis of urban morphology, remote sensing and Geographic Information Systems (GIS) may be able to take advantage of the physical explicitness represented by urban blocks, since they are defined incontrovertibly by roads in urban areas. This would enable to face the challenges stated by Gamba et al. [8] regarding the integration of multiple datasets to characterise urban areas, and to integrate the information derived from remotely sensed data in GIS. Thus, several authors have employed the urban block boundaries, or occasionally even urban plot boundaries, to define objects in order to extract descriptors quantifying the geometry and the area covered by buildings, vegetation, or the diverse construction materials [9], [6], [10], [3], [11], [12], [13]. These metrics are complemented with height information and volumetric descriptor sets when three-dimensional (3D) information is available [7], [14], [2], [15], [16].

This paper aims the development of methods to: (i) extract, integrate, and organize quantitative informational attributes from aerial images, airborne laser scanning data, and cadastral limits at plot and urban block levels; (ii) classify urban areas in land uses (at plot level) and structural typologies (at block level), in order to structurally characterise urban neighbourhoods. In addition, the potential of the former tools for the study of socio-economic variables and their relationship with the structural typologies and land uses will be discussed, useful to better understand the functional organization, evolution and quality of living urban spaces.

STUDY AREA, DATA AND PREPROCESSING

The study was performed in the metropolitan area of the city of Valencia, Spain, the third largest urban concentration in Spain in terms of population. The municipality of Valencia is administratively divided in 19 districts, which are subdivided in 87 neighbourhoods.

Imagery and LiDAR data were used. These data were acquired in the frame of the Spanish National Program of Aerial Orthophotography (PNOA). The images were collected in August 2008, with 0.5 m/pixel spatial resolution, 8 bits radiometric resolution, and three spectral bands were used: infrared, red and green. These images are distributed orthorectified and georreferenced, the panchromatic and multispectral bands fused, mosaics and radiometric adjustments applied.

LiDAR data were acquired in September 2009 using a RIEGL LMS-Q680 ALS with a scan frequency of 46 Hz, 70 kHz of pulse repetition rate and a scanning angle of 60º. The mean flying height was 1,300 meters, a nominal density of 0.5 points/m^2 and an average density value of 0.7 points/m^2. A normalised digital surface model (nDSM), i.e., the difference between the digital surface model (DSM) and the digital terrain model (DTM), representing the physical heights of the elements with respect to the terrain, was generated from LiDAR data. The DTM was computed using an algorithm that iteratively selects minimum elevation points and eliminates points belonging to any aboveground elements, such as vegetation or buildings [17].

The urban cadastral plot, represents a distinguishable administrative unit in terms of land ownership of an urban area. Urban blocks are groups of plots, surrounded by public roads. Plot and urban block boundaries were provided by vectorial cadastral cartography in shapefile format, produced by the Spanish General Directorate for Cadastre (*Dirección General de Catastro*). This cartography has a scale of 1:1.000.

Several descriptors are based on the building and vegetation covers. Both, building and vegetation covers were obtained using an automatic building detection technique consisting of applying a multiple-threshold based approach, which is fully described and assessed in Hermosilla et al. [18].

METHODOLOGY

In complex environments such as urban areas, the analysis of the structure of the elements must be faced at different complexity or scale levels. Further combination of these levels may help us to understand the evolution of these dynamic areas that conform a city. In order to study administrative neighbourhoods and to relate their structural properties with socio-economic variables, two lower scale levels were considered – plot and urban block – to extract different quantitative measurements that provide information to classify and structurally characterize the neighbourhoods. Fig. 1 shows a flowchart summarizing the methodology applied. The objective of the plot-level characterisation was to extract descriptive features from the remotely sensed data and the cadastral cartography limits that enable to assign a land use to each cadastral plot. Afterwards, the urban block level characterisation aimed to classify each urban block into an urban structural typology based on the information provided by descriptive features, plus the land-use information obtained at plot level.

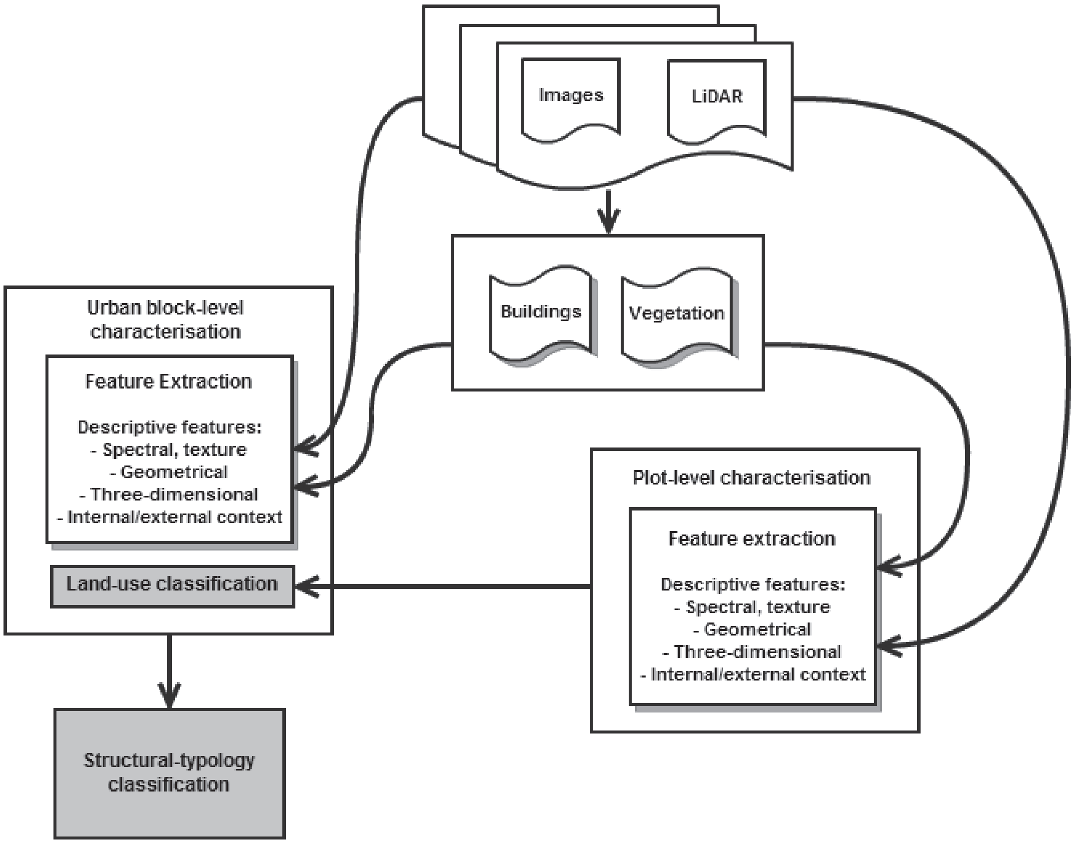

Fig. 1. Scheme of the proposed methodology for classification in urban land uses and structural typologies.

Extraction of object-level descriptive features

Plot-level and urban-block-level feature extraction were performed using and object-based image analysis approach. In an object-based approach, image analysis is performed by considering objects instead of pixels. An object is a group of pixels with common characteristics created by means of a determined segmentation criterion [19]. In this case, plot and urban-block boundaries from cadastral cartography were used to define objects at their respective levels.

Seventeen land use classes were defined to perform the classification of the cadastral plots: ten urban and seven agricultural uses. Five urban classes were related to residential uses: *historical buildings*, *urban buildings*, *open urban buildings*, *semi-detached houses*, and *detached houses*. The rest of urban classes were: *industrial/warehouse buildings*, *religious buildings*, *commercial buildings*, *public buildings* –including schools, universities, sport facilities and civic and governmental buildings–, and *gardens and parks*. The agricultural classes defined were: *arable lands*, *citrus orchards*, *irrigated crops*, *carob-trees orchards*, *rice crops*, *forest*, and *greenhouses*.

At this characterisation level, objects were defined using the plot boundaries. A set of object-based descriptive features depicting each object as a single entity based on diverse aspects reflecting the variety of information used were computed using the object-based image analysis software FETEX 2.0 [20]. The computed features provided information regarding spectral, texture, structural (based on the semivariogram graph, see Balaguer et al. [21], geometrical, and height properties (derived from the nDSM). Context was described by characterizing higher and lower aggregation levels of the plots. Thus, internal context features describe an object attending to the land cover types and distribution of the elements contained within the object (denoted as sub-objects), in this case buildings and vegetation. External context is defined characterizing each object by considering the properties of the urban block containing the plot. This context is described by means of specific building-based, vegetation-based, geometrical, and adjacency features (see Hermosilla et al., [15] for a full description of the context features).

Nine urban typologies were defined for the urban-block-level classification, based on the analysis of the urban structure of Valencia, partially defined by the evolution of the city along the time: *historical town*, *late XIX century expansion* (known as *ensanche* in Spanish), residential areas built in 1950 and 1960 decades (*1950-1960s residential areas*), residential areas from 1970 and 1980 decades (*1970-1980s residential areas*), residential areas constructed during the 2000 decade (*2000s residential areas*), *single-family suburban areas*, *industrial areas*, *gardens and parks*, and *community service facilities*, including public, commercial, and religious buildings and landmarks. Fig. 2 shows examples of the nine structural typologies defined.

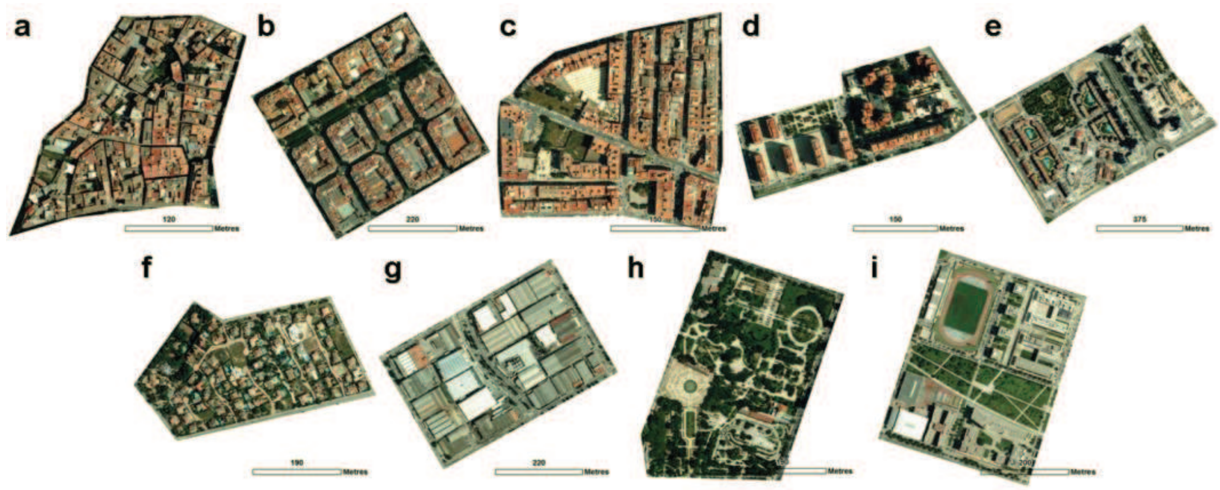

Fig. 2. Examples of the urban structural typologies defined: a) Historical town, b) late XIX century expansion (ensanche), c) 1950-1960s residential areas, d) 1970-1980s residential areas, e) 2000s residential areas, f) single-family suburban areas, g) industrial areas, h) gardens and parks, i) community service facilities.

Urban blocks were characterised using features describing the geometry or their shape, and to the area, height and volumetric information of the buildings and vegetation contained in them. These descriptive features constitute the external context descriptors when working at plot-level. The build-up and vegetation area and percentage of occupation, mean and standard deviation of the building and vegetation height, mean volume of the buildings, and mean and standard deviation of the NDVI in the vegetation cover were computed. In addition to these features, the land-use percentages of the plots contained in each urban block were also included as descriptive features. These land uses were obtained as a result of the plot-level classification. The considered land-uses were the urban classes: *historical buildings*, *urban buildings*, *open urban buildings*, *semi-detached houses*, *detached houses*, *industrial/warehouse buildings*, *religious buildings*, *commercial buildings*, *public buildings*, and *gardens and parks*.

Since many descriptive features were defined, some of them were redundant in terms of efficient description of the objects, and their use may introduce noise in the classification process. Consequently, a selection was carried out in order to determine the best set of descriptive features for classification, using forward stepwise linear discriminant analysis (LDA). In this method, all variables are reviewed and evaluated at each step to determine which one will contribute most to the discrimination between classes. That variable is included in the model and the process is iterated. Thus, LDA was employed for selecting the most relevant descriptive features to be used in each classification process, selecting variables until the estimated classification accuracy was stabilised.

Classification of objects

Classifications were performed using of decision trees constructed with the C5.0 algorithm combined with the boosting technique. This algorithm divides the sampling set by using mutually exclusive conditions, until homogeneous subgroups are generated, i.e. all the elements in a subgroup belong to the same class, or a stopping condition is satisfied [22]. Previous to the classification, training and evaluation samples were collected following two criteria: per-class representativeness and spatial distribution homogeneity. Two types of samples were considered, cadastral plot or urban block, for both classification levels. Sampling was designed applying a restricted randomization scheme [23], consisting on a random sampling selection to ensure the spatial homogeneity, followed by a redistribution and addition of some samples with the criteria to maintain the appropriate number of samples according to the internal variability of each class. A reference class was assigned to each object by means of visual photointerpretation of the high-resolution aerial images.

The evaluation of the classifications is based on the analysis of the confusion matrices [24], which compare the class assigned to each evaluation sample with the reference information. The overall classification accuracies were obtained, as well as the producer's and user's accuracies for each class, which respectively expose the classification errors of omission and commission. The classification accuracy assessment was done by using leave-one-out cross-validation technique to increase the efficiency in terms of number of samples and to use independent training and test samples. This method uses a single object from the original sample set as validation data, and the remaining objects as training data. This is iterated until each observation in the sample set is used once as validation data [25].

RESULTS

In the land use classification at plot level an overall accuracy of 84.8% was obtained, showing a high performance of the method for the agricultural and urban classes defined. Most unbalanced values in terms of user's and producer's accuracy (see graph in Fig.3) were obtained for the following land uses: *commercial buildings*, *religious buildings*, and *public buildings*. These results are in concordance of previous results Hermosilla et al. [26], and are explained by the high diversity of *public buildings* and *commercial buildings*, the low representation of samples available from *religious buildings*.

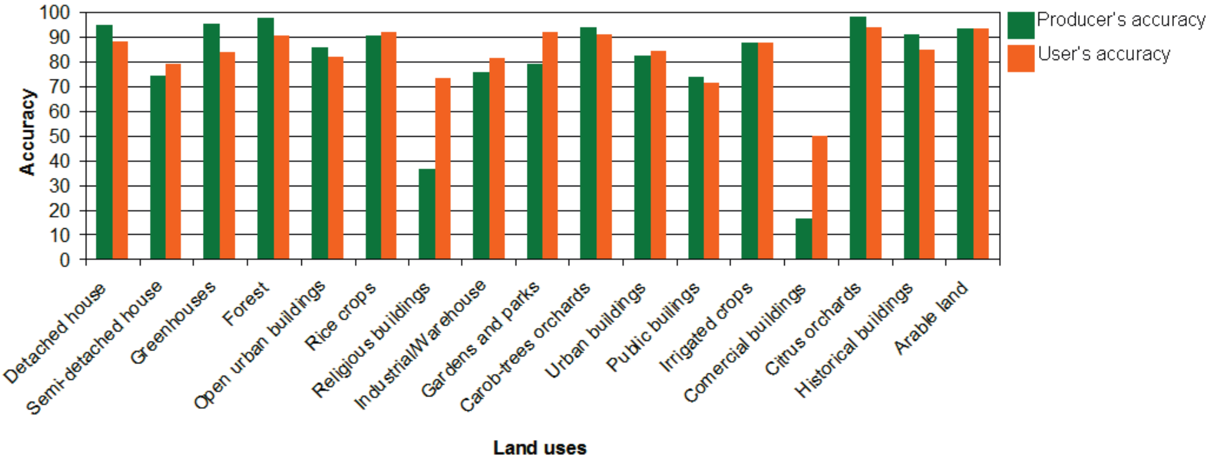

Fig. 3. User's and producer's accuracies for the land-uses defined at plot-level classification.

In order to assess the improvement of the introduction of multi-level features, two different results were reached, considering only the urban-block features, and combining those with information extracted from the land use classification of plots. In general terms the results of the classification in structural typologies at block level show that the addition of the land use information obtained at plot-level significantly improves the overall performance of the classification, increasing the overall accuracy from **68.6%** to **80.2%**.

Analyzing the impact of the addition of land use information in each specific class (see Fig. 4), all urban typologies noticeably increase both, their user's and producer's accuracies, with the single exception of the 1970-1980's residential typology, which has a decrease in its producer's accuracy. The major increases are shown in the typologies *Community service facilities* and *Gardens and parks*, followed by *Historical town* and *1950-1960s residential areas*. This may be due to the internal variability inherent to these urban classes, in terms of number and distribution of the elements within them. The urban typologies presenting the highest accuracies are *Industrial areas* and *Single-family suburban housing*, reaching values closer and higher than 90%. This is given since these typologies present constructions and morphological properties significantly different to the rest of urban typologies considered. Thus, *Industrial areas* are composed of large buildings, whereas *Single-family suburban housing* shows small buildings and noteworthy presence of vegetation. The lowest precision is reached for the *1950-1960s residential areas* and *1970-1980s residential areas*, with user's and producer's accuracy values of approximately 60%, presenting both classes major confusion with *Historical town* and *Late XIX century expansion* typologies.

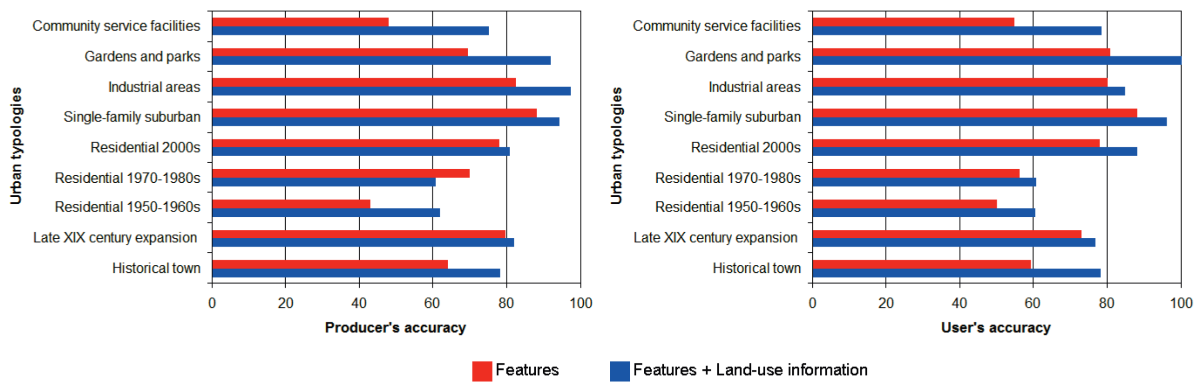

Fig. 4. User's and producer's classification accuracies for the urban-typologies defined at urban-block level characterisation considering only the urban-block features, and combining these with the information of the plot level land use classification.

DISCUSSION AND POTENTIAL APPLICATIONS

A multi-level approach for urban classification based on high-resolution imagery and LiDAR data has been proposed and evaluated in the area of Valencia. The availability of Earth observation data is growing fast in the last decades, in particular for large cities. The regular application of these techniques may provide valuable input to analyse the dynamics of urban areas, but they may have even more potential to study, understand and model the evolution in spatial urban structures of big cities. This is a critical issue, since it is accepted that spatial structures have great influence in the degree of economic and ecological efficiency of the cities, in their functional organization and quality as suitable spaces for the development of human life [27].

Evolution of internal structure in metropolitan areas is related to changes in resident population, employment, migration, and other socioeconomic parameters. Rossi-Hansberg et al. [28] studied this evolution in urban structure and its relations to the number and size of commercial establishments in different areas of US cities, creating a model to understand the fragmentation of firms based on structural measurements. Additionally, they found an effect of population growth on urban structure in the 1980s.

In our work, we obtained a land use classification at plot level, and a classification of structural typologies at block level. This two-level information can be used at a broader scale to analyze the status and evolution of the different neighbourhoods or districts that form the city. Thus, as a result of the classification map, main structural differences can be observed in the neighbourhoods (Fig. 5). Some of them present an evident homogeneity in their composition of structural typologies (see Fig.6a and Fig.6c), whereas others have a higher variability. This variability can be expressed in a different manner, e.g., the neighbourhood in Fig. 6b presents a high degree of fragmentation of structural types, while that in Fig. 6d shows a distribution of the structural typologies grouped in clusters. This occurs because the boundaries of the neighbourhoods of a city have administrative purposes, and they do not have always a direct correspondence to the actual urban structural morphology.

The generation of fragmentation indices of structural classes combined to the land uses within neighbourhoods can be related in future work to population movements, spatial distribution of employment, or commercial activities, helping to explore and understand changes in socioeconomic parameters and their relation to the urban structure.

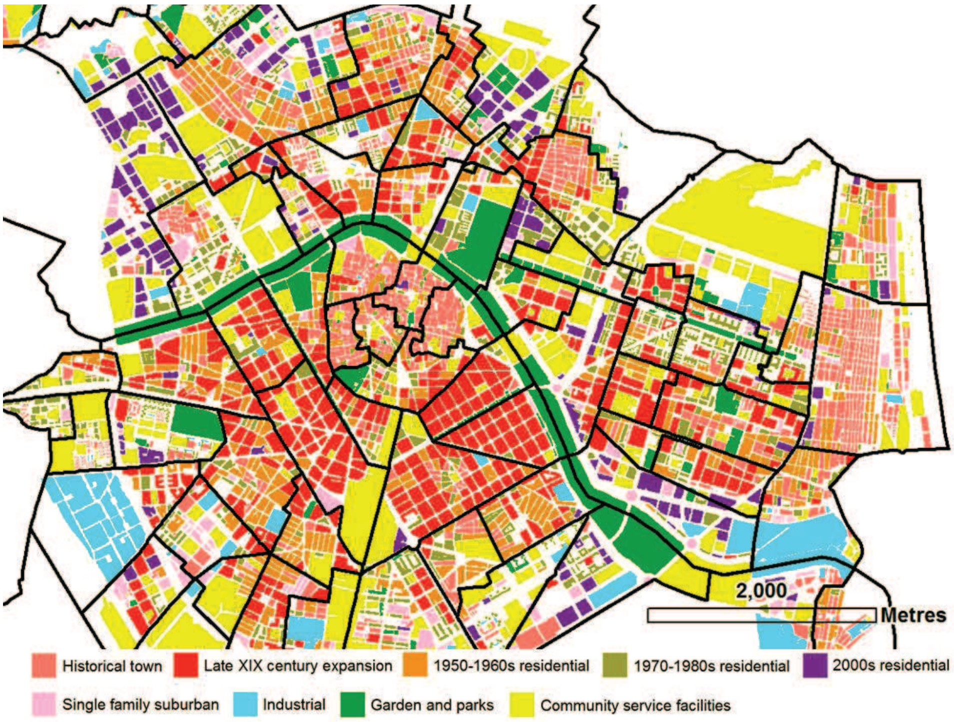

Fig. 5. Thematic map composition showing the result of the structural classification of the urban-blocks with the administrative neighbourhood boundaries.

Fig. 6. Examples of classification in structural typologies of four administrative neighbourhoods.

A preliminary use of these attributes extracted from imagery and 3D data is the prediction of population at neighbourhood level using single linear regression. Considering the 71 neighbourhoods in Valencia that present a pure urban structure (the remaining 16 neighbourhoods are mainly rural or present a mixed peri-urban structure), and using only the total volume of buildings obtained from the LiDAR data set as descriptive attribute or independent variable, the population is estimated with $r^2 = 0.60$. However, restricting the volume calculation to only those buildings with residential land-use, the coefficient of determination increases to $r^2 = 0.78$ (Fig. 7). This first results show the potential of the combination of land use and structural information to improve the explanation of socioeconomic variables.

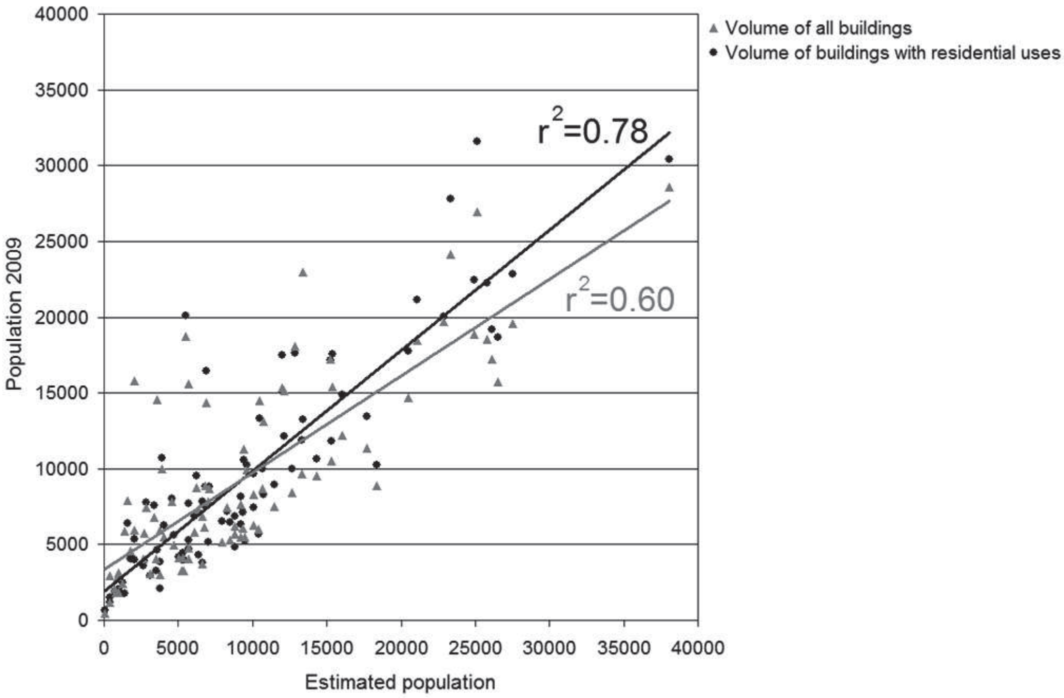

Fig. 7. Predicted vs. actual population using two different models: considering the volume of all buildings, or only the volume of those buildings with residential land uses.

CONCLUSIONS

This paper presents a multi-level approach to classify and further characterise urban areas integrating high-spatial resolution multi-spectral imagery, airborne LiDAR data, and cadastral cartography. From these data, a set of descriptive features quantifying the discriminative properties of image elements were extracted at two analysis levels: plot and urban-block. The objective at plot-level was to categorise land uses. The resulting classification, together with other image-derived and 3D descriptive features, was used to characterise and classify urban blocks into structural typologies. The analytical results showed that the use of multi-level descriptors providing specific information about the land use enable to significantly improve the classification accuracy of the urban structural typologies. Thus, the proposed methodology enables to derive valuable information for a massive and non-subjective characterisation of urban areas, defining and adapting the land-use and structural-typology legends to each particular scenario analyzed.

The proposed multi-level characterisation may be used to understand and model the spatial evolution of urban structures within a city. As the urban structure is strongly related to socio-economical aspects, the analysis of the spatial distribution of the urban typologies, among other image-based and 3D descriptive features, may also be useful to describe and analyse changes in resident population, employment, migration, and other socioeconomic parameters.

An actual challenge of these methods is the current lack of base cartography, needed to create the objects at different scales or levels, in some large metropolitan areas of developing countries. This could be partly solved by using automated image segmentation techniques based on images [11], [13].Improved stratification techniques can also be used to define the study objects or zones, providing a more realistic behaviour of the configuration of the urban units at different scales.

ACKNOWLEDGEMENTS

The authors appreciate the financial support provided by the Spanish Ministry of Science and Innovation and FEDER in the framework of the projects CGL2009-14220 and CGL2010-19591/BTE, and the support of the Spanish *Instituto Geográfico Nacional* (IGN).

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REMOTE SENSING AND FIELD STUDIES TO EVALUATE THE PERFORMANCE OF GROYNES IN PROTECTING AN ERODING STRETCH OF THE COASTAL CITY OF CHENNAI

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Abstract

The city of Chennai, on the Coromandel Coast in south east India, has been facing the problem of severe coastal erosion due to improper coastal engineering practices. The landward displacement of the shoreline caused by the forces of waves and currents has been a perennial problem for the Chennai coast since the last 100 years. In 2004, groynes were constructed along the north Chennai coast and the lost shoreline and the beaches are now being regained. This study is concerned with remote sensing, GIS and field based studies to evaluate the performance of these groynes along the north Chennai coast and quantify the rate of accretion. Digitally processed multi-temporal (1972-2011) satellite images were interpreted and the shorelines for 7 different years were digitised in a GIS environment. The digitised shorelines, imported into the USGS developed Digital Shoreline Analysis System (DSAS) were analysed and final maps were generated depicting erosion in pre-2004 and accretion in post-2004 periods.

These maps show that the shoreline has eroded about 220 meters in the last 32 years up to 2004, while it is accreting at a rate of about 8 m/yr from 2004 up to 2011. Finally a shoreline change prediction model was prepared in the DSAS environment. The positions of the future shorelines were determined using a component of DSAS called LRR and the position of predicted shorelines was obtained. This study has shown that due to the construction of groynes, erosion has reduced and deposition is in progress to regain the lost beaches in Chennai City, thus indicating that the groynes are performing well.

Keywords: Chennai city, coastal protection, groynes, multi-date satellite images, GIS, DSAS

Recommended Citation: SHANMUGAM, S., NAYAK, J. (2013) Remote sensing and field studies to evaluace the performance of groynes in protecting an eroding stretch of the coastal city of Chennai. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Construction of coastal structures and dredging activities for the development of ports interfere in the coastal processes of a region [1]. Sea level rise has also been an important factor responsible for coastal erosion. Wang [2] mentions that the increasing sea-level along China's coast in the recent past, has enhanced erosion by waves breaking on the upper beaches. The author observes that river-channel slopes have been reduced and fluvial sediment discharges to the ocean have decreased, thus resulting in increased coastal erosion. He finally concludes that all such effects are the result of human impact. Xia et al. [3] noted that 70% of the sandy coasts in China are prone to erosion, thus threatening villages, roads, factories, coast-protection forests and tourism. The speed of erosion ranges between 1 and 2 m/ yr in general.

The city of Chennai (erstwhile Madras), which adorns the Coromandel coast in south east India, boasts of the marina which is the world's second longest beach. This coastal city, however, has been facing certain problems. In its report, the Integrated Coastal and Marine Area Management Project Directorate, India mentions that "it is well known that the shoreline along Chennai coast is subjected to oscillations due to natural and man made activities. After construction of Chennai port, the coast north of the port is eroded and 350 hectares land is lost into sea. The state government resorted to short term measures for protecting the coastal stretch with sea wall and the erosion problem shifted to further north" [4]. Since there has been severe erosion since the past 100 years, preventive measures such as construction of ten groynes in the stretch between Royapuram and Ramakrishna Nagar along the Ennore expressway by the National Highways Authority of India and the Tamilnadu Road Development Company have been implemented. Such measures have helped reclaim the shoreline by a few metres. The department hopes to reclaim shoreline up to 130 metres in two decades [5]. After the construction of groynes in this area, it is necessary that we study accretion, if any, due to the construction. It is also necessary that we estimate the rate of accretion and evaluate the performance of the gryones. Accordingly, the objectives of this paper are: (i) to use multi-temporal satellite image data and quantify erosion along the shoreline before the construction of groynes, and accretion along the shoreline after the construction of groynes (ii) to use a prediction model and predict the position of shoreline in the next decade.

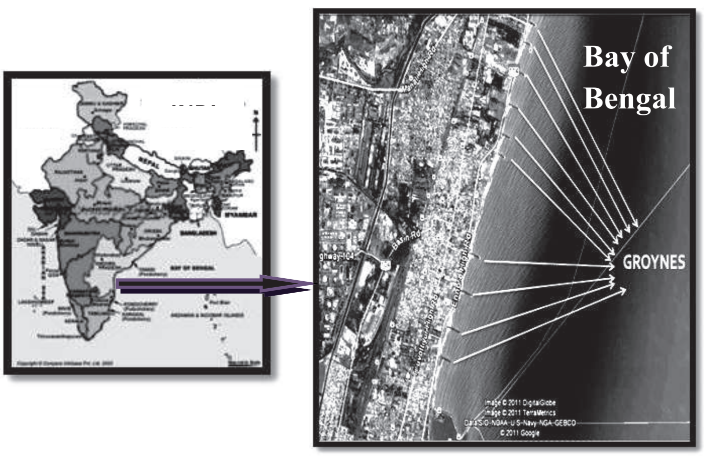


Fig 1. Map of India and study area (left) and the satellite image of Chennai city (right) showing the gryones.

Study area

Chennai city lies on a flat coastal plain on the south east coast of India, known as the Coromandel Coast. The climate is tropical wet and dry, and for most of the year, the weather is hot and humid, with temperatures ranging from a maximum of 42°C in May to a minimum of 18°C in January. Most of the rainfall is received from the northeast monsoon winds, from mid-October to mid-December. Cyclones in the Bay of Bengal also hit the coast. The annual rainfall is about 1250 mm, and the spring tides are up to 1.2 m. Historically, the Chennai port was responsible for the shoreline changes in the region, where the area south of the port has accreted significantly, resulting in the formation of the Marina Beach, whereas the coast in the northern region has undergone severe erosion. Ever since the harbour was constructed, the coast north of the harbour has been experiencing erosion at the rate of about 8 m annually. The shoreline has recessed by about 1,000 m with respect to the original shoreline in 1876. It is estimated that 500 m of beach has been lost between 1876 and 1975 and another 200 m between 1978 and 1995. About 350 ha land in the coast north of the port is lost into sea. On the other hand, the area south of the port is increasing 40 sq m every year due to the progradation [6].

The study area (Figure 1) is between Chennai and Ennore ports where the groynes have been constructed. The Ennore- Manali road forms the main communication link. The ten groynes are located each at an interval of about 500-1000 meters over 6 kilometres. Sea wall has also been constructed to reduce erosion. The groynes vary in length from 165-300 m and their height is 4m above MSL. These gryones have been performing well by enhancing accretion. Analysis of historical sea level data for the Chennai coast indicates that since 2004, co-incidentally, there is a trend of decrease in sea level. This could, in turn, result in reduction in the incidence of erosion, or perhaps accelerate accretion along the Chennai coast.

METHODOLOGY

The methodology adopted for this study is shown in Figure 2. The main components of the methodology include : (i) Remote sensing, (ii) GIS analysis (iii) Preparation of shoreline change model and predicting the future shorelines. The individual components of the methodology listed in Figure 2 have been described in detail in the following sections.

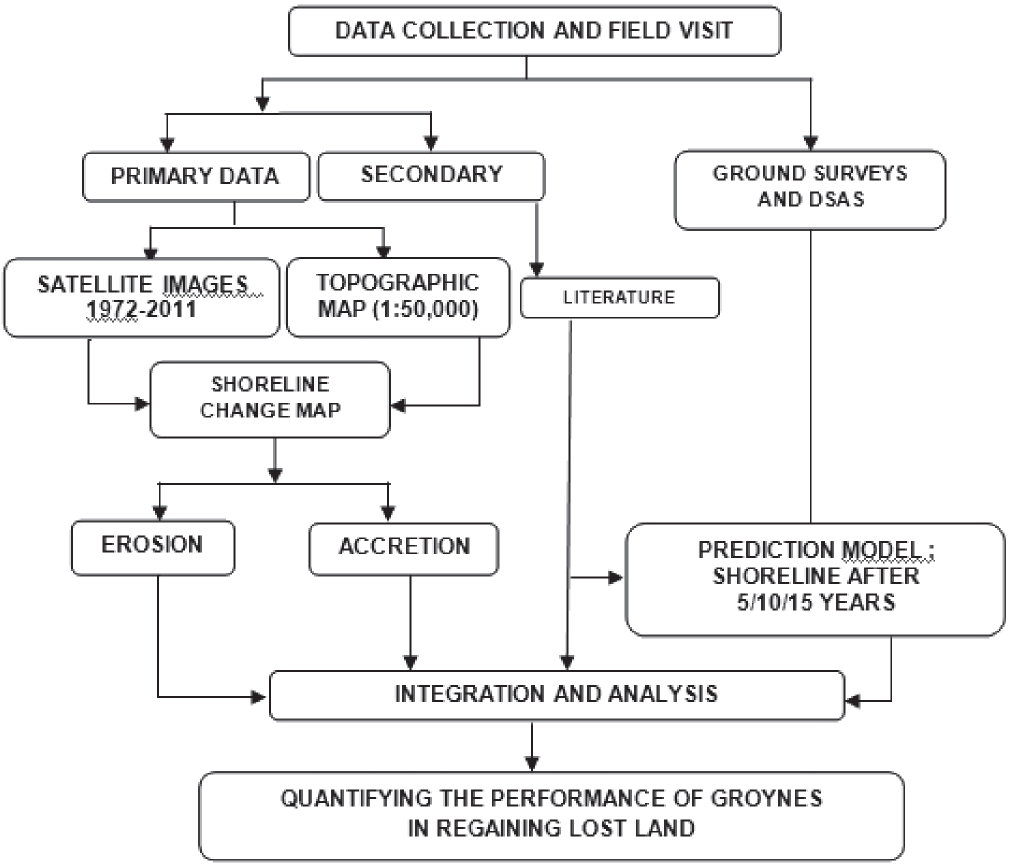


Fig. 2. Flow chart depicting the methodology adopted in this study

REMOTE SENSING AND GIS BASED STUDIES

Remote sensing is an efficient tool for mapping and monitoring coastal geomorphology and geomorphic changes because of the synoptic view and receptivity offered by multi-temporal satellite images. The conventional method of mapping has its own drawbacks and advantage. In this case it is not possible to go to the field and map a large area during every year, season or during every month in a varying climatic conditions. Hence, remote sensing is helpful to detect the changes and mapping the coast. By using the satellite images usually one can map a large region without the physical efforts.

There are many satellites used for mapping especially for coastal zone monitoring. RADARSAT, IRS-1C and IRS-1D, CZCS, AVHRR are some of the sensors that are used for monitoring and mapping the coast and the coastal features. According to the needs of the study we can get the satellite imagery for the effective year or every season for monitoring the coastal change. The images are interpreted by visual techniques with the help of image texture, tone, pattern, form, color, association etc. From this interpreted maps, we can quantify the erosion of emergence of the coast during that particular time period. In the current study, remote sensing and GIS techniques have a major role in the evaluation of shoreline change in pre-2004 and post-2004 by analysing the multi- temporal satellite images acquired from 1972 to 2011. Table 1 lists the multi-temporal satellite images used for the current study.

After overlapping the maps showing the shoreline in each date, the distance between the shorelines were measured taking the nearest land mark as reference in pre-2004 i.e. 1974-2004 and post-2004 periods. Then, the map distances were converted into a ground scale and the erosion and accretion rate was determined. Table 2 shows the results of such a measurement.

Table 1. Multi-temporal satellite images used in the study

Sl. No	DATE OF IMAGE	SENSOR	RESOLUTION (m)
1	16/09/1972	LANDSAT MSS	80
2	25/08/1991	LANDSAT TM	30
3	28/10/2000	LANDSAT ETM	15
4	29/12/2004	IKONOS	1.0
5	06/04/2009	LANDSAT TM	30
6	02/09/2011	LANDSAT ETM	15

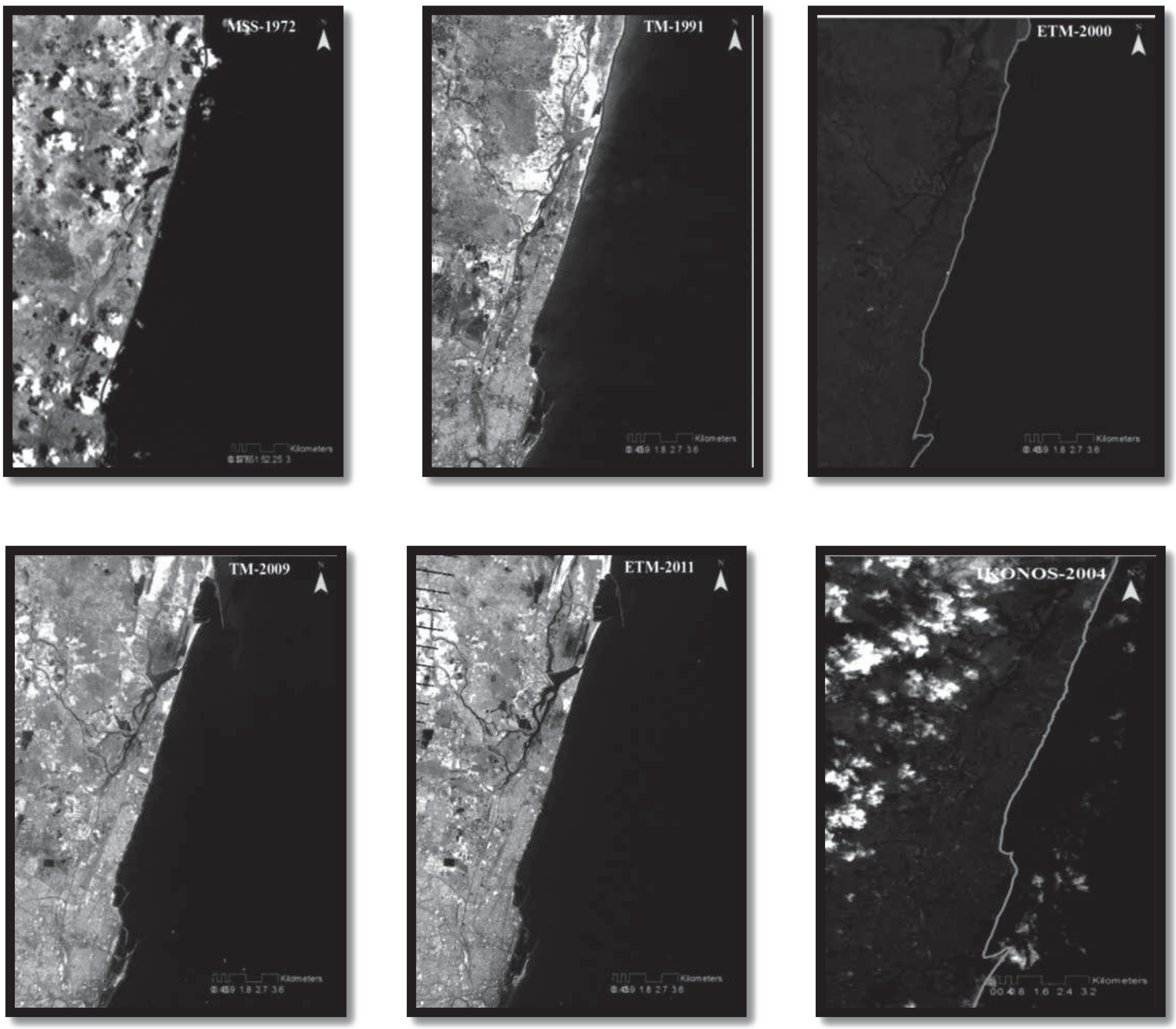


Fig. 3. Satellite images (1972 to 2011) showing the positing of shorelines

Table 2. Erosion and accretion along the land marks in pre-2004 and post-2004

LANDMARK (Also see Fig.1)	**1972-2004 Coastline change mtrs(≈)**		**2004-2011 Coastline change mtrs(≈)**	
	Erosion (In mtrs)	Rate of erosion (m/yr)	Accretion (In mtrs)	Rate of accretion (m/yr)
LANDMARK-1 (GROYNE-10)	-170	5.3	+22	3.1
LANDMARK-2 (GROYNE-5)	-225	7.03	+69	**9.8**
LANDMARK-3 (GROYNE-1)	-316	**9.1**	+55	7.8

The results obtained by the shoreline change analysis using remote sensing and GIS based studies clearly indicates that there was severe erosion at a rate of approximately 9.1 m/yr near to groyne No – 1 (Landmark-3) upto 2004. However, after the construction of groynes in 2004 accretion took place at a rate of about 7.8m/yr. There was a low rate of erosion (5.3 m/yr) near to Groyne No – 10 (landmark-1) upto 2004 and accretion started at a rate of about 3.1m/yr after 2004. Again in south of groyne No - 5 the erosion rate was about 7.03m/yr before 2004. However, there was a maximum rate of accretion of about 9.8m/yr after the construction of the groynes.

The results obtained from the remote sensing analysis were compared to the Google Earth image (2011) and field observations (Figure 4). it was observed that there is a wider beach south of Groyne No – 5, which matches with the results of the remote sensing analysis.

Fig. 4. Field evidence showing accretion south of Groyne – 5.

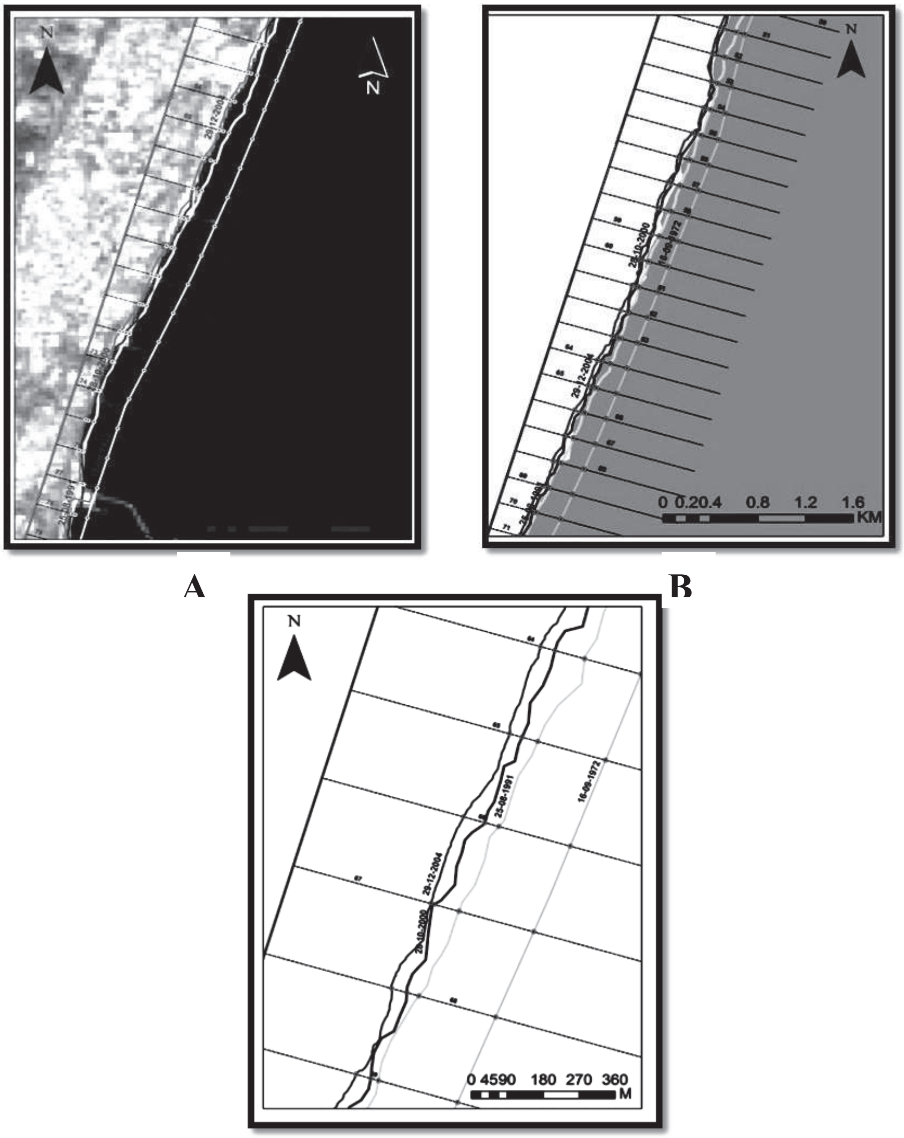
SHORELINE CHANGE ANALYSIS USING DSAS AND GIS

The USGS-DSAS (Digital Shoreline Analysis System) extension created for use in Arc Map® has enhanced the ability of coastal scientists to obtain robust statistically-based results describing the changing position of shorelines. Yu and Chen [7] used DSAS and quantified the rates of shoreline recession and accretion from 1990 to 2000 of different headland-bay beaches. The authors conclude that most of these 31 bays maintain relatively stable and the rates of erosion and accretion are relatively large with the impact of man-made constructions on estuarine within these bays from 1990 to 2000; while only two bays, Haimen Bay and Hailingshan Bay, have been unstable by the influence of coastal engineering. The results obtained from the employment of the DSAS extension provide accurate statistically based information which will enhance the ability of local coastal planning and policy makers to make sound coastal zone management decisions based on accepted scientific protocols [8]. All the DSAS results used in this study were determined at a 90% confidence interval with a +/- 1 m spatial error.

The created layers of multi-date shorelines (1972, 1991, 2000, 2004, 2007, 2009, and 2011) were used as input for the DSAS modeller to calculate the rate of change at various transects created at 250m interval in the shore-normal direction. The inputs required are: base map (e.g. Survey of India Topographic map), map depicting multi-date shoreline positions and the user-generated baseline (see Figure 5). DSAS generates transects that are cast perpendicular to the baseline at a user-specified spacing alongshore. The transect along this baseline are then used to calculate the rate-of-change statistics. The distance from the baseline to each measurement point is used in conjunction with the corresponding shoreline date to compute the change-rate statistics

QUANTIFYING SHORELINE CHANGE USING DSAS

To carry out this study, the satellite images used in the previous analysis i.e. from 1972 to 2011 (Table 1) were used in additional to the 5th July 2007 satellite image obtained from Google Earth. To measure the amount of shoreline shift along each transect, an imaginary buffer line was created along the landward side. With reference to that baseline, seaward shift of the shoreline along transect is considered as a positive value, while landward shift is considered as negative. The rate of shoreline variations was calculated using the Linear Regression Rate (LRR) method in a GIS. The analysis is done for two periods, one for pre-2004 i.e. period of erosion and the other for post-2004 i.e. period of accretion.



A B

C

Fig. 5. A-C showing the baseline, transects and the interpreted shorelines for pre-2004 period.

Erosion In pre- 2004 period

To know the erosion in the pre-2004 period, the maps depicting shorelines (1972, 1991, 2004, and 2004) were taken and processed in the DSAS software. The software generates a baseline and transects at 250 meters interval and evaluates the shoreline change from 1972 to 2004 taking the baseline as reference (Figure 6). The outputs of DSAS in terms of EPR (End point rate), SCE (Shoreline change envelope), NSM (Net Shoreline Movement) are obtained after DSAS analysis along the transects (from 54 to 74) and at the corresponding groyne locations. Transect numbers 54 to 74 cover the study area. Here the SCE (Shoreline change envelope) and NSM (Net Shoreline Movement) are same because, in this case the last and youngest shoreline is same, i.e, the shoreline of 1972. From the analysis, it is observed that there was severe erosion along groynes 1-3 at a rate of about 8-10 m/yr, i.e. maximum erosion. There is minimum erosion at about 5.8 m/yr near groynes 9 and 10. Near groyne 8, the rate of erosion was about 8 m/yr and between groynes 3 and 6, the erosion rate was about 7-8 m/yr.

Accretion In post- 2004 period

To know the accretion in Post-2004 the maps depicting the shorelines (2004, 2007, 2009, and 2011) were taken and processed in the DSAS software. The software generates a baseline and transects at 250 meters interval and evaluated the shoreline change from 2004 to 2011 taking the baseline as reference (Figure 6). The outputs of DSAS in terms of EPR (End point rate), SCE (Shoreline change envelope), NSM (Net Shoreline Movement) are obtained as in the case of pre-2004 period (from 54 to 74 and the corresponding groyne location). Here, it is observed that there was good rate of accretion of 15-16 m/yr. That is, the maximum accretion throughout the study area. It is worth mentioning here that it is the same location that experienced maximum erosion up to 2004. However, there is minimum accretion i.e. about 4-6 m/yr north of groyne no 4.

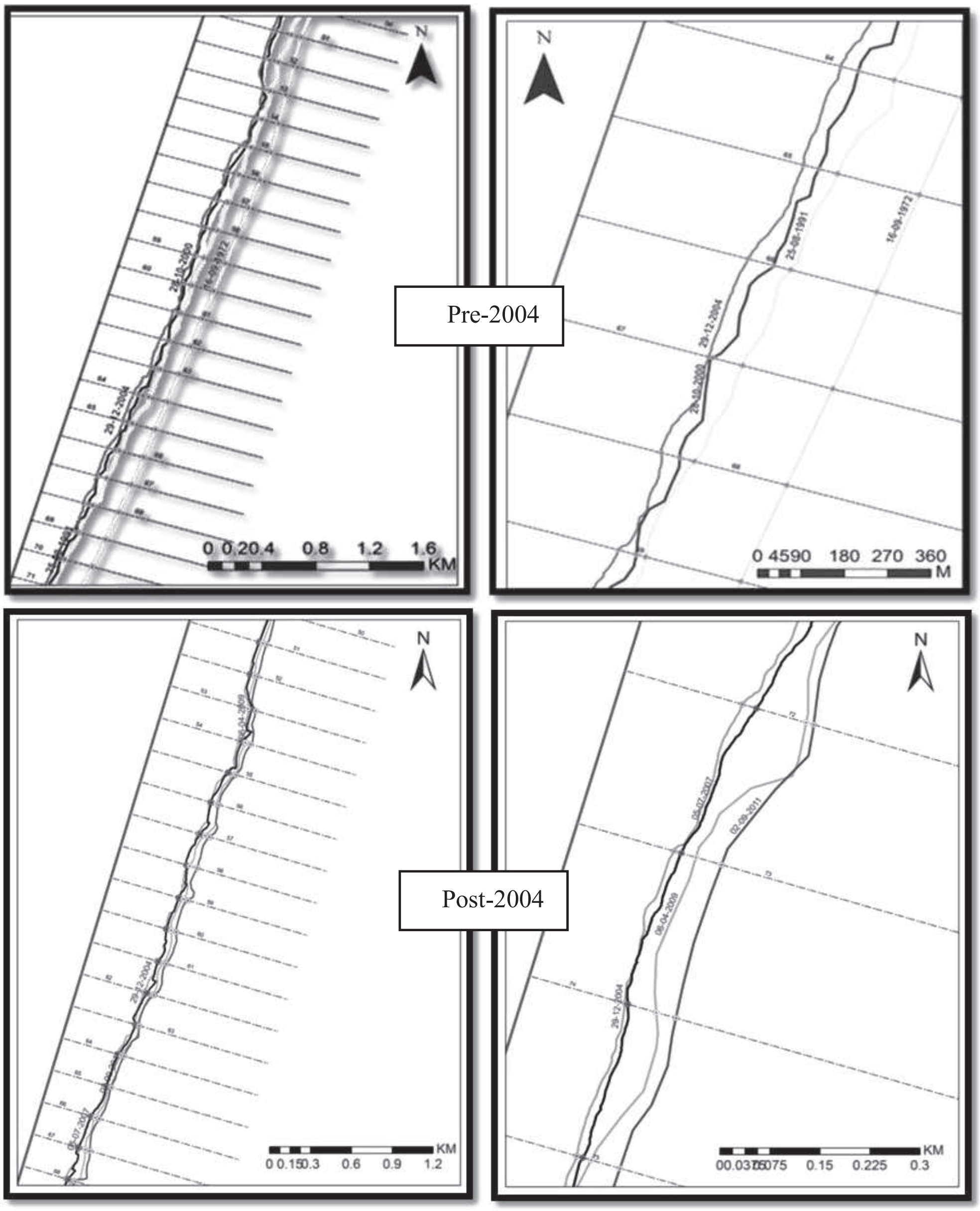


Fig. 6. Baseline, transects and the interpreted shorelines for pre-2004 and post-2004 periods

DSAS FOR ESTIMATING THE AREA REGAINED DUE TO THE GROYNES

DSAS is an efficient tool for calculating area gained or lost in the past years, i.e. the rate of accretion or erosion in term of area. But it is not 100% accurate. Accurate area loss or gain can be estimated by proper field measurements and long term data, however a little effort has been made to estimate the area gained by the construction of groynes using DSAS and Arc GIS sofwares. Here a simple methodology is adopted. Like the previous procedure, all the shorelines from 2004 to 2011 are plotted in the DSAS software. These transects were created at an interval of 250 meters which are intersecting the newly accreted sand pockets. By taking two adjacent transects and part of shorelines i.e. the last shoreline of 2004 and 2011 falling under the two transects, polygons were prepared. The areas of the polygons were estimated using the software, and thus the area regained between each groyne field is estimated.

Table 3. DSAS estimated area gained between 2004 and 2011 along the groyne fields

Groyne fields	8-9	7-8	6-7	3-5	1-3
Area (Sq.m)	74,458	73,074	35,660	66,129	94,465

FUTURE SHORELINE PREDICTION MODEL USING EPR AND LRR

For the current study, the shoreline data from multi-temporal satellite images and the DSAS software-derived linear transgression rate are used to prepare a future shoreline prediction model. The end point rate (epr) is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements (i.e., the oldest and the most recent shoreline). The major advantage of the EPR is its ease of computation and minimal requirement for shoreline data (two shorelines). The major disadvantage is that in cases where more than two shorelines are available, the information about shoreline behavior provided by additional shorelines is neglected. Thus, changes in sign or magnitude of the shoreline movement trend, or cyclicity of behavior may be missed. The End Point rate (EPR) method is based on an empirical equation which shows that the future position of a shoreline can be derived by a linear relationship between past shoreline positions and time. The change rate (m) and intercept (c) involved in this model are derived by a line ($y = mx+c$) extracted from the points on the earliest and latest available shorelines (y and x represent the shoreline position and time respectively) [9].

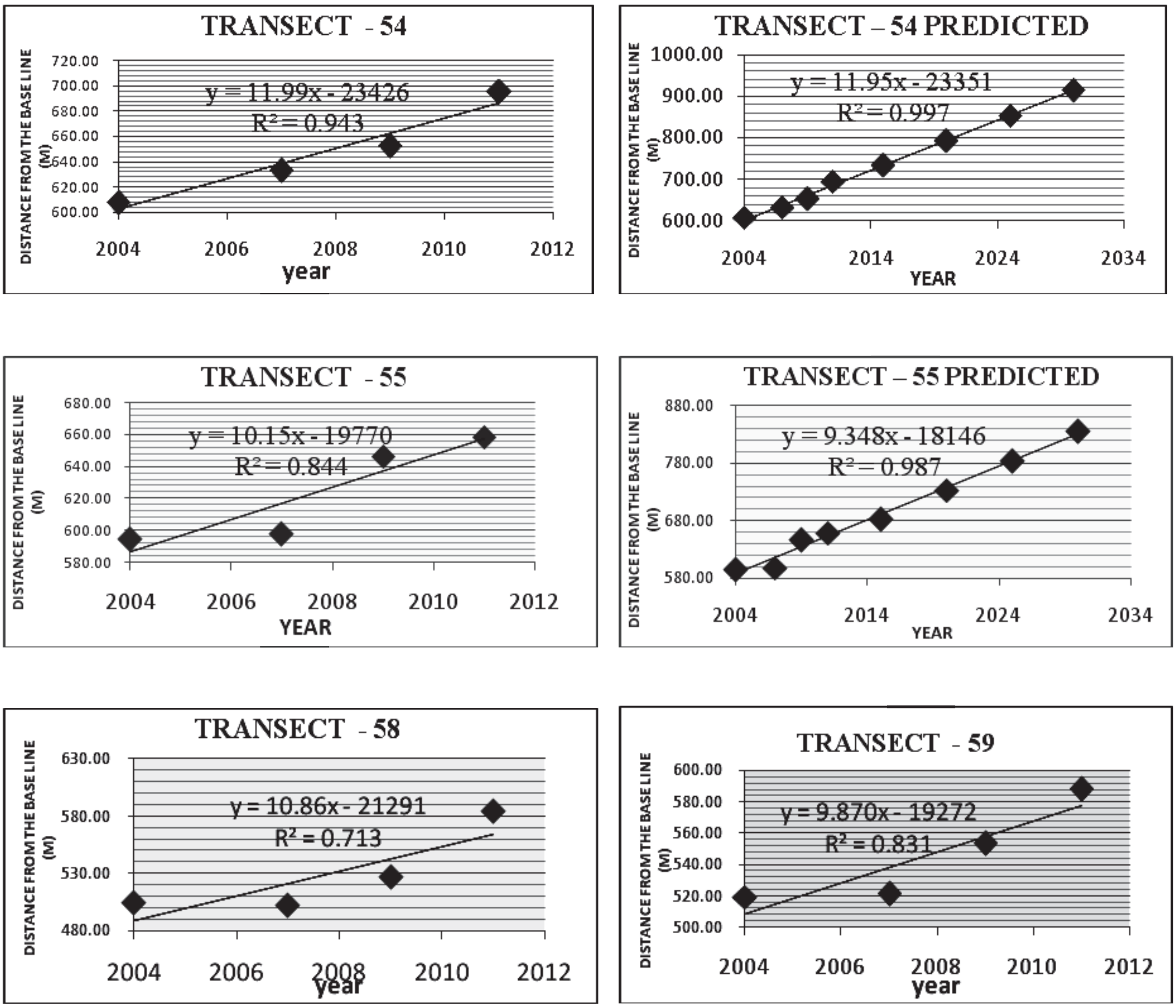


Fig. 7. Graphs showing the predicted shoreline positions at three example-transects (54, 55, 58)

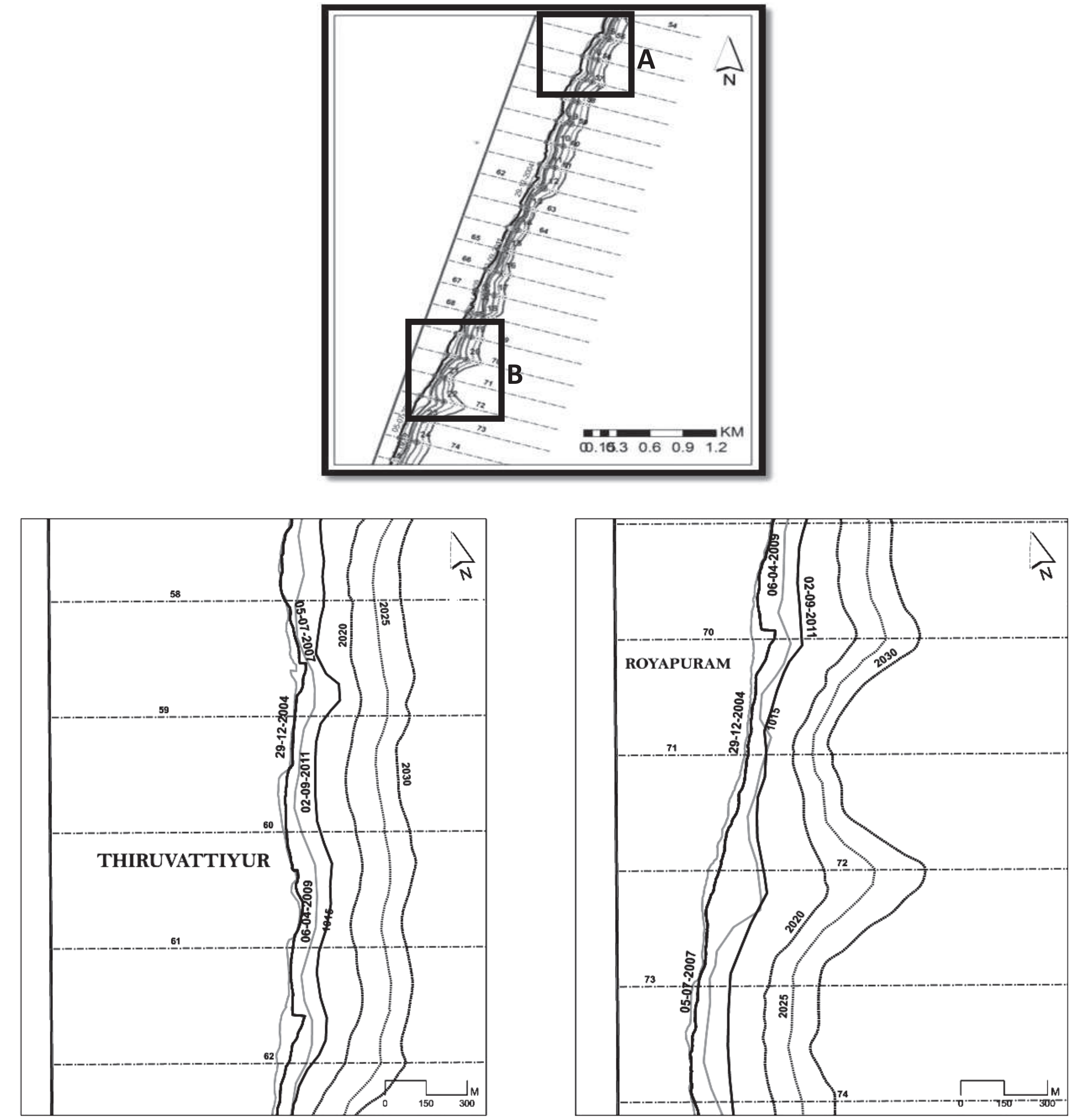


Fig. 8. Future shoreline positions near, A- Thiruvattriyur B - Royapuram

A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a particular transect. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression includes these features: (1) All the data are used, regardless of changes in trend or accuracy, (2) The method is purely computational, (3) The calculation is based on accepted statistical concepts, and (4) The method is easy to employ [10].

Graphs are prepared for each transect (from transect no 54- 74) derived by DSAS analysis by using the mathematical formulae where in x-axis the years and y-axis shows the distance of shoreline from the baseline. A few examples of the graphs are shown in Figure 7. By plotting the years 2015, 2020, 2025, and 2030 in the graph, the distance of the shoreline can be predicted for each year in the future. The values obtained from the graphs are plotted in a GIS software to get the future shoreline positions for the years 2015, 2020, 2025 and 2030. Such predicted shorelines are shown in Figure 8.

CONCLUSIONS

We are very much aware of the fact that coastlines are dynamic and they have been changing as long as there have been coastlines. This statement is very well applicable to the city of Chennai also. The population of Chennai has grown over the years, and the demand for seaside land and the related development has increased. Given the magnitude of the wind and wave forces active along the Chennai coast, the government has adopted several measures of defence mainly in the form of constructing groynes since 2004 to arrest the ongoing erosion and regain the land lost to the sea over the past century. Though it can be argued that attempts to contain the sea may be futile, it is witnessed here that the groynes are performing well.

The study presented in this paper has demonstrated that remote sensing and GIS are potential tools for monitoring the status of coastal cities, especially those undergoing erosion. This paper has demonstrated the applicability of multispectral satellite images to monitor both erosion and accretion that the Chennai coast has witnessed in the past. Despite the limitation offered by coarse resolution images in the early 70's and 80's, near accurate depiction of the shoreline was done and the changes are also accurately estimated. This study, carried out in Chennai city indicates that the ten groynes constructed by the government are performing well by arresting erosion and enhancing accretion, thereby promoting the re-growth of the shoreline.

Based on the shoreline obtained from multi-temporal satellite images, it may be inferred that alarming rate of erosion witnessed by the coast up to 2004 has considerably reduced and the process of accretion began in 2004 with an appreciable rate.

The DSAS module, which has taken an input from satellite remote sensing has also yielded adequate information about the rates of erosion and accretion at different places. Accretion, as analysed by satellite images and by USGS-DSAS model is certainly very active in most of the groyne-field areas. A maximum of 94465 sq m of land has been gained in the southern part of the study area (near Royapuram), while a minimum 35660 sq m in the central part of the study area and on an average, 68757 sq m of land has been regained between 2004 and 2011. Such a rate of accretion will lead to a better landscape along the Chennai coast and the people will have a better life in the future.

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PILOT SYSTEM FOR TRANSPORT CONFIRMATION WITH LOCATION AWARENESS

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Abstract

Many Finnish municipalities have experienced an increase in the demand for logistics services. In addition, the requirements for energy efficiency and the goals of reducing traffic and noise pollution have created more costs for the municipalities and triggered a need for improvement and optimization. Nowadays there are various route and logistics optimization applications that can be used to replace routes previously calculated by hand. Automatically generated routes can increase the efficiency of logistics operations by lowering the overall costs and providing faster delivery of goods. These applications can be further improved by offering real-time information to those responsible for the management of the services, and also providing the people making the actual deliveries, e.g. the drivers the most up-to-date routes. The goal of the system presented in this paper is to combine the route optimization and tracking possibilities required by logistics managers with an easy-to-use mobile application, which utilizes location data and is targeted especially to the drivers making the deliveries. The paper describes the system architecture, and evaluates the usability and potential of the system from the perspective of logistics optimization. The paper is based on the pilot run of the system, and on the research done in co-operation with the City of Pori, Finland.

Keywords: mobile application, location awareness, geographical information, pilot system

Recommended Citation: WIDBOM, T., LEPPÄNIEMI, J., RANTANEN, P., SILLBERG, P., SOINI, J. (2013) Pilot system for transport confirmation with location awareness. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB – Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

There are several factors that need to be taken into account when planning for municipal logistics services: delivery time windows; the number of vehicles used for deliveries and routes; vehicle capacity and capabilities; and potential special customer needs. Cost-effective routes should be planned on the basis of these factors, which can be a challenge if done by hand. The various tasks are generally not grouped together in the most cost-efficient and optimal manner.

For example, the grouping could be based on a simple geographical task organization by zip/postal codes, or by grouping deliveries related to schools in one group, which may or may not be the optimal solution.

This research has been carried out in co-operation with the City of Pori [1] located at the west coast of Finland. Pori has around 900 kilometers of streets, which, in addition to normal road maintenance, require snow plowing in the wintertime. There is also a need to manage around 300 000 home visits (e.g. elder care), school and meal transport, and various mail and goods deliveries with multiple vehicles. Optimizing these activities can benefit not only in terms of lower costs, but also in better service quality.

The issues related to logistics management have been studied in various projects participated by the City of Pori for several decades, and the research field, in itself, is not a new one (for more detailed discussion e.g. [2], [3], [4], [5], [6]. However, the previous projects did not provide the results the City expected. This has been attributed mainly to the fact that most of the route optimizations were done manually without the aid of automated tools. In recent years attention has shifted to various software solutions, and to the use of location data in conjunction with mobile applications.

In preliminary studies made by the City of Pori, it was noticed that many of the old routes could be executed in a much shorter time, and in some cases it would be possible to combine multiple routes, thus requiring fewer vehicles for the logistics operations. These findings encouraged further studies, one of which is the project undertaken with the Tampere University of Technology, Pori Unit [7]. The goal of the two-year project – MOP (from Finnish: Mukautuvat OhjelmistoPalvelut, or "Adaptive software services") – is to research the possibilities offered by location aware applications. During the project, a pilot system was developed for the logistics department of the City of Pori. The system can be used by both logistics managers and the personnel involved in the various day-to-day logistics activities. This paper describes the system architecture that was developed, as well as the implemented mobile application for the delivery and pickup drivers. In the context of this paper, if not stated otherwise, the term delivery is used to mean a logistics operation, which can be a pickup and/or a delivery of goods, mail or other similar items.

The structure of the paper is as follows: in the next chapter (The Requirements for Pilot System) we represent the basis and the starting point of the system development work. After that (Pilot System), we describe the structure and elements of the developed pilot system and the functions included in the mobile application in more detail. In the chapter Discussion, the developed system is evaluated and the next steps we are going to take in our research are also presented. Finally, the contents of this paper are summarized in the last chapter (Summary).

THE REQUIREMENTS FOR PILOT SYSTEM

The starting point of logistics planning is the proper analysis of customers' locations, travel distances and times, timetables, and the possible special requirements for the goods to be delivered. There are successful commercial applications (e.g. [8]) available that can be used to calculate the initial values. In addition, it is beneficial, if the system can offer suggestions on the vehicle types, and what kind of changes is required to the used vehicles if the order and delivery volume changes. The suggestions can be based on the pre-set properties (the capacity of the vehicle, driving speeds, working hours, driving cost per kilometer, etc.) of the vehicles. Based on the aforementioned requirements and properties, it is possible to calculate not only the optimal route, but also, to generate various alternative scenarios for future conditions and use cases.

For the pilot system the ArcLogistics [9] route optimization application developed by Esri [10] was chosen. The route optimization in ArcLogistics is based on Vehicle Routing Problem (VRP) algorithms. VRP is discussed more detailed by [3], [11], [5], [4], [6], [12], [8], [13]. There were two basic reasons for this. Firstly, the application had all the requirements needed for the implementation of pilot system architecture based on the preliminary research work done by the City of Pori [14]. Secondly, it has already been used by the City for test applications related on the optimization of personnel transport and wintertime road maintenance, for example snow plowing route optimization.

In addition to the requirements created by the route optimization, which are largely managed by the chosen third party application (ArcLogistics), there are other requirements, perhaps more directly related to the end-users, i.e. drivers of vehicles. In case of the deliveries, it is also important to acquire a confirmation. In practice, the confirmation process is usually implemented by a simple pen-and-paper signing process, where the delivery driver has a form, in which he/she fills in the details of the delivery, such as arrival time to the customer's location, and maybe asks for the customer's signature. This is the way the confirmation is often done by the regular courier/express services, and is also the way currently used by the City of Pori. This method, in its simplicity possesses a couple of risks. Firstly, there is always the possibility of human error, for example, mistyping the arrival time, or forgetting to ask the customer's signature. Also, this manual confirmation process lacks the real-time tracking that could be implemented with automated systems. There have been some minor problems, in which the customer has complained about the city's delivery services, claiming that the package did not arrive in time, or was not delivered as reported by the driver. These claims are very hard to verify or deny, as in principle, the customer and the driver both could be right, and thus it is hard to – definitely, and with proof – to say who made an error.

To enhance the confirmation process, we decided to design and implement a simple mobile application for the drivers. The main purpose of the application is to provide more solid confirmation process, and also to easily provide the details of the next destination. By using the navigation capabilities of the modern smartphones, it is also possible to provide directions to the next destination. In case of the regular and experienced drivers, these instructions may not be necessary, as the destinations themselves do not often change, though the order and amount of destinations per day can change. By using a smartphone application it is possible to automatically log the drivers' location and the time of arrival to destination. Additionally, by logging the departure time, the duration of the event can be calculated, which can be used to improve the optimization process. It is also important to note that the confirmation process is not only for the benefit of the logistics system, but also for the benefit of the driver, who will have a definite way of proofing his opinion of the matter.

As the mobile application is especially targeted to the drivers, this also creates additional challenges. It should not be assumed that all of the drivers are familiar with smartphones or feel comfortable in using the devices; it becomes crucial to design the user interface as simple and easy to use as possible. It should also be noted that we, as researchers, are not the ones doing the actual driving, it can be hard to figure out which features should be in the application, and what is only unneeded extra, or how easy the functionalities are to use in practice. For these reasons, it was important to do test runs with the actual drivers to get their inputs and opinions, and we decided to design a pilot system, which would first be tested with real transport routes optimized by the City of Pori. In the future, the system might entirely replace the delivery lists, which are often manually created and printed on paper for the drivers.

PILOT SYSTEM

In order to solve the aforementioned problems in logistics services, a pilot system consisting of a management server and a mobile application was created. The main goals of the system were to offer a semi-automatic management of delivery schedule and an easy interface for drivers to verify the completion of the deliveries. At the moment, the system is being piloted by logistics and transportation services of the City of Pori.

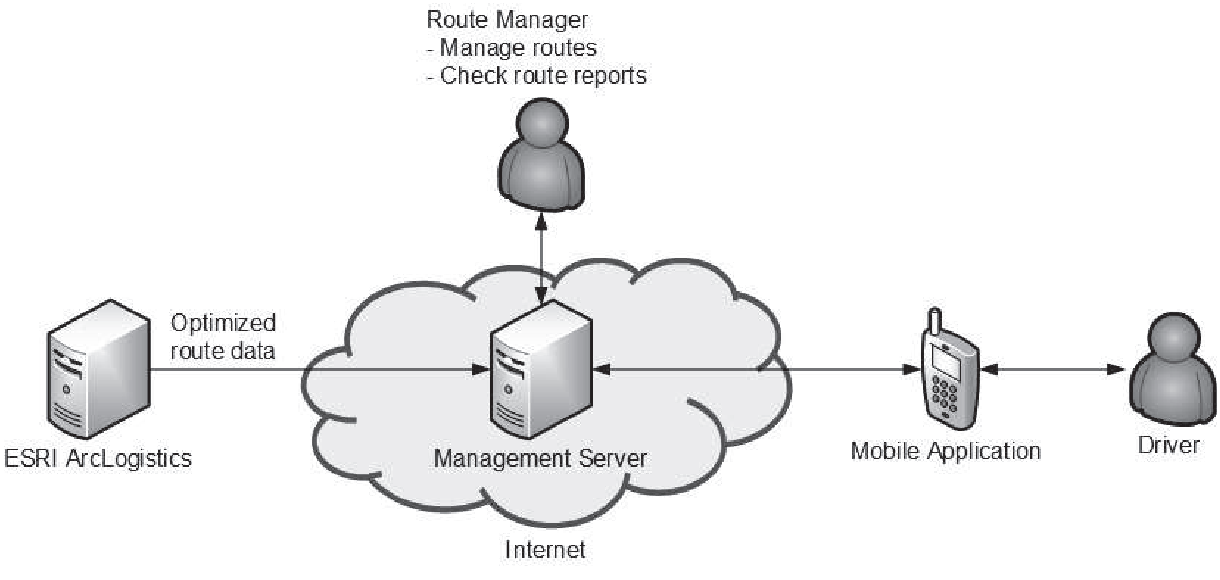

Fig. 1. The overview of the pilot system.

In Fig.1 is the overview of the pilot system which shows the relationships and directions of data flow between the different components. The *Management Server* is in a central role of the pilot system as it allows the route management, it generates real time route reports and it provides the newest data (i.e. route schedules) for mobile applications. The route management is carried out by uploading an optimized route data for each working day. Optimization, route management and upload require some amount of manual work. In the case of the City of Pori, there would only be five different route schedules for a each working day, and in general, the routes do not often change – and some of the routes can be valid as long as a couple of months. However, we agreed that this was an acceptable work load in the pilot stage.

Usually optimization begins by defining the preferred time windows, resources, destinations and other information of the routes. Once the initial data is defined, it can be optimized by hand or by any suitable application. In this case, we used the ESRI ArcLogistics for the optimization. The *management server* accepts the optimized data generated by ArcLogistics. This way the only remaining action is to upload a corresponding route data for each workday into the system.

The reporting web user interface allows the route manager to easily see in real time which delivery tasks have been finished and which tasks are still in queue. If there are network connectivity problems on the mobile device, the confirmations will be temporarily stored on the device. As soon as the network connection is re-established, the information is synchronized with the server. An example of a generated report is shown in the Fig. 2. The displayed data is for route with identification *ABC-123* for date *25th of September 2012*. The following data is shown for each task:

- Status of the task: queued, in progress, completed.
- Time window: earliest and latest time when the task should and/or can be completed.
- Customer’s name and address.
- Timestamps of arrival to destination (*Arrived*) and departure from destination (*Completed*) confirmations. These are also links, which open a map with a marker of the confirmations.
- Duration between the confirmations.

In the generated report the first three tasks are marked as completed and the rest of the tasks are not started yet (i.e. *queued*).

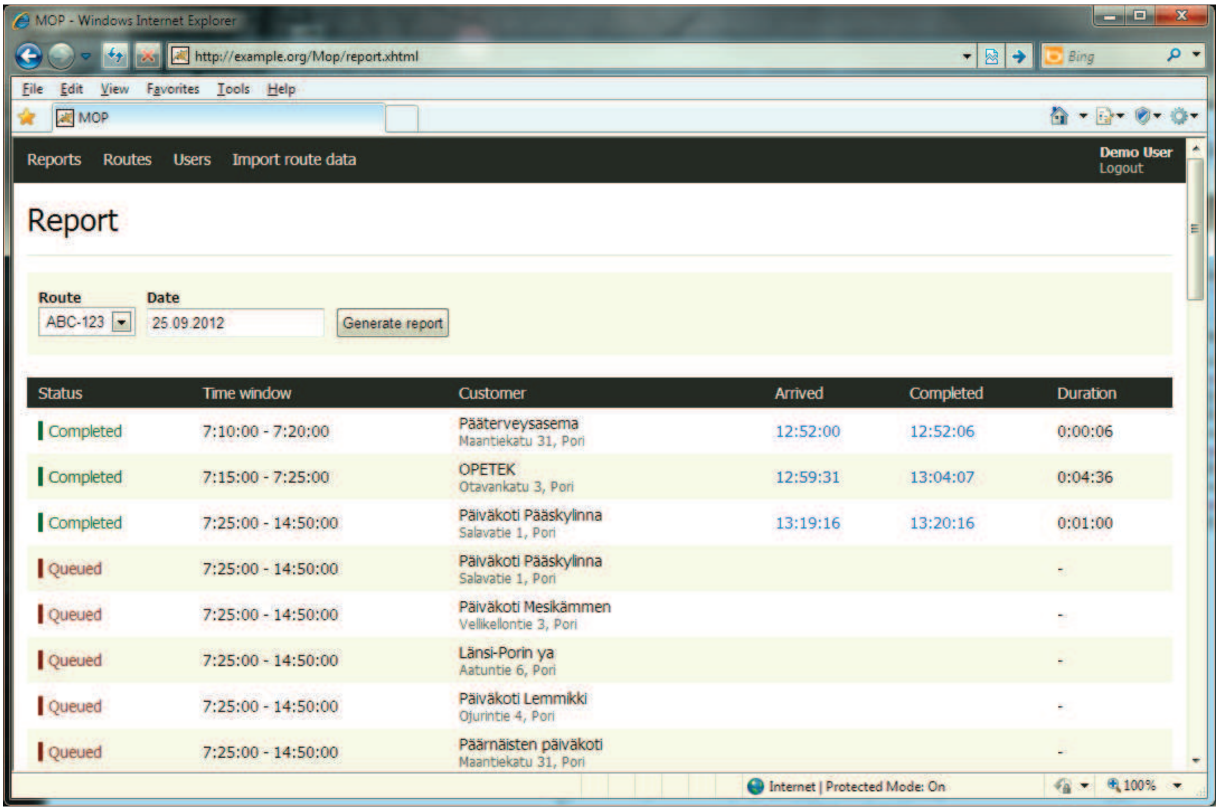

Fig. 2. Management view: Route report.

By clicking the time stamped link, a map window is opened. This map shows where the driver sent the confirmation by using his/her smartphone. A sample of this view is shown in the Fig. 3.

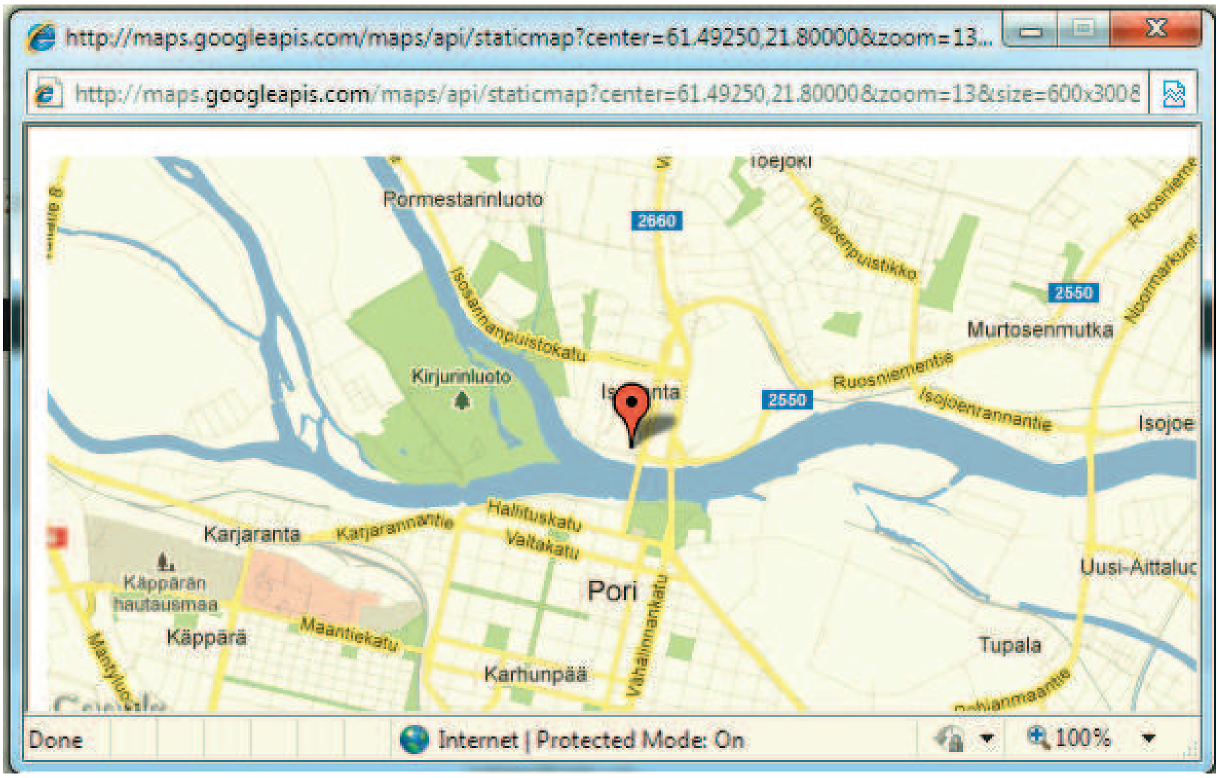

Fig. 3. Management view: Location of confirmation.

As the third main feature of the management server, it provides the most current route information for the drivers' smartphones. The information between the management server and the mobile application is exchanged in platform independent way by using Extensible Markup Language (XML) [15]. This allows the developer to choose any modern target platform and development environment. In the pilot stage, we targeted Symbian platform (Qt framework, [16]) as these devices were already used by the City of Pori. Because of the simplicity of the client software and of the chosen XML-based communication protocols, it is relatively straightforward to implement clients for different platforms, such as iOS or Android.

As the application is to be used in a car by a driver, or a co-driver, a special care for the user interface (UI) must be taken into account. The features must be easy to use with a touch-screen as an input device, simple enough for a user to understand and to learn. Finally, the user must receive an impression that the application helps to complete his/her job. Otherwise, the application may not be adapted as a new, and a natural part of the job. The mobile application provides the following main features:

- Task list. The application retrieves the current work list from the server (see Fig. 4. left side).
- Detailed information of the task. This view shows all relevant information of the task (see Fig. 4. center).
- The confirmation of arrival to the destination and departure to the next destination. With these features, it is possible to send information – such as GPS location and time stamp – to the server. This information can later be used to verify whether a certain task was completed on time or not.
- Map view with route drawing. This view allows seeing where you are and also a route to the task's location (see Fig. 4. right side)

The design of the graphical user interface is an attempt to combine a minimalistic layout with an easy readability and a touch screen friendly operation. The screen shots of the driver's mobile application are shown in the Fig. 4. Leftmost screen shot is the main view of the application. By using this view drivers can browse all tasks of the current date. In the example case there are four visible tasks. The first task, titled with customer name "*Pääterveysasema*", has a green tick and is partially opaque. The green tick means that the task status is completed. The next two tasks differentiate between each other by having different delivery types: pickup and delivery. The second task is a pickup task and has an icon of an unloaded truck while the third task is a delivery and it has a loaded truck as an icon. The type of the delivery can also be seen below the title. Estimated time of arrival is after the delivery type written inside parentheses. The destination address (i.e. customer's address) is the last piece of information that is seen of the task in the task list.

In fig. 4, the estimated time of arrival does not adapt to the delays in the delivery schedule. The optimization process can use the time window value to allow minor delays in the schedule. In case of longer delays it is possible to send an automatic notification to the route manager who can contact the drivers and modify the task list or take other applicable action. In the figure, the time precision is shown in seconds for testing and illustrative purposes, but for a production environment a lesser precision can be chosen.

Fig. 4. Application screen shots: Task list (left side), Task details (center) and Map view (right side).

When a task is clicked, a view that is in the center of the Fig. 4. is opened. This view has the same information as the previous with a few additions. These are the *comments* field, and confirmation buttons. The comment field may include an optional text description that the customer or the route manager has deemed to be relevant for the driver. The confirmation buttons are used for verification of the task. By pressing the button *Arrived to destination,* followed by pressing the button *Departing to next destination* the task is marked completed. The confirmation information can be seen in the management view seen earlier in the Fig. 2. If the confirmation was mistakenly done, the driver can *cancel* the confirmation. The cancellation can be done by using the cancel button which will replace the confirmation buttons in the task details view (not visible in Fig.4.).

The last view (Fig. 4. right side) is the map view which can be accessed by pressing the truck icon while in the detailed view. The map view can give the overview of the task by calculating a route from current location to the destination. A few markers can be seen on the map. A blue "S" (top part of the figure) marker is the starting point which shows the location of the previous destination (if available), and a green "E" marker (i.e. end marker, in the bottom part of the figure) is where the destination is. The recommended route is shown between these two markers, and it updates automatically while navigating to the next destination. While navigating, a green square marker will show the driver's current location. The green marker is barely visible in the figure, under the "S" marker. The map can freely be panned by using the touch screen. The map also provides a way to zoom by using the buttons "+" and "-". The "car" button in upper left corner will recalculate the route if needed. Button labeled "E" pans the map to show the destination. Pressing the button on the bottom left will center the map to driver's current location, and follow the car's position on map.

The previous chapters explained the main features of the developed pilot system, and described a general use case scenario. The following chapter evaluates the usability and feasibility of the system, its applicability to logistics domain, and more specifically, to delivery tracking and confirmation from the municipality's point of view.

DISCUSSION – PILOT SYSTEM EVALUATION

Today, both private and public sectors are faced with the somewhat conflicting and ever increasing needs for new improvements on their operations. There exist a continuous demand for both tight cost control and high quality services in all functions of the organizations. At the same time, new applications based on the information and communication technologies are introduced to markets almost every day. Re-engineering, or in other words, changing the existing business process somehow, is not necessarily a low hanging fruit, but rather a risky business. In terms of resources and calendar time, it usually consumes both of them, although the success is not guaranteed. In order to avoid a failure, it is usually a good practice to run a pilot project on the new approach before making almost irreversible decisions on new technology. That was the case, when the City of Pori decided to co-operate with Tampere University of Technology, Pori unit (TUT Pori).

Explorative usage of existing information at organization's legacy systems by developing new user interfaces for the new data types and new compositions of content is a common measure when organizations improve their processes. However, a poor or too complicated user interface of a new application is quite often a common scenario for failure. When the users are not willing to invest a lot of their time in order to learn the complex usage of an application, it will lead to the frustration of the users. That will be unacceptable situation, because in that case the deployment of the application is probably useless effort. For that reason we decided to focus on the easiness of the use of the pilot application. The developed graphical user interface for the drivers is quite minimal thus removing the drivers' need to worry about the usage of the application during the workday.

Before the deployment of the pilot system, there have been some minor problems, in which the customers of the delivery system have complained about to the City's delivery services. Some customers claimed that the package did not arrive in time, or was not delivered as reported by the driver. These claims are very hard to verify or deny. We considered about implementing automated arrival and leaving confirmations, but decided to leave that feature out of the pilot system. The reason was that automatic confirmation system may introduce undesired side effects that could be seen as major flaws by the drivers. From the programming point of view, the automatic confirmation system isn't too complicated, so it can be implemented if the pilot system succeeds and the users feel that they need that feature. Entirely automated process does have some other issues though. For example, there might be cases when it is absolutely necessary to inform the customer of the arrival of an important delivery. If customer's signature is required, that limitation cannot be removed, and at most the application can only remind the driver to ask for one. Another serious problem can be the accuracy of the positioning device. In a city with tall buildings the accuracy of smartphones' GPS (Global Positioning System) or network-based positioning can cause errors by reporting the location incorrectly, making it harder to confirm a visit solely by using simple geo-fencing. This is especially true when there are multiple locations close to each other, making it even more problematic to detect which location was actually visited at what time. In the case of nearby locations it is also possible that one of the destinations has not been visited at all, but this is impossible for the system to detect. It is also possible that the positioning source becomes unavailable (typically in the case of lost fix of the GPS signal). As it is hard to predict when and where the positioning errors may occur, the automatic confirmation should not be blindly trusted.

Because of these reasons, it was decided that a better solution would be a semi-automatic system, in which the application will provide destination information, and the key details of the required operation, but would not automatically confirm the delivery. In principle, a fully-automated solution would be preferable, but based on the initial tests, it was decided that the problems caused by the accuracy and connectivity problems can cause very hard to find errors, making the system perhaps in some way even more problematic than the traditional pen-and-paper confirmation scheme. Of course, with the mobile application, the list of destinations could be delivered directly to the driver's phone, and possibly updated on-the-go if needed, which would have been difficult with the old system, especially if large changes of the route were required.

The pilot is still ongoing, but the first results have shown that both the functionality and the appearance of the application's user interface are well balanced. There are some concerns still left which could limit the value of the system to the customer. The optimized routes have been quite fixed until now, meaning that there have been only limited amount of variation from day to day. This means that the procedure of making and deploying the new routes for vehicles do not happen very often and thus it is not routinized. Optimized routes may be valid for months. In the event that the situation changes, there is always the possibility that either the process of exporting the input data from ESRI to the management system or the deployment of the new routes to application fails for some reason.

Some topics for future research are new features of the user interface (bigger screens, signatures by electrical pen, contextual functionality, etc.), improvements for the positioning issues and explorative usage of the rich variation of geographic information produced and archived by the City of Pori [17]. Some of the positioning issues may also be solved in future by using preinstalled NFC (Near Field Communication) or RFID (Radio Frequency IDentication) tags on the destination. Based on the success of the first pilot, and the positive feedback and experiences received in the co-operation with City of Pori, we are now planning to use the developed and piloted service composition as a key component of the other mobile applications based on optimized routes and resources. Next candidates for new pilots are snow removal and several types of transport services to the homes of elder or handicapped citizens. In these new pilots we will also study the economical views, and continue to evaluate the customer satisfaction when compared to the traditional methods used by the City of Pori.

SUMMARY

The current trend towards energy-efficiency and effective utilization of all kinds of resources is reflected to an increasing degree in municipal services, too. In this research the subject was approached from the aspect of optimizing public sector logistics. The aim was to improve and streamline the transportation process through the utilization and combination of mobile and location aware technology. The idea was to improve transport verification and facilitate the work of the drivers during the transportation process. The initiative for the system development was to create an environment where logistics managers could monitor the transportation process, and where the system would have the capability to verify actions and resources, like the exact time stamps and locations of deliveries and pickups. Moreover, one of the starting points was that the system should support the drivers in their daily work. The research result, a pilot system with a mobile application developed during the MOP research project, was introduced in this paper. The presented system is one way to assist and support the transportation optimization, as well as reliably verifying the events that occur during deliveries. Furthermore, it gives one example of how the available technology can be utilized so that it looks and feels useful and is also very simple to use from the end-user's perspective. The next step will be to study the opportunities for expanding utilization of the system to cover other fields of operation in the public sector, as well as studying the economical effects of the route optimization process.

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THE SENSOR CITY INITIATIVE: COGNITIVE SENSORS FOR SOUNDSCAPE TRANSFORMATIONS

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Abstract

The authors introduce a novel urban measurement system. Sensor City, located in the Netherlands, is a large network of outdoor sensor nodes with high-bandwidth communication to a central database and GIS. The network expands the ability to systematically investigate human perception and evaluation in real urban settings and it is the first known cognitive sensor network available to soundscape researchers. The emphasis for this paper is on soundscape evaluation, or the way the acoustic environment is perceived. The authors outline the challenges posed by a cognitive sensor system and how it can approach a more human-like understanding of soundscape, such as through the detection of meaningful events, deciding what data to record, and in-field sensor placement. The authors then explore the potential benefits to the host city in a number of domains and highlight upcoming research directions that rely on this technology, such as the automatic judgment of appropriateness in an urban setting.

Keywords: cognitive sensor network, soundscape, urban design, GIS Ostrava 2013

Recommended Citation: STEELE, D., KRIJNDERS, D., GUASTAVINO, C. (2013) The sensor city initiative: cognitive sensors for soundscape transformations. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Sensor City

In 2009 the Dutch Province of Drenthe and the Municipality of Assen teamed up with local research institutes to create a city-wide sensor network named Sensor City. The project offers a novel approach to sensor research in both the size of the installation and the scope of its objectives. Sensor City primarily creates a robust organization of technological and knowledge-based resources on which subsequent projects can be built. The network consists of 150 measurement nodes connected to a central hub via a private, dedicated fibre cable. Each node has a dedicated power source and a secure cabinet for storing processing hardware. This arrangement, redundant to city services, allows the network to be run at a low cost, with unlimited bandwidth, and without interference from or dependence on third parties. The network has also been designed to be robust enough to feasibly run far into the future. Most importantly, the capability of acquiring information from all of these nodes simultaneously enables researchers to instil the network with more cognitive-like powers.

Human Evaluation

The Sensor City project aims to balance the rigorous quantitative evaluation of the daily sonic environment with the more subjective aspects of human perception. Measurements are taken through many types of sensors simultaneously, including microphones that can take full sound recordings from which level and other content can be derived, temperature, light, pollution, and precipitation sensors, and magnetometers for measuring vehicle movements. Researchers expect to be able to combine physical measurements obtained by the network with research into human perception, evaluation and, eventually, behavior to provide better insight about urban conditions. At the project start these classifications will be coarse, but will be refined in subsequent iterations of the technology informed by both machine learning and human testing. The physical environment will be captured by combining public GIS with information about land use, points of interest, zoning plans, etc. Figure 1 provides a plan view of Assen with an indication of existing (represented by pink, blue, and green circles) and expected node placements (in red). Finally, observations, questionnaire studies, and laboratory experiments will provide insights into situated perception and cognition in everyday life context. These data will then inform the next iteration of automated classification algorithms to detect specific events and discard less meaningful but abundant data. Eventually the sensor system, with context information provided by the GIS will be used to predict the perception and evaluation of outdoor spaces for different user groups. We call such a sensor system a cognitive sensor system in that it bridges the gap between physical measurements and automated classification on one hand and perceptions and meanings attributed by people on the other hand. According to Shenai and Mukhopadhyay [1], “A cognitive system is one that can perceive the environment and adapts to it, can make intelligent decisions based on its knowledge that effect changes in the environment, can self-manage, and self-heal.”

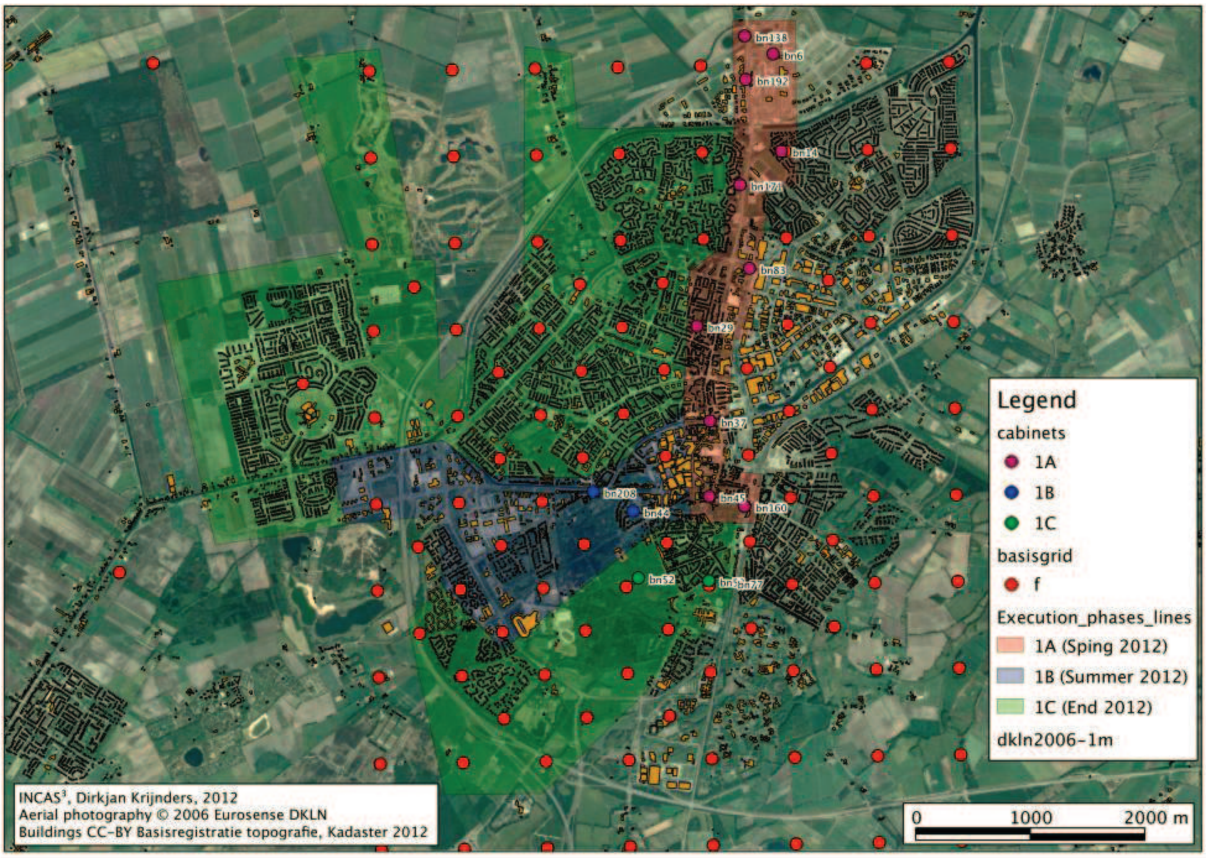

Fig. 1. Plan view of Assen, the Netherlands with Sensor City superimposed

Sensor City further provides a unique opportunity to study outdoor urban and peri-urban environments systematically and reproducibly. Sensor City currently supports two major projects: one focusing on urban mobility, the other on urban sound. This paper focuses on the sound project.

Sensor City Sound

The sonic environment, or the auditory component of the urban environment, is measured by recognizing and classifying sound events. When a human perceives the sonic environment, it is considered to be the soundscape. With the aid of the cognitive sensor technology, we aim to move beyond simply recognizing events, but to actually process them as well.

The ability of this research to transform the landscape through better evaluation is palpable, but there are some issues to be worked out. First, it is important to understand that soundscape interventions can be made within and between large, more established disciplines [2]. Those working on this project must understand the impacts of this research across multiple domains and take into account the particular needs of multiple stakeholders. Second, we must keep in mind that since soundscape is the human understanding of the sonic environment, our findings can be extremely individually or culturally specific.

COGNITIVE SENSORS AND SOUNDSCAPE

What is soundscape?

The concept of soundscape has garnered increasing research attention over the last decade in different fields of practice (e.g. urban design, wilderness management, noise control, transport, psychoacoustics) involving researchers from diverse disciplinary backgrounds (e.g. acoustics, music, architecture, ecology, psychology, sociology, geography, urban planning). Various definitions and synonyms have been proposed (see [3], [4], [5]); but nearly all uses of the term soundscape have in common the emphasis on the way the acoustic environment is perceived and understood by the individual, by a group, or by a society [3], [5], [6].

Central to soundscape research is the recent paradigm shift from quantitative analytic approaches (e.g. psychophysics) to more qualitative cognitive approaches focusing on meanings attributed to soundscapes in relation to human activities (e.g. [7], [8]). Indeed, there is converging evidence that soundscape cannot be assessed/measured exhaustively in terms of acoustic measurements as humans typically evaluate the meaning of the activity, source and/or agents producing sound when evaluation soundscapes. These judgments rely on cultural values attributed to the different types of activities and not on inherent properties of the sounds produced

Soundscape and urban design

The field of urban design emerged as a response to the tendency of urban planners to design in plan view and ignore the city user. Urban designers now preoccupy themselves with designing experience at the human scale, but they lack common metrics for evaluating good design. Introducing humans into the design picture motivates a change in the purpose of design – not all people are satisfied by the same product or treatment – so diversity and individuality must be taken into account. This distinction is actually built into the definition of soundscape. The acoustic environment is the sum of all of the sounds in a given space, or in other words, the sounds that transpire independent of the listener. The soundscape is the way an individual (or society) perceives and understands the acoustic environment. But why involve urban designers in the soundscape debate? In fact, it has been demonstrated that the best outcomes for urban soundscapes appear at the intersection of acoustic and urban design [2]. Yet very little work has ever been done to understand how exactly specific urban morphologies lead to specific soundscape outcomes, and Sensor City offers that opportunity.

Urban sound information has traditionally been reported with only one property of the sound being measured - its sound pressure level (SPL). The data is then superimposed on a noise map that greatly oversimplifies the context and source of each of those sounds. Noise maps still maintain value, however. Noise annoyance grows steadily with loudness [9] so noise maps are useful for predicting residential annoyance. However, measurement of sound levels alone fails to take into account the context and meaning of the sound, the presence of multiple sources, and the interaction of other modalities (especially vision). GIS data, as it is being used by Sensor City, can help to shed some light on these various issues by telling us, for example, the particulars of the built form or zoning considerations. GIS data for the Netherlands is extremely precise, complete, and recent, and Sensor City researchers are already aiming at systems designs that can take this advantage into account.

Soundscape researchers, in response to these criticisms of noise maps, are looking for better ways to represent soundscape from the plan view. A thorough soundscape map would likely involve multiple layers to deal with the multifaceted features affecting soundscape judgments. Sound recognition is widely considered to be an important first step in the process of updating urban sound maps, since identification is key to understanding context. Krijnders et al. [10], conceive a sound recognition system driven by signal processing and, if available, the known context of the signal. This entails that the incoming sound spectrum is separated in tonal parts, pulse-like parts and broadband parts, for which different features are extracted. Standard machine learning algorithms then classify the parts to arrive at a final, more cognitive recognition. Raimbault and Dubois [11] go further and propose charting soundscape impacts, with different categories of soundscape clearly identified, such as transportation, people presence, and natural sounds. They suggest that such a system will improve spatial analyses and facilitate visual communication. Visual communication is crucial for representing soundscapes because change-makers in this domain, such as architects and urban designer, are trained and operate almost exclusively in the visual modality [2].

SOUNDSCAPE AND GIS – SYSTEMATIC MULTIMODAL SOUNDSCAPE OBSERVATION

The Sensor City network represents a new approach for soundscape research in a number of ways. First, the multimodal interactions of soundscape will be considered. Because the sensor nodes will be collecting data not only about sound, but also weather, time, and special circumstances, it will be possible to systematically investigate the relative contribution of the audio content of soundscapes and other sensory inputs to the understanding of soundscapes *in situ*. The idea that soundscape is influenced by non-auditory factors is well-established [12]; Second, Sensor City enables soundscape evaluation on a large scale – the scale of the whole city, including residential and work areas, as well as restorative and other recreational landscapes. Third, Sensor City evaluates soundscapes in time, extending previous studies by offering longitudinal capabilities, tracking the evolution of time at various scales (i.e. hourly, weekly, seasonally, generationally). At the same time, the introduction of the temporal aspect of soundscape poses interesting challenges for representation with GIS. How does one represent something that exhibits strong patterns (such as the Monday to Friday workday and associated traffic movements) but that has subtle changes over time? In fact, city mobility and built form are inherently intertwined, so it is worth looking at an example of how Sensor City might learn from the particulars of urban movement.

Considering the heavy influence of automotive traffic on the perception of soundscape [13], it follows naturally that mode share, or the distribution of the population using certain modes of transportation for daily activities, can have a large effect on soundscape. Since the Netherlands is known for having a remarkably high bicycle mode share (in Assen, nearly half of the population routinely rides their bicycles), the interactions between mode choices can provide for interesting results. The Sensor City network could automatically determine the proportion of bicycle to automobile (and pedestrian) traffic at any given point through magnetometer and microphone data. This information would be hard to obtain with traditional counting techniques because it requires all-day monitoring, and tracking the less predictable movements of people on foot and bicycle. Instead, the combination of microphone and other data could provide permanent long-term monitoring to account for different morphologies all over the city at the same time, at different times of day, at different weather conditions, and during special events. This data could be useful for helping the city to determine which areas of the city officials should concentrate on if they wish to alter the mode share in a particular direction, such as having more people ride bicycles to a popular racing venue on the outskirts of the city or music festivals. Assen could take data at various points in the city and find out if people from a particular neighborhood are taking bicycles or cars to an event and perhaps provide better incentives for bicycling to the event if they wanted to save resources by not having people park their cars at the event. At the same time, continuous data would be available to help the city determine if their installation or educational program provided the intended outcome.

But here a critical problem emerges: how does one select sensor locations to achieve “meaningful” data? It is paradoxical to both choose interesting locations and remove systematic bias in site selection. Do we aim for activity centers where things might happen, such as a park bench where someone is likely to sit and read a book? Or do we aim to achieve a fair representation across the municipality’s different morphologies to maximize our understanding of design patterns? Or finally, do we select sites at random to equalize the potential for interesting findings across the municipality, such as dead spaces? Sometimes, unexceptional spaces can be ignored despite the important lessons and feedback that can be obtained from them. Figure 2 shows an unremarkable tunnel for bicyclists crossing underneath a busy road, which could help us to reproduce and validate (ecologically) Korte and Grant’s [14] finding that people move more quickly through noisy spaces. Should this space be ignored for not being particularly positive or is its commonplace design conveying meaningful information about how humans use built form?

Fig. 2. A tunnel for people on bicycles passing underneath a busy road. Assen, the Netherlands

WORKING WITH THE COGNITIVE ELEMENT

Previous researchers have taken on the problem of meaning in soundscape research, asserting that laboratory testing takes human subjects outside of the context of the environment where the sound is experienced. To address this problem, the concept of ecological validity has been extended to soundscape reproduction [15]. In the case of sensor city data, combined with intended questionnaires and other data collection techniques, the concern of ecological validity can be mitigated. As well, the social considerations, such as the fairness aspects of noise exposure [16] can be dealt with systematically.

Since soundscape is the culmination of perception and understanding of the acoustic environment, it is important to understand that there are elements of soundscape cannot be measured directly by a set of one-dimensional sensors. It will be important to also determine which of those real-world elements cannot be determined by a proxy measurement either – we may be able to predict annoyance but not overall well-being or aesthetic merits. These elements will encompass many domains, so it is important to think in a multidisciplinary way to understand the limits of Sensor City. For example, the task of measuring traffic noise will be quite easy. Further, the effect of traffic noise on soundscape perception is fairly well understood. However, soundscape is generally improved when residents of a certain location know their neighbors. There is no direct way to measure familiarity with neighbors with a sensor, but it is perhaps conceivable to measure it indirectly. Sensors could detect a spontaneous interaction in a residential setting and check for low aggression in the voices. In the event of high aggression or no verbal communication, we might infer that neighbors are not familiar with each other in the vicinity of this sensor set, whereas low aggression and extended outdoor conversations might indicate the opposite. Lastly, it has been demonstrated that soundscape can be considered good when residents perceive they have a safe and short walking journey to a nearby park [17]. While it's true that it is quite easy to measure the physical distance between a residence and a park, it is impossible to understand the intricacies of an individual's perception about whether it is a good or a bad walk to that park (i.e. someone does not like a particular restaurant passed on the walk). In general, elements from the "understood" portion rather than the "perceived" portion of the soundscape definition will be those that are hardest to automate, thus the cognitive sensor movement.

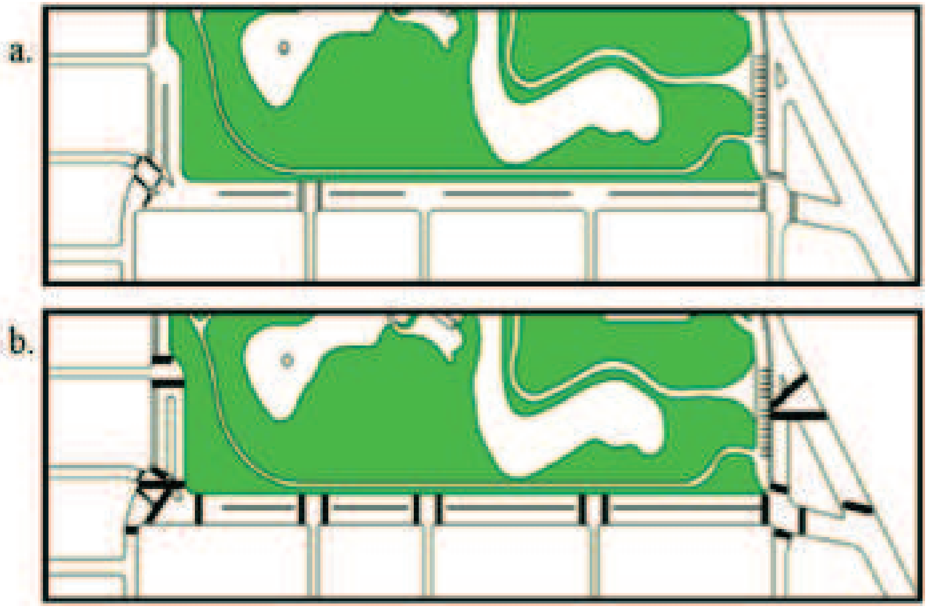

Fig. 3. An urban park surrounded by dense residential units. a) In its current form, the park has poor pedestrian access, b) an intervention is proposed that installs new crosswalks (black) at every intersection. The intervention will improve soundscapes for nearby residents inside and outside of their homes. Parc La Fontaine, Montreal, QC, Canada. (Image credit: Kris Steele).

Possible outcomes from the data

An upcoming movement in urban design will be design validation, or tests that demonstrate a particular design operates as expected. Surprisingly, a culture of evaluation of the performance of the built environment by its designers is not standard practice. Evidence-based architectural design has been largely limited to designs for healthcare. Urban designers need to embrace the many calls that have been made for post-occupancy evaluations and learn how to capitalize on poor results. Post-occupancy evaluation should not be considered a method to be used in special cases. In a sense, Sensor City automatically provides a post-occupancy evaluation, with identical measurements taken before and after a hypothetical new installation. In fact, post-occupancy evaluation is generally not performed for urban installations because it is often not clear what to look for. Sensor City provides the flexibility to decide metrics on the fly or well after measurement.

Consider the case of an urban park, presented in Figure 3. It has been established that urban parks provide restorative benefits to users and that the perceived access to a park from a person's residence improves the daily indoor and outdoor soundscape [17]. In the first drawing, the park lacks good access because it does not have good crosswalks. If researchers can identify an opportunity like this, sensor data such as unique conversations and park visits can be counted and a questionnaire could be circulated to park neighbors and users to understand the current park usage and soundscape evaluation. An identical study performed after the installation of new crosswalks will tell researchers the efficacy of that installation. If later, researchers realize that the new crosswalks may have slowed cars, sound level and magnetometer data can be gathered from before and after the installation to confirm whether this is true.

LONG-TERM IMPLICATIONS FOR ASSEN AND URBAN DESIGNER/SPECIALISTS

The authors engaged in a literature search for urban design and architectural resources on the pedagogy of both adopting scientific approaches in architecture, such as evidence-based design, and soundscape design. They also performed a manual search by speaking to architecture and design colleagues and the overwhelming result is that no such education exists. While there is a recent trend for evidence-based methods in healthcare infrastructure, these lessons have not been transferred to more general cases of urban infrastructure. Currently, urban designers build their designs but have no responsibility to evaluate the performance of their designs – the final product to the designer is an image of the space before it opens to the public. The unfortunate meaning of this culture gap is that the "scientific" and evaluative approach that Sensor City is taking is potentially unmeaningful as a feedback mechanism for designers. Therefore, it will also be the responsibility of Sensor City researchers to formulate meaningful research outcomes for designers that can result in real change.

Politically, soundscape evaluation does not receive a lot of weight either, despite the evidence that it should. Some studies have demonstrated that while soundscape concerns are not considered with priority in political or residential considerations, decision makers still have a responsibility to provide good soundscapes [16], [11] because poor soundscapes can adversely affect individual public health, happiness, and productivity. With proper knowledge management, Sensor City is capable of providing a real, tangible and meaningful product for designers with automatic ecological validity, negating designers' concerns about the shortcomings and validity of laboratory testing. In addition, the municipality of Assen gets real-time feedback on the effects of policy, installations, construction/demolition, special events, wildlife changes, and more both spatially and temporally.

Finally, once appropriate lessons have been gleaned from the Sensor City Project, simply reporting them is not the end of the story. The language used to convey findings must be audience-specific. Such a consideration is critical because the expertise of those who make decision about the functioning of a city comes from many sources – architects/designers, scientists, engineers, contractors, and politicians (who are further influenced by the lay public.)

Raimbault and Dubois [11], for instance, revealed through a semantic analysis that even experts fail to agree on basic technical vocabulary to describe usual sound events. At the same time, the already limited technical vocabulary of experts is totally unused by the "city users" who opt for "vocabulary of comparison" and "human noise descriptions" much more than urban planning experts. Also, experts' descriptions of phenomena showed richer and deeper categorical structure. Thus, we must distinguish the sounds of 'bicycle wheels' from 'people on bicycles' if we are to communicate meaningfully to our audience with Sensor City. It is clear that a one-size-fits-all tool will not be the best solution for conveying our findings.

CONCLUSIONS

This paper presents a cognitive sensor network capable of powerful urban measurements. The unique setup allows researchers to expand their ideas and pursue research questions they might not have asked. Our lab is pursuing the idea that soundscape can be rated according to its appropriateness for a certain situation. The appropriateness measure takes into account both the urban morphology, by suggesting that a certain type of place might call for a certain type of soundscape that affords certain types of activities to take place there, and the human, by suggesting that determining appropriateness is necessarily a cognitive task. We will investigate this idea by conducting laboratory and *in situ* questionnaires and observances about how people use certain spaces for certain kinds of activity and whether the soundscape of that space appropriately matches their expectations. Soundscapes that violate listener expectations by being inappropriate would be considered unsuccessful and, we speculate, would discourage use. For example, a noise-exposed park would fail to attract visitors wishing to exercise, while a quiet marketplace might discourage people from browsing and shopping. Soundscape appropriateness nicely balances the expectations of automatic recognition with the imposition of human-like cognition and could ultimately lead to fungible success measures agreed on by both the scientific and design communities. Such corroboration would ultimately lead to a better cycle of design and evaluation across fields of practice and potentially lead to practices in the field of the built environment that consume fewer resources to do a better job.

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THE BENEFIT OF FUZZY LOGIC TO PROTECTION OF CULTURAL AND HISTORICAL HERITAGE

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Abstract

The development of urban agglomerations and human settlements brings increasing a pressure to effective protection and preservation of cultural and historical heritage. Geographic information systems could play here an important role, on the one hand to help register and manage approachable information about existing cultural and historical heritage, on the other hand they can help in the prediction of areas with high cultural and historical potential that are threatened by the development of human settlements and the city transformations. Early prediction of endangered areas allows their consequent protection, respectively inclusion into the urban planning and suchlike.

This contribution deals with different aspects of the application of fuzzy logic in archaeological predictive modelling, which represent an effective tool to identify areas with potential of archaeological sites presence. The base constitutes the issue of determining the course of fuzzy membership functions for each input layer to the prediction. Onwards we deal with the difference between aggregate functions and individual t-norms that have a direct influence to the creation of predictive models. Finally, we devote to the fuzzy clustering that allows you to more effectively identify and single out categories of input features – archaeological sites. As well an increasing the process quality of archaeological predictive modelling, from creating individual prediction models for various components of archaeological sites, up to the possibilities of enhancing a validation quality of predictive models.

Keywords: cultural and historical heritage, fuzzy logic, predictive modelling, archaeology, t-norms, clustering

Recommended Citation: ĎURAČIOVÁ, R., LIESKOVSKÝ, T., STOPKOVÁ, E., KROČKOVÁ, K. (2013) The bendit of fuzzy logic to protection of cultural and historical heritage. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

SOURCES OF UNCERTAINTY IN ARCHAEOLOGY

One of the main issues in the application of GIS in archaeology is the geometric positioning of the archaeological site. In the current state of archaeological evidence in Slovakia can be accuracy of positioning moved within 100 m, especially for older and unverified records. This value is based on the rules of the Central Registry of Archaeological Sites in Slovakia (CEANS) where the basic unit of the registration system in the database is a point with diameter of 4 mm placed on the map with a scale of 1: 25 000, what means 100 m in the field [1]. This point form record of archaeological site is a significant source of uncertainty (Fig. 1). It means the generalization towards reality insofar as archaeological sites comprise large area polygons. The issue is determining the centroid of known archaeological site (core of site versus its geometric centre) as well as its scope. It is rare that the site is exposed and whole area of the site is known.

Archaeological findings itself fall to various transformation processes; doom process or spatial movements, such as erosion, soil movements, or suchlike. Similarly, in modelling certain phenomena and the application of theoretical knowledge is necessary to take into account human behaviour, not always based on rational principles and characterized by high variability and adaptability. This is reflected in the vagueness of the opinions in the investigation of human history and human behaviour ("proximity to water", "suitable slope", "suitable land") what is the cause of confusion in definition of the certain standards in spatial analyzes. All these facts bring to spatial analyzes significant degree of uncertainty and distortion. Fuzzy logic allows better reflecting the natural estimated properties and modelling the uncertainty of archaeological spatial data [2]. Fuzzy sets were used for modelling of spatial data for example in [3].

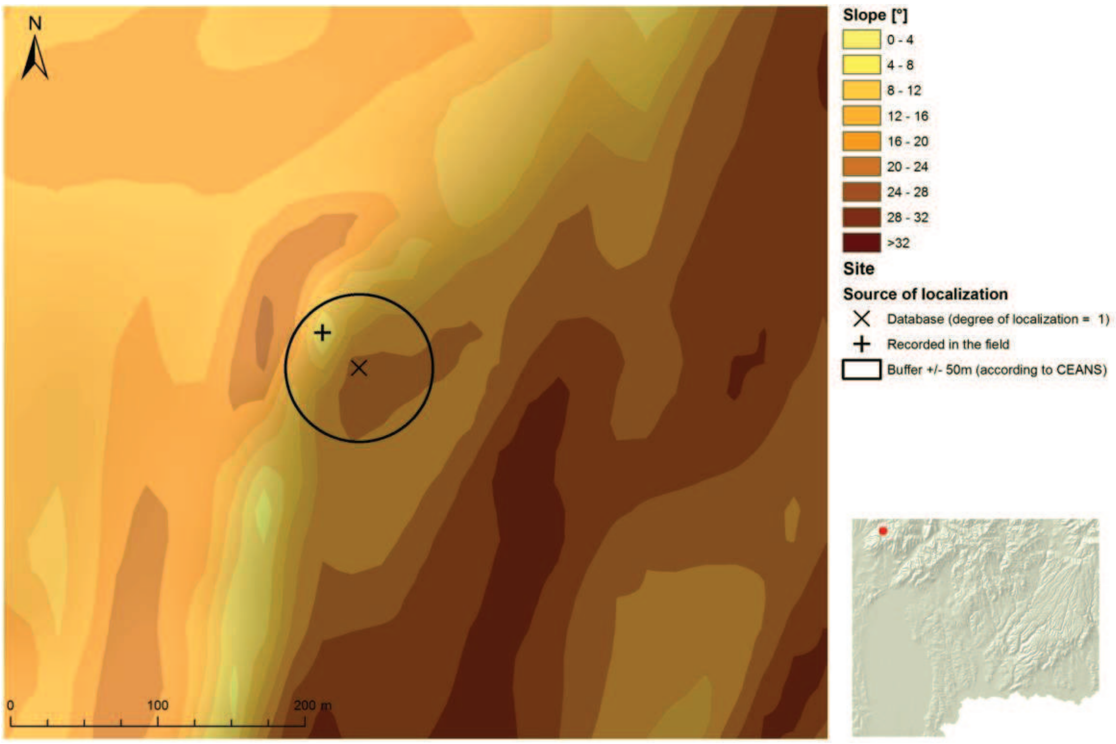


Fig. 1. The difference in positions of the site (real position and position according to database of archaeological sites evidence) [4].

BASIC CONCEPTS OF FUZZY SETS

The characteristic function of the crisp set $\chi_A : X \rightarrow \{0,1\}$ can be formalised [5]:

$$\chi_A(x) = \begin{cases} 1, & \text{if } x \in A, \\ 0, & \text{if } x \notin A. \end{cases} \tag{1}$$

The fuzzy set A of a universe X is defined by a membership function $\mu_A(x)$ such that $X \rightarrow [0,1]$, where $\mu_A(x)$ is the membership value of x in A [6]. (A fuzzy set is a set of elements $x \in X$ (X is called universe), where each of them is assigned by a degree of membership $\mu_A(x)$, whose values must be between zero (no membership) and one (definite membership).)

Fuzzy sets are, therefore, means that provides the ability to mathematical description of concepts of vagueness and to a work with them. Degree of membership reflects the rate to which the element belongs to the set.

The shape and parameters of the membership functions can be determined based on practical experience or on the known properties of the analyzed phenomenon. Trapezoidal (piecewise linear) membership function is the most commonly use one (Fig. 2a):

$$\mu_A(x) = \begin{cases} 0 & \text{if } x < a, \\ \dfrac{x-a}{b-a} & \text{if } a \le x \le b, \\ 1 & \text{if } b < x < c, \\ \dfrac{d-x}{d-c} & \text{if } c \le x \le d, \\ 0 & \text{if } x > d. \end{cases} \tag{2}$$

Other frequently used membership function shapes are e.g. Gaussian or sinusoidal (Fig. 2b).

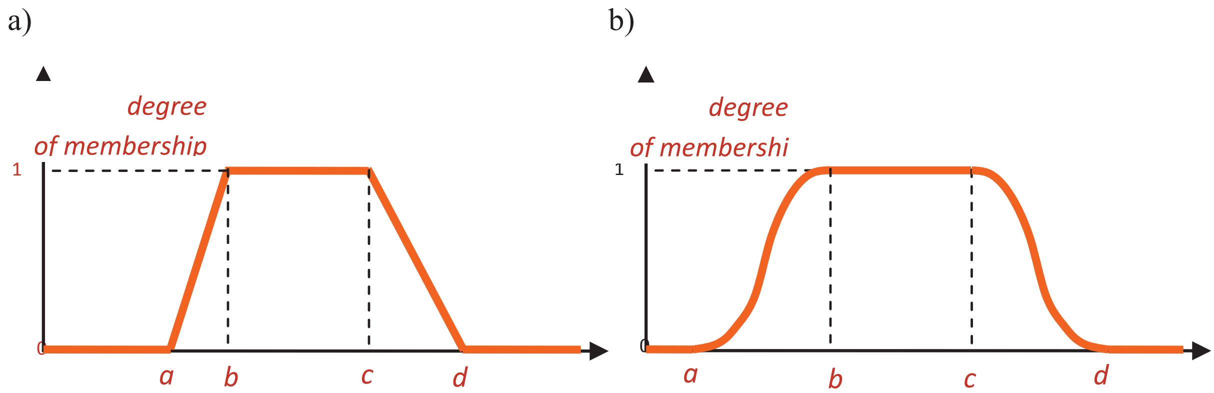


Fig. 2. a) Trapezoidal and b) sinusoidal membership function

PARAMETER DETERMINATION OF FUZZY MEMBERSHIP FUNCTIONS

In determining the parameters of fuzzy membership functions, we use similar approaches as for predictive modelling [2].

Deductive approach is appropriate in cases when sufficient knowledge exists about the expected knowledge of phenomena based on the results of archaeological excavations, archaeological theory, and possibly sufficient experiences. Similarly, deductive approach is the only option of modelling in areas with absence of information about archaeological localities, or in case where can be assumed that the data are not statistically relevant (low amount, uneven examination of the interest area).

Application of inductive approach allows us partially to objectify some assertions and used assumptions; and at the same time, it is suitable for the determination of individual parameter weights. However the approach does not fully model some phenomenon and is subject to distortion caused by uneven examination of the interest area, the accuracy of localization and failure the differentiation of various types of archaeological sites [7] .

In case of a deductive approach to modelling, the course of membership function of a fuzzy set representing the proper conditions for archaeological sites (e.g. Fig. 3) was determined based on expert judgment or based on available data in the archaeological literature. An alternative could be to determine a function course of the statistical processing of input spatial data (for instance extrapolated from the frequency histogram of individual characteristics of localities and landscape). Probably the most appropriate approach is the combination of two methods described above. For example, to create a model in deductive approach with using fuzzy logic is possible to adjust the shape of membership functions based on the results of statistical tests of known parameters and in a similar way to set the weight of each layer. On the other hand, in the case of applying mainly inductive approach we can eliminate remote and extreme values of the statistical tests based on the deductive assumptions [4].

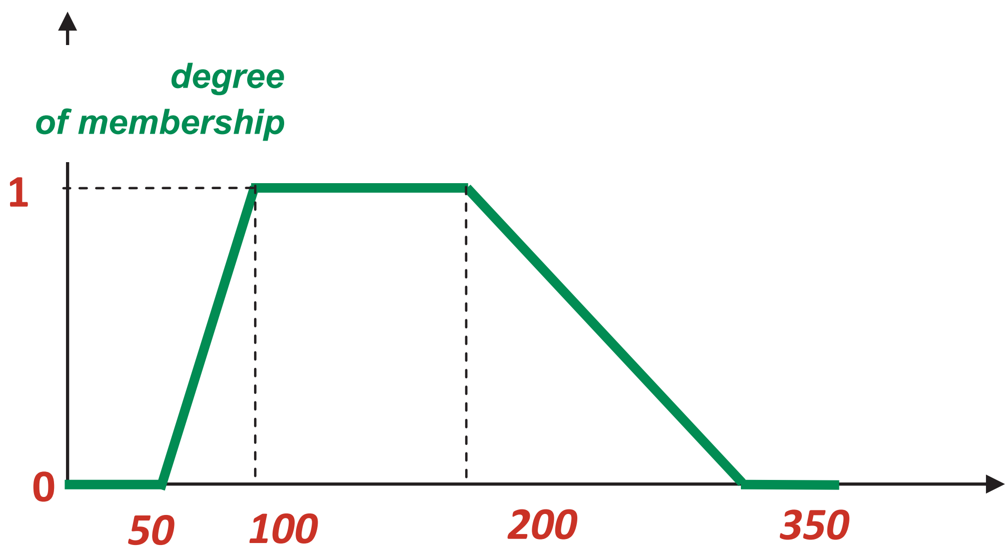


Fig. 3. Fuzzy membership function of distance between sites and watercourses

DETERMINATION OF INPUT LAYERS WEIGHTS

In most references about determination of weights for archaeological modelling is used deductive method of determining the weights. Inductive determination of weights designed by us is based on comparison of differences in two distribution of the phenomenon at sites f (x) and phenomenon in the landscape g (x). We come out from assumption that the difference of two distributions is bigger the given phenomenon have greater influence on the choice of site (Fig. 4 – Fig.6). Coefficient of differences between two distributions defines as follows:

$$w(f,g) = \int_{-\infty}^{\infty} \left| f(x) - g(x)dx \right| \quad (3)$$

Fig. 4. Example of difference in distributions of phenomenon at sites and phenomenon in landscape

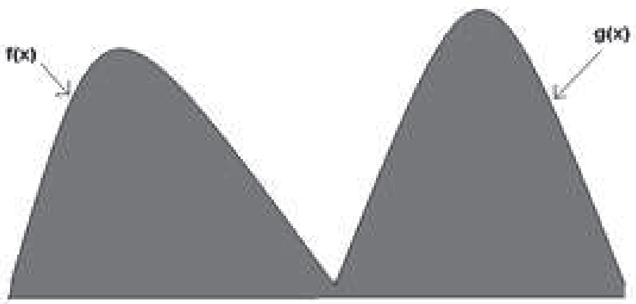


Fig. 5. The maximum difference in distributions of phenomenon at sites and phenomenon in landscape – difference gets value of 2

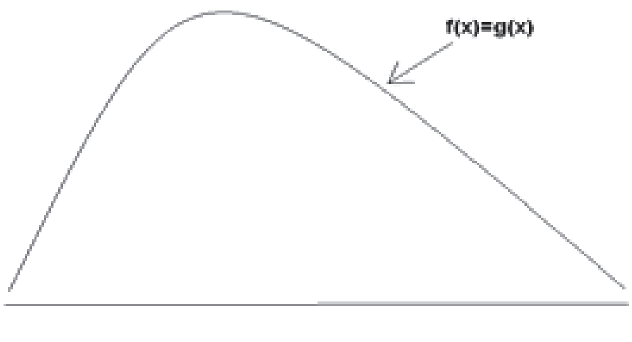


Fig. 6. The same distribution of phenomenon at sites and in landscape - difference gets value of zero

Since this rate differences is in range [0,2] it is proper to normalize:

$$w^N(f,g) = \frac{1}{2} w(f,g) \tag{4}$$

Examples of fuzzy layers are presented in Fig. 7 and their estimated weights are listed in Tab. 1.

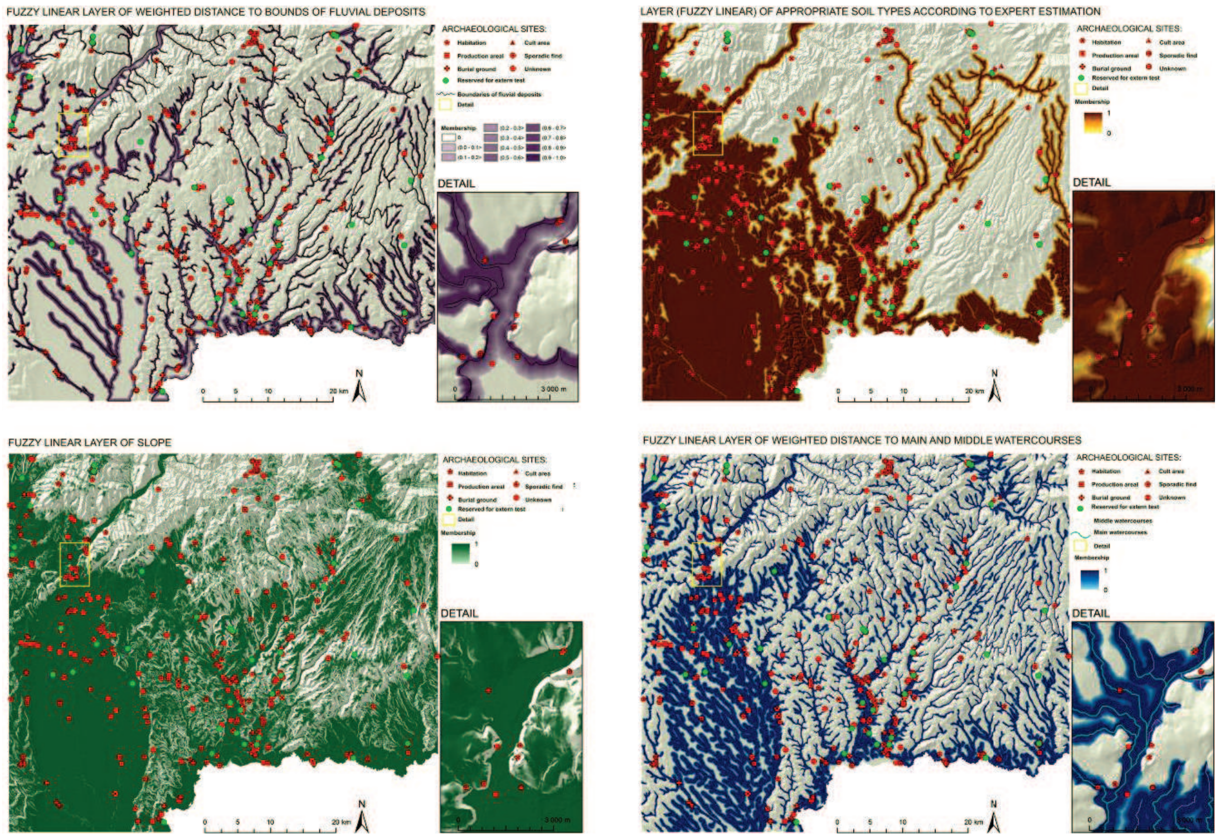


Fig. 7. Examples of fuzzy layers entering the prediction model with examples of calculated weights

Table 1. Examples of estimated weights for each layer

Layer name	**Weight**
Fuzzy linear layer of cost weighted distance to main and middle watercourses	0.588
Cost weighted distance to bounds of fluvial deposits	0.843
Slope	0.376
Main representation of soil type in perimeter of 500 m	0.5241

FUZZY LOGICAL OPERATIONS AND AGGREGATION FUNCTIONs

Logical operations like intersection, union and complement, which are corresponding to propositional operations conjunction, disjunction and negation in mathematical logic, are the basic functions with sets in GIS environment. Logical operators are also part of the query to spatial databases in SQL. The basic operations are defined in Boolean algebra for crisp sets. In spatial analysis for example, we need to select sites, which [8]:

- must be near to fluvial deposits (less than 250 m),
- must have moderate slope or favourable aspect (e.g. south-west),
- must not be far away from a river (more than 350 m), but must not be too close (less than 50 m),
- must be in the lowland.

If:

- *F* is a set of sites located within 250 meters from boundaries of fluvial deposits,
- *S* is a set of sites with moderate slope (e.g. slope within 10°),
- *A* is the set of sites in south-west aspect,
- *L* is the set of sites with altitude less than 300 m,
- *R1* is the set of sites whose distance from the river is ≤ 50 m,
- *R2* is a set of sites whose distance from the river is ≥ 350 m,

then for a set of appropriate sites applies:

$$V = F \cap (S \cup D) \cap N \cap \neg(R1 \cap R2) \tag{5}$$

Fuzzy logical operators (with the truth-value of interval [0,1]) are the basis of fuzzy propositional calculus for operations with fuzzy sets [9] (Navara & Olšák, 2004). In fuzzy set theory:

- fuzzy standard intersection of two sets *A, B* is fuzzy set $A \cap B$ with membership function (Fig. 8):

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)) \tag{6}$$

- fuzzy standard union of two sets *A, B* is fuzzy set $A \cup B$ with membership function (Fig. 8):

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)) \tag{7}$$

- fuzzy standard complement of set *A* is fuzzy set $\overline{A}$ with membership function:

$$\mu_{\overline{A}} = 1 - \mu_A(x) \tag{8}$$

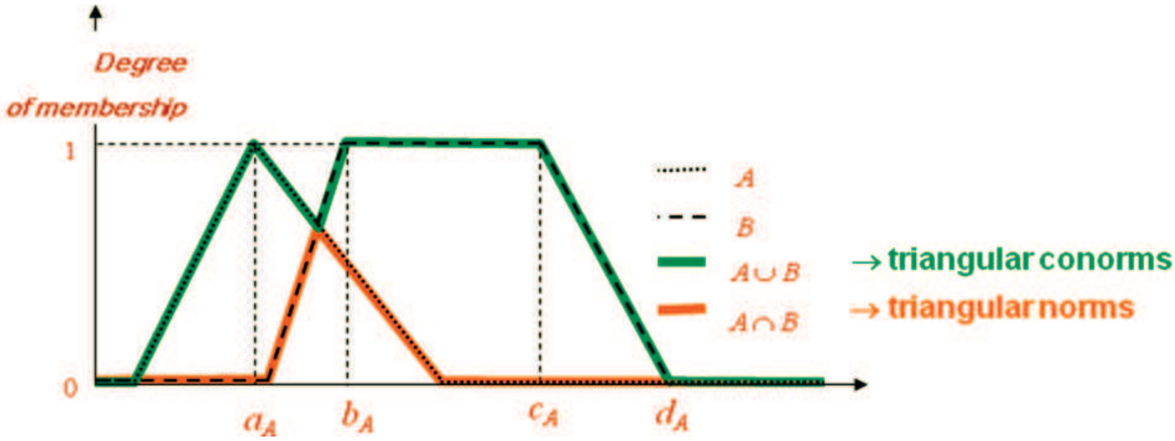


Fig. 8. Fuzzy intersection (conjunction) and fuzzy union (disjunction)

Generally, fuzzy intersection (conjunction) is in many cases defined by the so-called triangular norms (t-norms). The generalization of the classical union (disjunction) is interpreted by triangular conorms (t-conorms) [10]. The most commonly used t-norms are (Fig. 9):

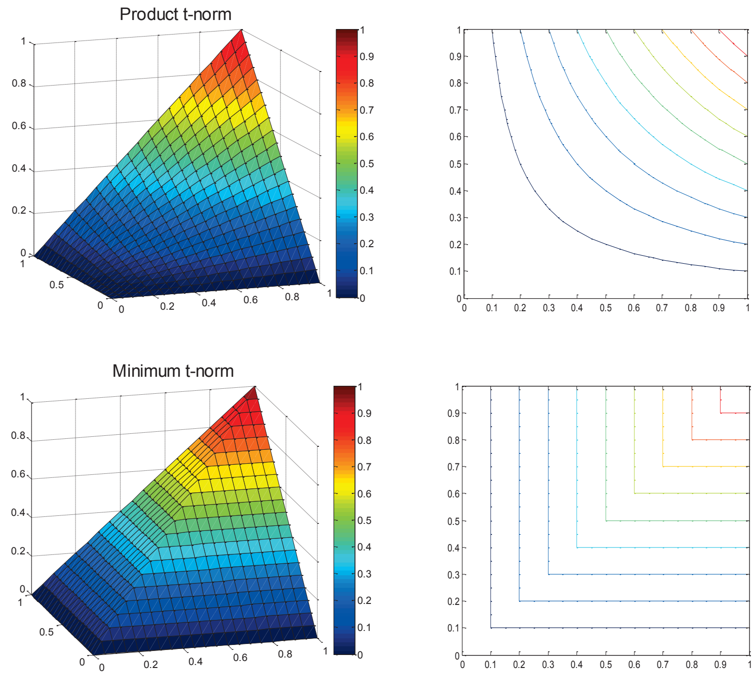
$$T_M(x, y) = \min(x, y)$$ - minimum t-norm (9)

(it corresponds to the standard intersection)

$$T_P(x, y) = xy$$ - product t-norm (10)

$$T_Ł(x, y) = \max(0, x + y - 1)$$ - Łukasiewicz t-norm (11)

$$T_D(x, y) = \begin{cases} \min(x, y), & \text{if } \max(x, y) = 1 \\ 0, & \text{else} \end{cases}$$ - drastic t-norm (12)



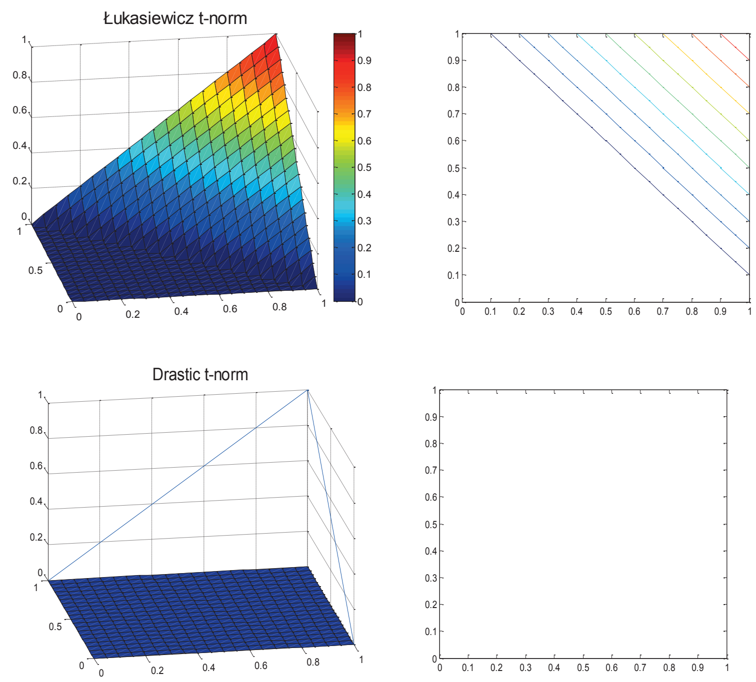


Fig. 9. The most commonly used t-norms

Weighted average is an appropriate aggregation function for the introduction of various weights of each criterion modelled by fuzzy sets. The impact of choice of overlapping function (t-norm, weighted average) to the resulting predictive model (detail) is shown in Fig. 10.

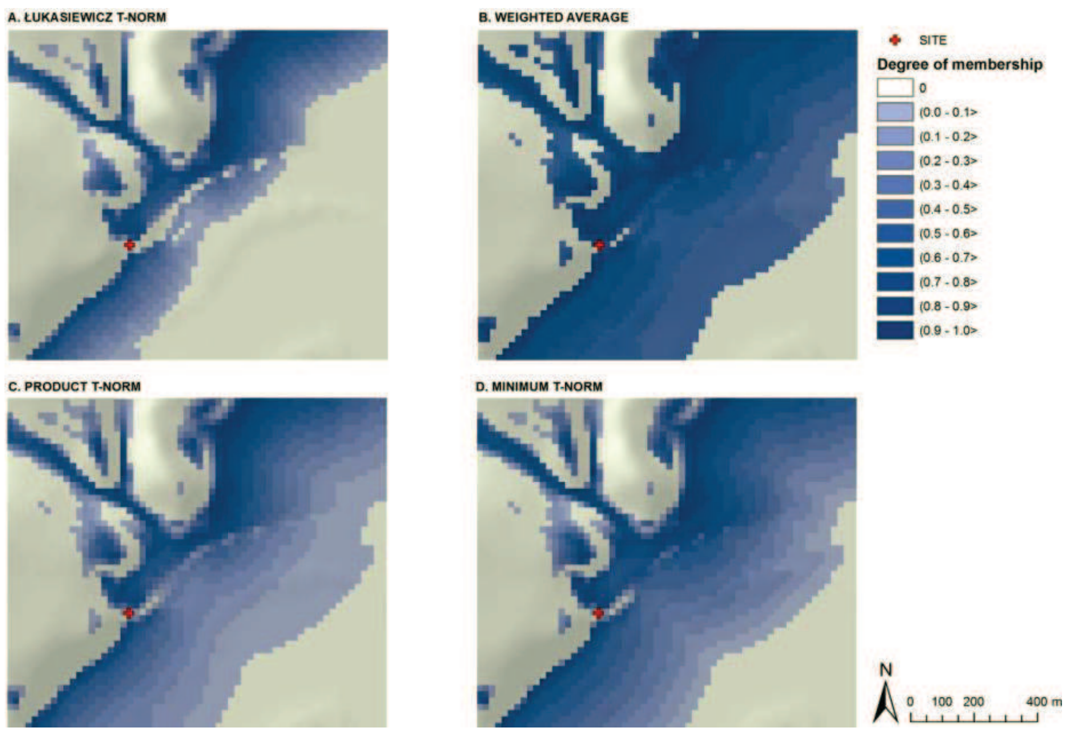


Fig. 10. The impact of choice of overlapping function (t-norm, weighted average) to the resulting predictive model (detail)

Spatial decision making using fuzzy sets is discussed for example in [11] or in [7].

POSSIBILITIES OF FUZZY LOGIC USAGE IN CLUSTER ANALYSIS

Determination of parameters of fuzzy membership functions could be in some cases complicated by fact, that knowledge of the phenomenon may be inadequate to describe all its variants. For example, if we analyze optimal conditions for settling habitation (shown upper), these criteria may valid for casual settlement in ancient ages. However, hill forts were settled, according to [12], at steep slopes or close to rivers, wetlands or at lakes and they could not be described by the criteria. Prediction model based on these criteria could not detect potential site - hill fort. If type of habitation (casual or hill fort) is known, it is possible to develop more prediction models based on criteria that describe properties of both groups.

Parameters of fuzzy membership functions have been estimated using data of archaeological sites evidence. The items differ in accuracy of position and of attributes and they are different in complexity of information. Absence of note about habitation type may lead to some uncertainties, for example during prediction model testing there have been 13 known sites undetected - that means almost 1% of total number of sites.

One of the possibilities to eliminate the risk of potential site rejecting based on properties that not completely suit to the prediction model is application of fuzzy cluster analysis. This means data clustering - determining if element belongs to the membership of similar elements or not. Fuzzy theory enables to determine, if the element belongs to more than one group and also ratio of this relationship [13]. Grouping of similar elements enables to differentiate special cases and obtain information about variations of the data. Fuzzy C-Means (FCM) is one of the most often used methods based on the minimalism of sum of weighted differences between feature values and average value of the group [14].

Analytical tool *Grouping analysis* based on similar principle [15] have been developed and implemented to ArcGIS 10.1 (ESRI) into toolbox *Mapping Clusters*. Topic is quite circumstantial; we will try to explain experiment focused on surveying of hill forts common signs, specifically of potential differences in their site terrain configurationWe expected hill fort to be located at:

- raised locality with smooth or little more steep slope (flatland),
- locality in medium or higher hills with steep slope,
- locality in medium or higher hills with very smooth slope (top of the hill).

Analysis results are summarized in Fig. 11, Graph 1 and Graph 2. Graph 1 describes memberships of elements with minimal sum of weighted differences between values of elevation or slope and the mean of the membership. Graph 2 combines memberships according to distribution of elevation and slope. According to experimental criteria, memberships have been differed as *hill forts* and *habitations* (Fig. 11). As optimal number of memberships was empirically confirmed membership of five.

The result of experiment have been tested by comparing with known castles, hill forts and fortifications, that have been researched in literature, maps and in some cases found as note in database. For check was used also layer of sites that never been predicted before during testing of prediction models. Fig. 11 shows coincidence of majority of known fortifications with unpredicted sites and with membership of *hill forts*. Exceptions might represent Levice Castle (located at flatland close to the town) and Čabraď Castle (protected more by river than by steep terrain). Other massive exception we can found in Banská Štiavnica surrounding, there is too many elements in membership of *hill forts* because of special terrain configuration.

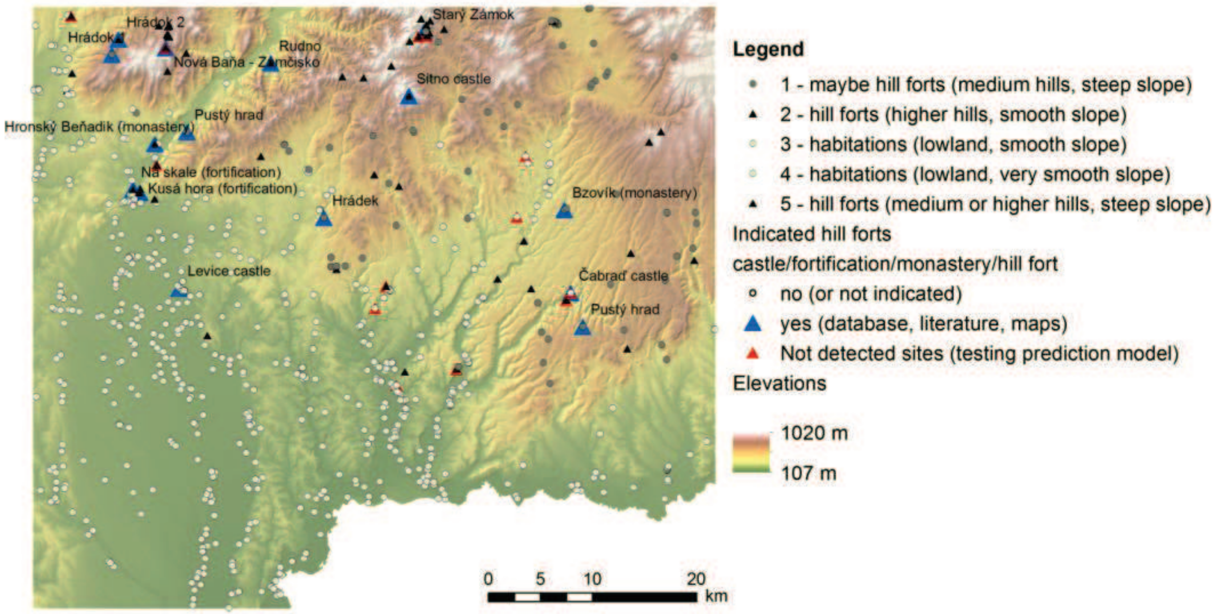


Fig. 11. Results of cluster analysis of sites - *hill forts* and *habitations* memberships

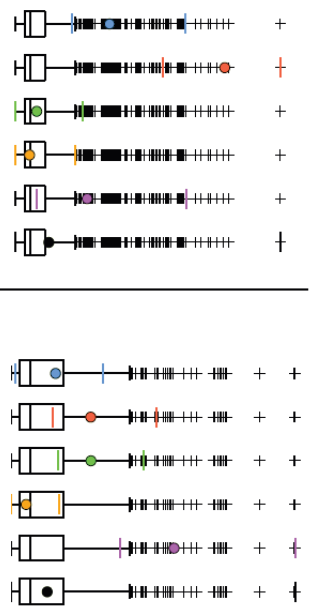
Variable-Wise Summary

H_ELEV_M: R2 = 0.86

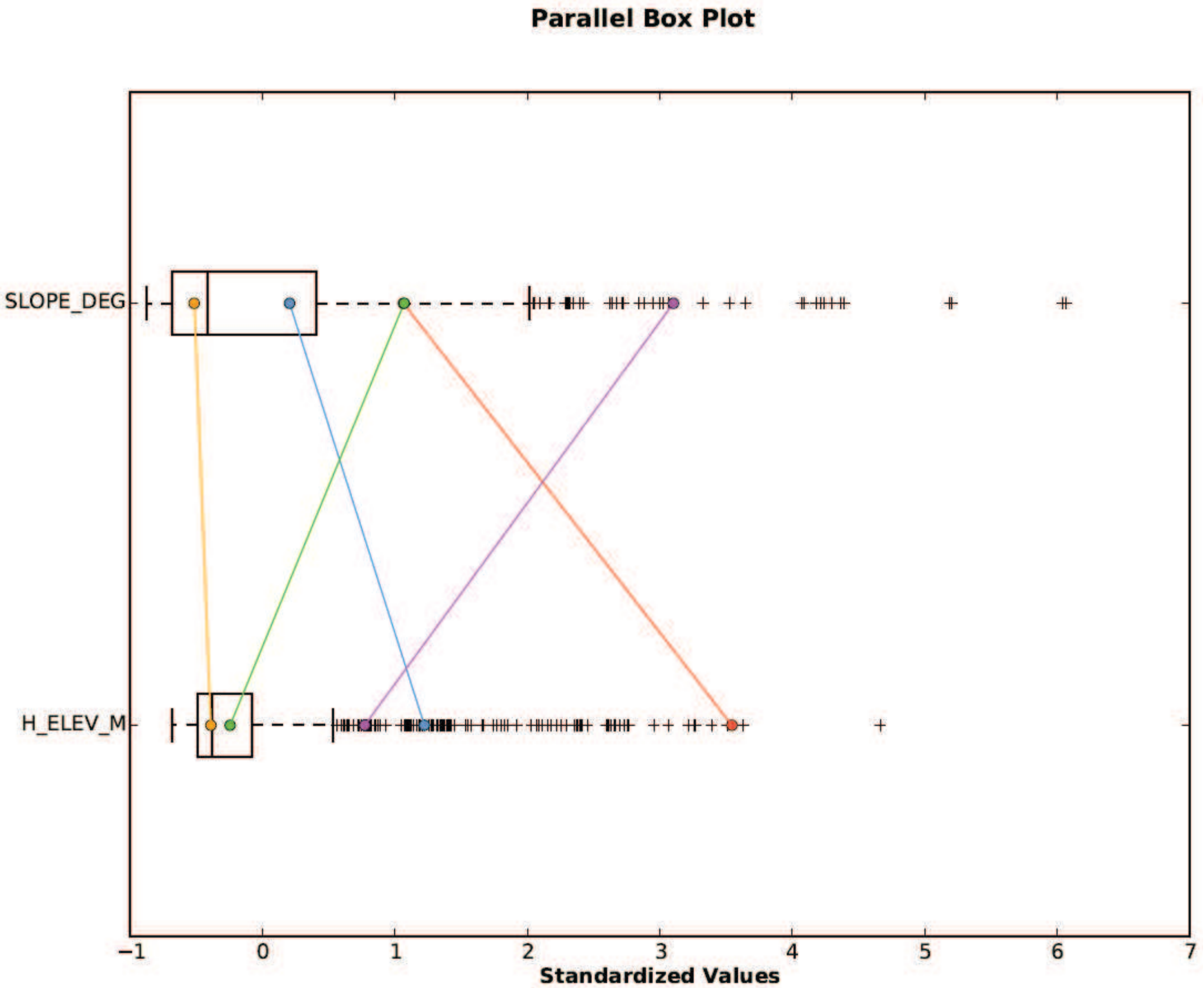
Group	Mean	Std. Dev.	Min	Max	Share
1	431.5814	80.9031	303.7827	688.0181	0.4293
2	820.3468	165.1267	611.9446	1007.7792	0.4422
3	185.9384	49.2733	113.9975	342.2664	0.2550
4	161.7254	32.4184	112.6567	314.5240	0.2255
5	356.1201	144.7384	187.0491	690.0831	0.5620
Total	226.7521	167.4192	112.6567	1007.7792	1.0000

SLOPE_DEG: R2 = 0.83

Group	Mean	Std. Dev.	Min	Max	Share
1	4.4887	2.0845	0.3580	9.3029	0.3112
2	8.0438	2.3141	4.1717	14.7037	0.3664
3	8.0673	2.4141	4.7821	13.3524	0.2982
4	1.5067	1.1311	0.0092	4.8367	0.1680
5	16.4802	3.8969	11.0452	28.7526	0.6161
Total	3.6376	4.1382	0.0092	28.7526	1.0000



Graph 1. Memberships according to characteristics of elevation and slope



Graph 2. Combinations of variables describing memberships

Topic will be research in the future because of potential in adding more parameters (for example soil types) of cluster analysis or in defining specific properties of fortifications settled in river or wetland environment. The results could be more precise after obtaining more information about known hill fort from literature and other sources. Membership 1 (potential hill forts) should be also analysed because it might contain habitations except hill forts - it depends on similar terrain configuration.

CONCLUSION

Application of fuzzy approach in GIS means the contribution to increasing of quality and plausibility of spatial analyses. Fuzzy sets enable to model, analyse and describe phenomena in more natural way: with regard on their constitution and (in)accuracy of available data describing. Fuzzy approach may be useful for example in archaeological prediction modelling. High degree of inaccuracy is caused by absence of common approach to data acquisition, by long term of recording archaeological data and by generalization of polygonal sites to point data. In addition, quality and scale of other spatial data used in spatial analyses belong to important aspects of inaccuracy (for example maps of soil types as results of interpretation and interpolation of point data). Fuzzy sets mean more accurate way how to model the settlement propriety of the land in the past. It is more relevant to model for example fact, that localities within a distance of 350 m could be the most appropriate to settlement and within a distance of 500 m the appropriateness decreases, than to claim, that only localities within a distance of 350 m could be settled.

Application of fuzzy logic itself does not guarantee automatically more accurate and correct results in case of inconsistent knowledge of the phenomenon, or in case of too many degrees of freedom. It helps to quantify known phenomena in more objective way like to eliminate inaccuracy of them or minimize loss of approximate information too. That is the reason why multi-criteria decision-making with usage of fuzzy logic principle may be adequate method to develop prediction models in GIS. It provides high flexibility that enables to adapt model to reality by setting appropriate fuzzy sets and by using correct rules of evaluation.

ACKNOWLEDGMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0249-07.

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INTERFEROMETRIC DETERMINATION OF SUBSIDENCES IN PRAGUE CITY (preliminary results)

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Abstract

Radar interferometry (InSAR) method uses radar images for deformation monitoring of a large area. Four ENVISAT stacks of the ASAR images acquired from 2003 till 2009 provided by ESA were processed. The processing of the whole images would be very time and memory consuming, that's why only cuts covering the area of interest were created. These cuts were coregistered to a selected master in order for all possible interferogram combinations to be created.

The examined area of interest is the built-up area of Prague city. Some subsidences occurred there in the past, mainly because of the human activity. Since several tunnels were built after 2000 and others are still under construction, there is an assumption of the deformation within examined area.

The permanent/persistent scatterers (PS) method was used for deformation detection. The processing was performed by IPTA (Interferometric Point Target Analysis) package, which is a part of the GAMMA software. Only appropriate point targets were used for further processing, while the rest of points are omitted. Almost all available images can be used compared to the conventional interferometry method in which the critical baseline requirement must be fulfilled otherwise the interferograms are totally decorrelated.

The aim of the project is the determination of the unstable areas caused either by the natural conditions or by the human activity (e.g. tunnels construction).

Keywords: radar interferometry (InSAR), subsidence, permanent scatterers (PS)

Recommended Citation: SVOBODOVÁ, K., HLAVÁČOVÁ, I., HALOUNOVÁ, L. (2013) Interferometric determination of subsidences in Prague city (preliminary results). In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

Area description

The area of interest covers the area of Prague city. The motivation for examining this area was the fact that several landslides occurred there in the past [1]. There is an assumption that some subsidences are possible in present since several tunnels were built after 2000 and others are still under construction. Even small movement within such highly built-up area can cause large damage of buildings and constructions. IPTA method is supposed to work well here thanks to occurrence of the sufficient amount of the stable points suitable for processing (e.g. buildings, bridges, crossroads).

Data description

The data of four ENVISAT stacks of ASAR images were processed. The images acquired between 2003 and 2009 were provided by ESA – track 43 (12 scenes acquired, ascending pass), track 122 (10 scenes acquired, descending pass), track 272 (13 scenes acquired, ascending pass) and track 351 (11 scenes acquired, descending pass). The images of tracks acquired during ascending passes (from south to north) are vertically flipped and the images of tracks acquired during descending passes (from north to south) are horizontally flipped.

Only the area of interest was cut from each image because the processing of the whole scene (approx. 100 x 100 km) would be very time- and memory- consuming. The cuts (aprox. 20 x 25 km) were coregistrated to the master and radiometrically calibrated. After these steps the cuts were prepared for the processing. Unfortunately not all the images within each track were possible to coregister due to the long perpendicular baseline ($B_\perp$), see table 1 which summarizes the used images. IPTA method works well for the high number of the images and the insufficient number of images brought complications to the processing. But no more scenes were available for the examining area due to the conflicts with other projects.

Table 1. Data used - the perpendicular baselines were calculated with regard to the master scene (in bold typeface)

Track 43			**Track 122**		
Orbit	**Date**	**$B_\perp$ [m]**	**Orbit**	**Date**	**$B_\perp$ [m]**
08113	2003-09-18	-807	09695	2004-01-07	924
10618	2004-03-11	-980	12701	2004-08-04	615
11620	2004-05-20	-1284	15206	2005-01-26	264
13624	2004-10-07	-1781	22220	2006-05-31	-205
14626	**2004-12-16**	**0**	22721	2006-07-05	1126
18133	2005-08-18	-352	**24224**	**2006-10-18**	**0**
22642	2006-06-29	-1459	25226	2006-12-27	1019
25648	2007-01-25	-1306	27230	2007-05-16	237
			35747	2008-12-31	544
			37250	2009-04-15	181

Track 272			Track 315		
Orbit	Date	$B_{\perp}$ [m]	Orbit	Date	$B_{\perp}$ [m]
6839	2003-06-21	-8	12429	2004-07-16	627
9344	2003-12-13	1193	14433	2004-12-03	867
12350	2004-07-10	783	15435	2005-02-11	296
13853	2004-10-23	-285	22449	2006-06-16	607
15356	2005-02-05	628	**24453**	**2006-11-03**	**0**
17861	2005-07-30	926	25455	2007-01-12	1251
22871	**2006-07-15**	**0**	28461	2007-08-10	493
23873	2006-09-23	213	30465	2007-12-28	258
28883	2007-09-08	1126	35976	2009-01-16	829
29885	2007-11-17	998			
32891	2008-06-14	612			
34394	2008-09-27	367			
36398	2009-02-14	508			

Method description

IPTA (Interferometric Point Target Analysis) method is based on the principle of permanent or persistent scatterers (PS) which is implemented within the GAMMA software. The principle of the method is that not the whole scene but only appropriate points are processed. Then the process is much faster, more effective and output files are much smaller compared with the conventional interferometry method. Even the pairs with long baselines can be used because of the iterative process.

The outputs from the regression analysis includes linear deformation rate corrections, height corrections, residual phases, unwrapped interferometric phases and point quality information. These results are used to improve the model [2].

IPTA PROCESSING

Point data generation

Each track was processed separately. First the baselines were calculated with the limitation of the maximum perpendicular baseline set to 350 m. For each track several interferograms were obtained.

The candidate points were selected from coregistered SLCs and coordinates (range and azimuth pixel number) of each point were saved to the point list (plist, see Fig. 1). Selection of the appropriate candidate points is based on the low temporal variability of the SLC intensity and an SLC intensity above a threshold relative to the spatial average (minimum threshold was set to 1). The mean/sigma ratio was calculated to evaluate the temporal variability of the chosen candidate points (with minimum threshold set to 1.5) [2].

SRTM-X Digital Elevation Model (DEM) was used during the processing. The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth [3]. The model was already transformed to the geometry of SAR images using the GAMMA DIFF&GEO software. DEM data were transformed to the point data stack. Also the values of target points in SLCs were extracted and written to the point data file.

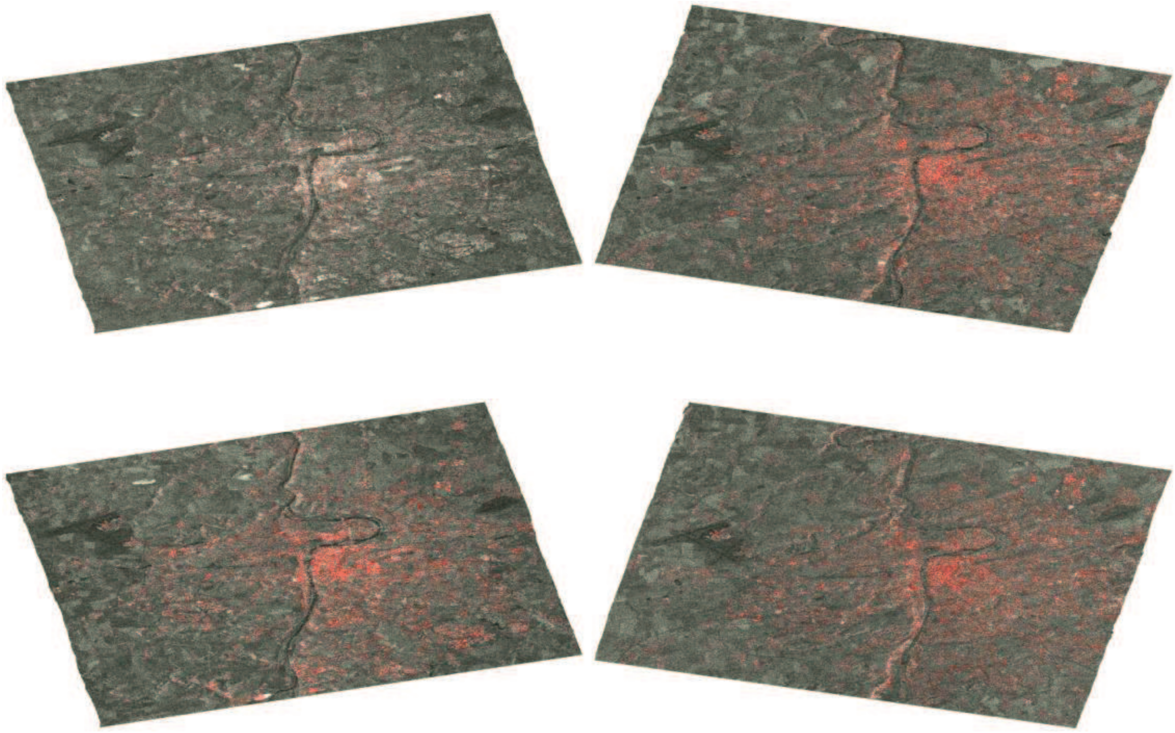

Fig. 1. The candidate point list (plist, represented by the red dots) plotted on the georeferenced image cuts – track 43 (upper left), track 122 (upper right), track 272 (lower left) and track 351 (lower right). The images are dispalyed in multilook (1 pixel in range and 5 pixels in azimuth) for easier interpretation.

Differential interferograms calculation

First the interferograms were calculated from the SLC point data. Then the simulation of the unwrapped interferometric phase was calculated. Differential interferograms were calculated by the subtraction of the unwrapped simulated phase from the complex valued interferogram.

A reference point must be determined in interferometry. This point must be either stable or its deformation must be known, because the changes are related to it. Since the examined area is assumed to be stable, then the reference points are assumed to be stable too. The selection of the reference point is very important. The amount of the processed points depends on the quality of the target point itself and on the quality of the reference point (see Table 2). All reference points are located roughly in the same place in the centre of the image.

Table 2. Reference points summary.

Track number	Size of the image [pix]		Ref. point number	Ref. point coordinates [pix]		Number of candidate points
	width	length		azimuth	range	
43	1300	5000	14934	814	2729	22784
122	1100	5000	19686	404	1974	62022
272	1100	5000	38893	693	2748	56001
351	1300	5000	22908	450	2043	72345

Regression analysis

The regression analysis was performed on the differential interferograms. The height corrections from the analysis were added to the initial heights and the pairs with the perpendicular baselines up to 500 m were added and the process was repeated. The procedure was repeated until all pairs were used.

During each iteration step the point quality is re-calculated. As a quality measure the standard deviation of the phase from regression is used. The points which is not suitable for IPTA analysis can be then detected and rejected from the process. If the phase standard deviation is smaller than 1.2 rad, the regression is said to be successful [2].

Table 3 shows the number of processed pairs with the dependency on the perpendicular baseline length for each track. Also the decreasing amount of the processed points for every iteration with the dependency on the baseline length. The temporal baseline is not important for the deformation detection and is omitted.

Table 3. Number of the processed pairs with the dependency on the perpendicular baseline length for each track. There is clearly visible the decreasing amount of the processed points for every iteration with the dependency on the baseline length.

Track 43			Track 122		
($B_\perp$) [m]	Number of interferograms	Number of the processed points	($B_\perp$) [m]	Number of interferograms	Number of the processed points
350	7	22692	350	14	47192
500	14	20177	500	24	29297
600	14	20103	600	27	27225
700	16	20237	700	30	27274
800	16	20183	800	34	24025
900	18	20135	900	38	20260
1000	22	18837	1000	40	18200
all	28	12668	all	45	14440
Track 272			**Track 351**		
($B_\perp$) [m]	Number of interferograms	Number of the processed points	($B_\perp$) [m]	Number of interferograms	Number of the processed points
350	27	26985	350	17	59777

500	37	19415	500	22	54517
600	46	16104	600	25	55553
700	54	12114	700	30	50698
800	58	12598	800	31	51102
900	61	11161	900	33	50151
1000	67	10359	1000	35	48379
all	78	7795	all	36	47122

RESULTS

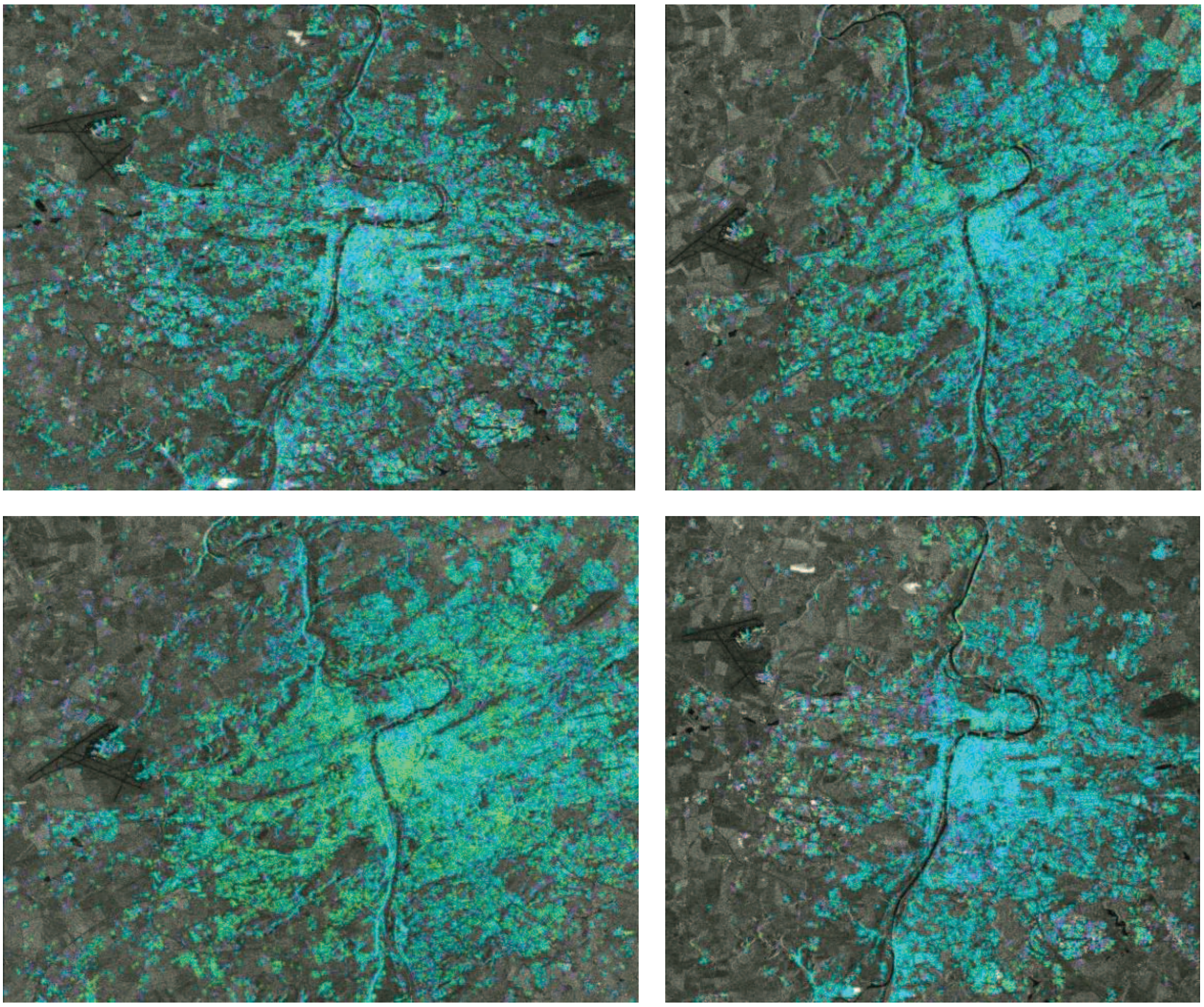

Fig. 2. Resultant linear deformation rate for each track - track 43 (upper left), track 122 (upper right), track 272 (lower left) and track 351 (lower right). The images are displayed in multilook (1 pixel in range and 5 pixels in azimuth) for easier interpretation. One colour cycle corresponds to the 0.05 m/year relative linear deformation rate.

Fig. 3. Colour scale for the deformation map, with the edges of ± 2.5 cm/year.

Suspicious areas

The histograms showing the number of points related to the deformation rate were plotted (see Fig. 4). There are two ascending (43 and 272) and two descending (122 and 351) tracks among which the deformations can be compared. A suspicious area was discovered in the track 272 but since there is not enough images in track 43, the area was not found there and cannot be compared.

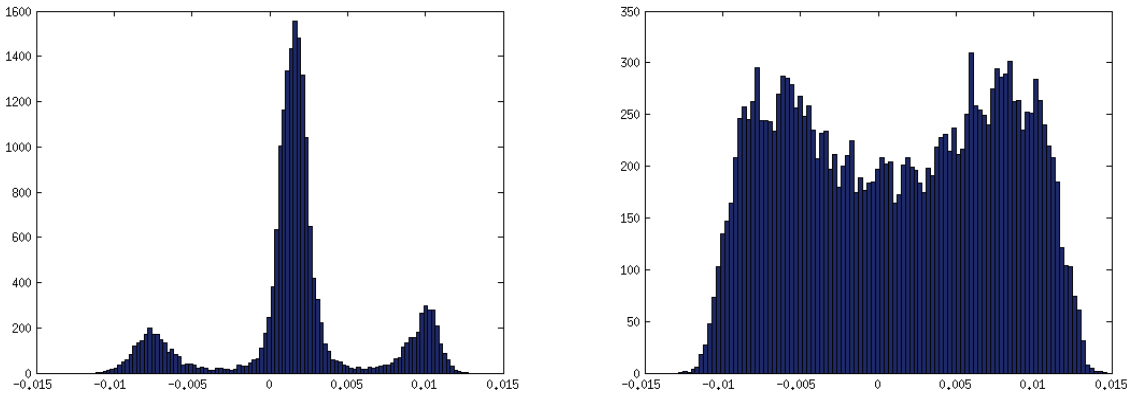

Fig. 4. Example of the histograms showing the number of points (vertical axis) related to the deformation rate (with removed zero value points, horizontal axis) – track 272 (left) and track 43 (right).

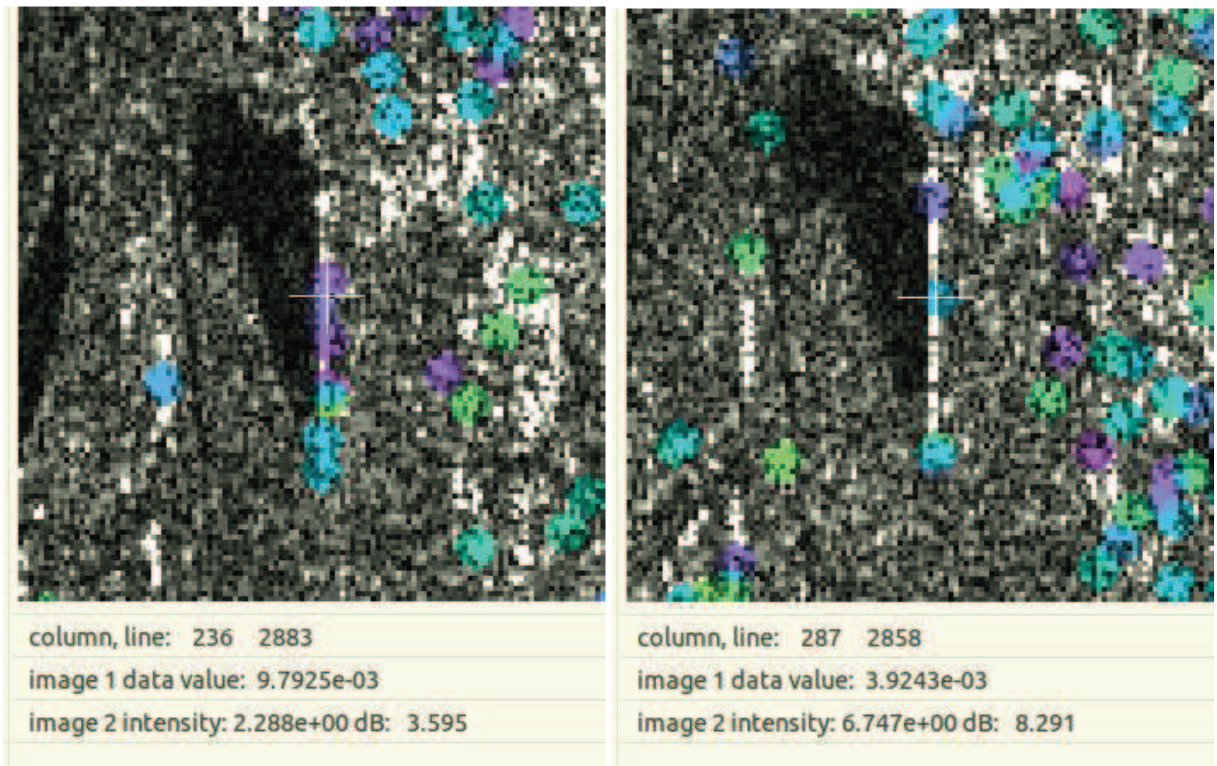

Fig. 5. The detail of the linear deformation rates of the retention basin Jiviny dam. On the left image there is a detail with the processed points and its values for the track number 272 and on the right image there is a detail for the track number 43.

FUTURE WORK

The deformation maps will be thoroughly researched and well interpreted. The final deformation maps from various tracks will be compared for better results interpretation. The process of the estimation and subtraction of the atmospheric influence will be implemented and maybe some interferograms will be excluded from the process. Also ERS 1 and ERS 2 image will be ordered and processed.

ACKNOWLEDGEMENTS

The data were provided by ESA within C1 project 5556: Interferometric determination of subsidence caused by undermining by permanent scatterers and phase unwrapping correction within interferometric stacks.

The research was granted by the project: Modelling of urban areas to lower negative influences of human activities (Ministry of Education, Youth and Sports No. OC 10011)

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DASYMETRIC MAPPING AS AN ANALYTICAL TOOL FOR THE CITY DEVELOPMENT IDENTIFICATION AND ITS CARTOGRAPHIC VISUALIZATION

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Abstract

The paper represents the result of an application of dasymetric mapping on the city development identification based on the aerial photography in the Olomouc region. Dasymetric mapping is a method of thematic cartography, which uses areal symbols to classify volumetric spatial data. Dasymetric mapping is suitable for the population density visualization because of its ability of realistic placement over geography. The same approach can also be used to monitor the development of the city in the long time period. To monitor such developments can be used aerial photographs in combination with statistical data related to the same time units, in which the aerial images were taken.

This contribution describes the methods of dasymetric mapping application, advantages and disadvantages of the methodology use and the resulting cartographic visualization and statistical evaluation on the example of Olomouc city. A good indicator of the city development is besides the city population density also the urban area type (residential buildings, industrial areas), which can be detected from aerial photographs. Detection of these areas and the subsequent application of statistical data are suitable for dasymetric visualization of the city development.

Keywords: dasymetric mapping, aerial photography, city development

Recommended Citation: VONDRÁKOVÁ, A., KOLAŘÍK, J. (2013) Dasymetric mapping as an analytical tool for the city development identification and its cartographic visualization. In: IVAN, I., LONGLEY, P., HORÁK, J., FRITSCH, D., CHESHIRE, J., INSPEKTOR, T. (eds.). GIS Ostrava 2013 – Geoinformatics for City Transformations. Ostrava: VŠB - Technical University of Ostrava, 21. – 23. 1. 2013. ISBN 978-80-248-2974-6.

INTRODUCTION

The dasymetric mapping uses areal symbols to classify spatial volumetric data. This method of thematic cartography was developed and firstly termed by the Russian cartographer Tian-Shansky, who developed the multi-sheet population density map of European Russia, published in the 1920s [1].

Dasymetric mapping allow realistic spatial visualization, it is considered as a hybrid between isopleth and choropleth maps. This method is based on non-administrative divisions. The population density is usually expressed numerically in terms of the number of persons per square kilometre. It means that the user does not know whether population occurs uniformly in the displayed area or whether the same average values of the population occurs once on a small area and sometimes disproportionately on the larger area. It can be difficult to compare the population living in multi-panel buildings, single-family houses in the suburbs or in houses in villages. Population density may be the same for the two administrative units, but in fact it does not take into account when comparing the total population size structure of the units and urban area types. It is therefore appropriate that statistical data from administrative units are related to the actual built-up area. During the analysis of the characteristics of the substrate aerial images is suitable to use dasymetric mapping methods, which makes the result more illustrative representation than using methods of choropleth maps. The development of the city is much more related to the distribution of population density in urban area types than in theoretical administrative borders, which include uninhabited areas, etc.

Besides the density of the population a good indicator of the city development is the urban area type (residential buildings, industrial areas), which can be detected from aerial photographs. Detection of these areas and the subsequent application of statistical data are suitable for dasymetric visualization of urban area types and population density in the study area as well.

STUDY AREA

Method of dasymetric mapping based on the aerial photos was applied on the set of photos of Olomouc city. Olomouc is a city in the east of the Czech Republic, located on the Morava River. It is the administrative centre of the Olomouc and with its 102,000 residents it is the sixth largest city in the Czech Republic. In its urban zone there is a population about 480,000 people.

The city was officially founded in the mid-thirteenth century and became one of the most important trade and power centres in the region. Olomouc was fortified by Maria Theresa during the wars with Frederick the Great, and this fact significantly influenced the development of the city in terms of spatial expansion. Its inner part is the second-largest historical monuments preserve in the country [2].

Department of Geoinformatics has aerial images of Olomouc region from the Military Geographic and Hydrometeorologic Office in Dobruška. All these images are from the period 1927 to 2006, in the TIFF format.

Statistical data

Statistical data about population in Olomouc were obtained from the Czech Statistical Office (CSO), additional data were obtained from the Department of Computer Science of Municipality of Olomouc and some information and additional data were obtained from VDB (public database) and publications of Czech Statistical Office, such as Historical Lexicon of Municipalities [3].

For aerial photos with missing link to the statistical data (aerial photograph was made in the year to which population data are not available), the necessary data were obtained by using statistical calculations between the years in which data were known. This imputation was created on the basis of population development over the years. Due to the fact that main aim of the work is to estimate population density, this method was chosen as the most suitable. Availability of data is listed in Table 1. Complementary data of urban area are from previous work realized at the Department of Geoinformatics [4].

Table 1. Availability of statistical data related to the aerial images

Year Aerial photo	**Year Population data**	**Year Urban area type**
1927	1930	1927
1953	1950	1953
1971	1970	1971
1978	1980	1978
1985	1985	1985
1991	1991	1991
1994	1994	1994
2001	2001	2001
2003	2003	2003
2006	2006	2006

Methods of dasymetric mapping

The implemented dasymetric mapping method utilizes aerial images as input and complementary data to define different types of urban areas. In the combination with population data (statistical data from Czech Statistical Office and Municipality of Olomouc) are these data redistributed to a set of urban area zones formed from the intersection of the urban area types and aerial photos.

There were tested many methods how to classify the urban area types from the aerial photos. The most suitable method is to classify areas manually with regard to supplementary data of urban area types.

METHODOLOGY

The basis for the creation of aerial photo-mosaic was the underlying set of georeferenced images. Aerial photo-mosaics for individual years were compiled in the ERDAS IMAGINE program environment, preparation was carried out in the MosaicPro, which is located in the Data Preparation, within the tool Mosaic Images. Number of individual frames was different for each year, for example year 1971 was recorded on 27 aerial images, year 1978 was recorded on 37 images and year 2003 was recorded on 18 images. Aerial images for the first two years were available only in shades of grey; next aerial photos were processed as colour images.

After considering the possibility of applying the chosen methodology there was determined following procedure: the whole area was covered with square cells and the values of urban area types were obtained by the evaluation of the underlying aerial images. As a suitable dimension of the square grid was set 100 m size, which is sufficiently detailed to the definition of various types of buildings as well as it is suitable for the resulting cartographic visualization. The result grid size is 264 × 217 squares.

The whole process of digitizing of the urban area types was realized in the software ArcGIS Desktop. There were classified five basic types of urban area – *separate housing*, *residential and apartment housing*, *panel housing* (tower blocks), *industrial areas* and *gardening areas*. For the purposes urban maps there were classified also other areas that include military objects and agricultural areas, which are not inhabited.

Digitization (assignment of the building types) was realized with regard to the majority of the type of buildings in the underlying image of the squares. If there were placed objects of type *separate housing* and *panel housing* as well, the square was assigned a value of panel housing, because it is quantitatively more significant. The work was realized regardless of administrative boundaries in its graphic design.

Number of squares of the urban type, together with the number of inhabitants in the administrative area was input data into the calculations. There were using weights (Tab. 2) that allow calculating specific population density in the defined area. These values were then re-entered in the attributes of the square grid.

Weights of individual urban types

To calculate the average value of population density in different types of urban area it was needed to define training sets in combination with statistical data. There were selected locations where occurred always one type of buildings. From the statistical data and polygon development of testing areas, there were counted an average population density for each urban area type.

There were used at least 10 samples of each type of urban area to achieve relevance. To determine the number of population density in each type there was used layer with address points that allow using the number of inhabitants in each house. For each type of urban area there was calculated the average value that was rounded to simplify the calculation. The values were as follows:

Table 2. Urban area types weight

Urban area type	Average of population density	Weight of urban type area
separate housing	160 / km^2	1
residential housing	820 / km^2	5,13
panel housing	2 230 / km^2	13,94
industrial areas	0,13 / km^2	0,0008
gardening areas	0,01 / km^2	0,00006

Cartographic visualization

There were realized two sets of output maps. In the first set of ten maps there is presented the population density (Fig. 1–10), in the second set of maps there are presented urban area types (example on Fig. 11). Both sets were processed in the period from 1927 to 2006 and both are processed by the same extent. It means the city of Olomouc and the surrounding areas. As a topographic base there were used aerial photo-mosaics.

The population density maps for different years were processed in different territorial range, which depended on the size of the underlying aerial photo-mosaics. Largest areas were processed for the years 1971 and 2003. On the contrary, for example, years 1953 or 1985 are shown completely, as their mosaics were far less extensive.

Map symbols for population density presentation were prepared according to the frequency graph of all values created from whole period 1927 to 2006. Intervals were adjusted to the form in which they are visualized on maps. The same range of values and colors of each interval is particularly important for visual comparison [5].

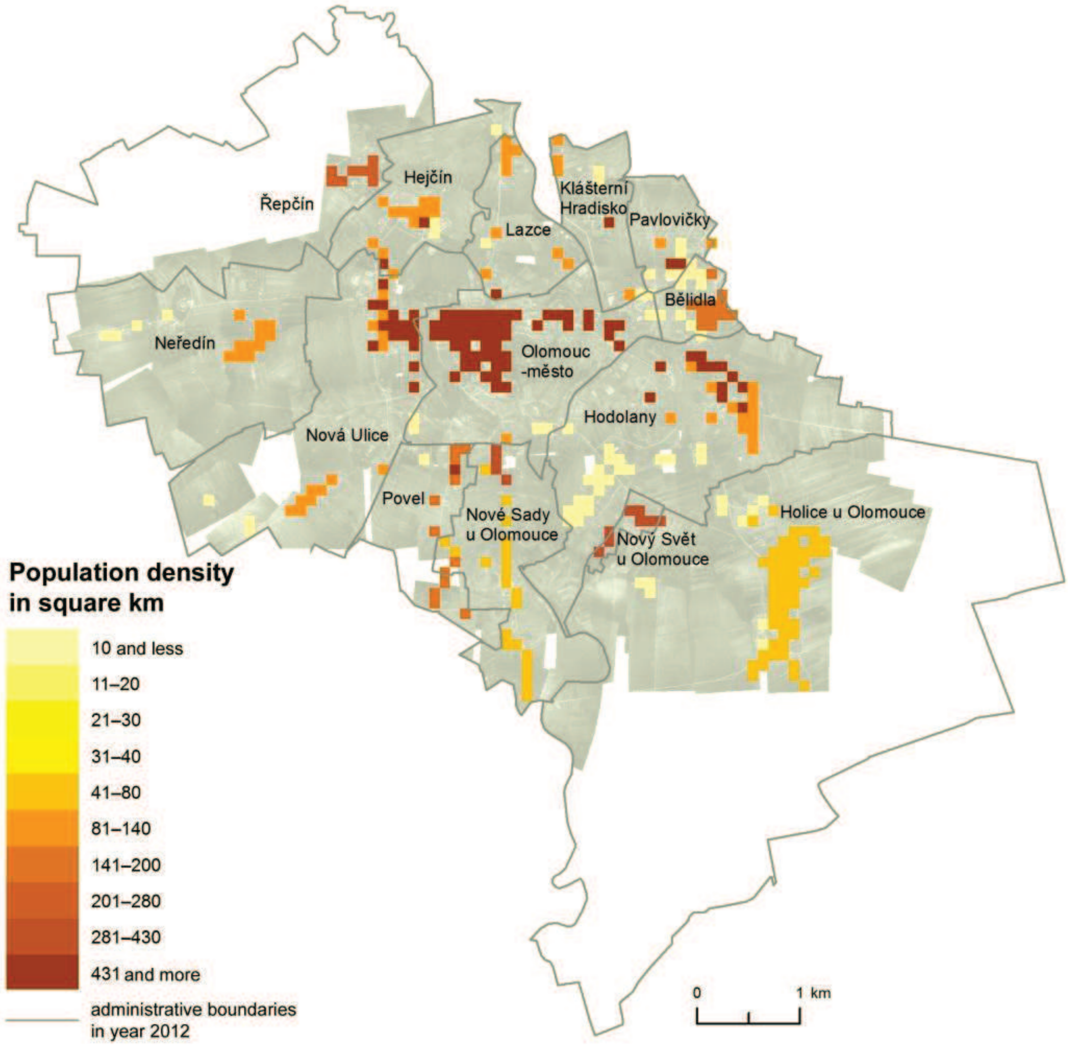

Fig. 1. Population density in Olomouc region in 1927

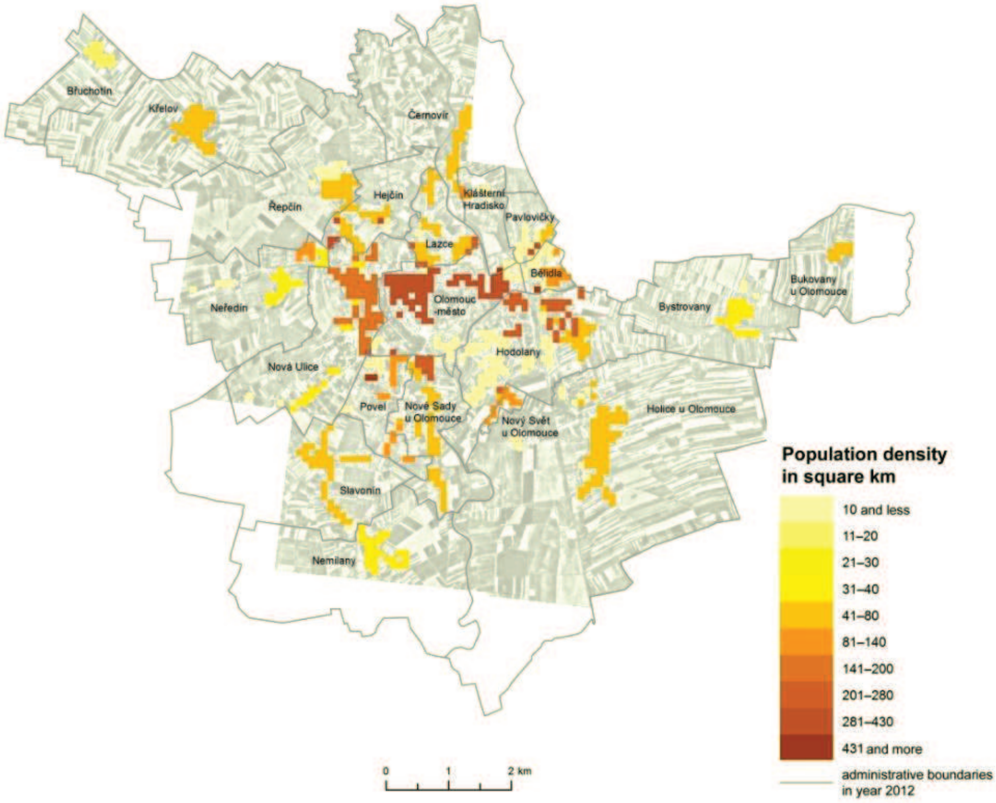

Fig. 2. Population density in Olomouc region in 1953

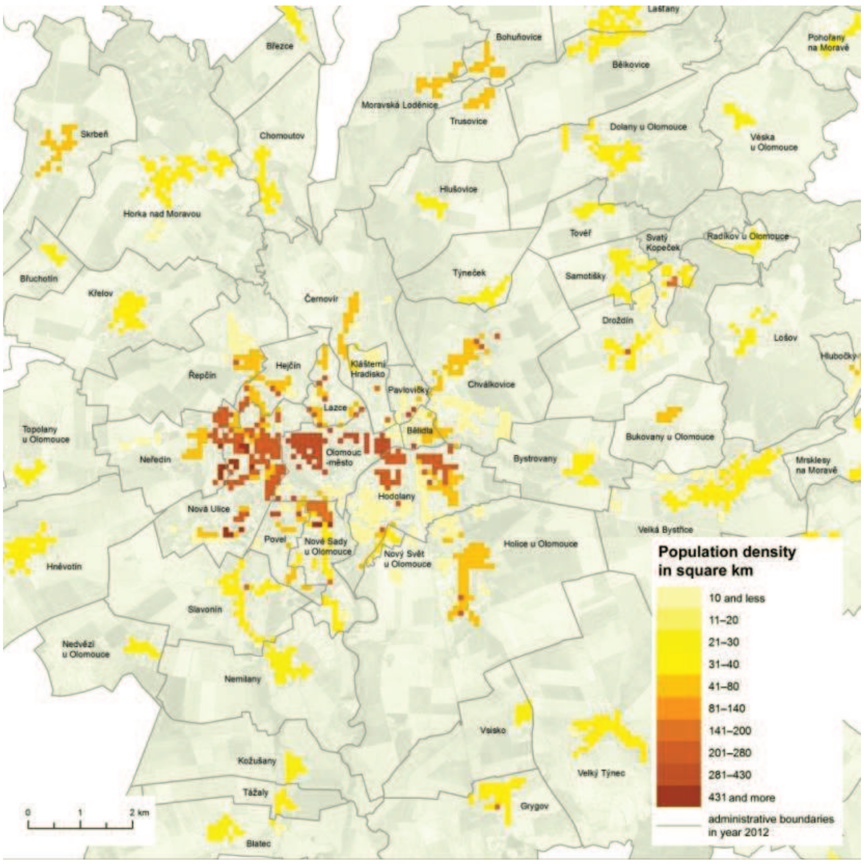

Fig. 3. Population density in Olomouc region in 1971

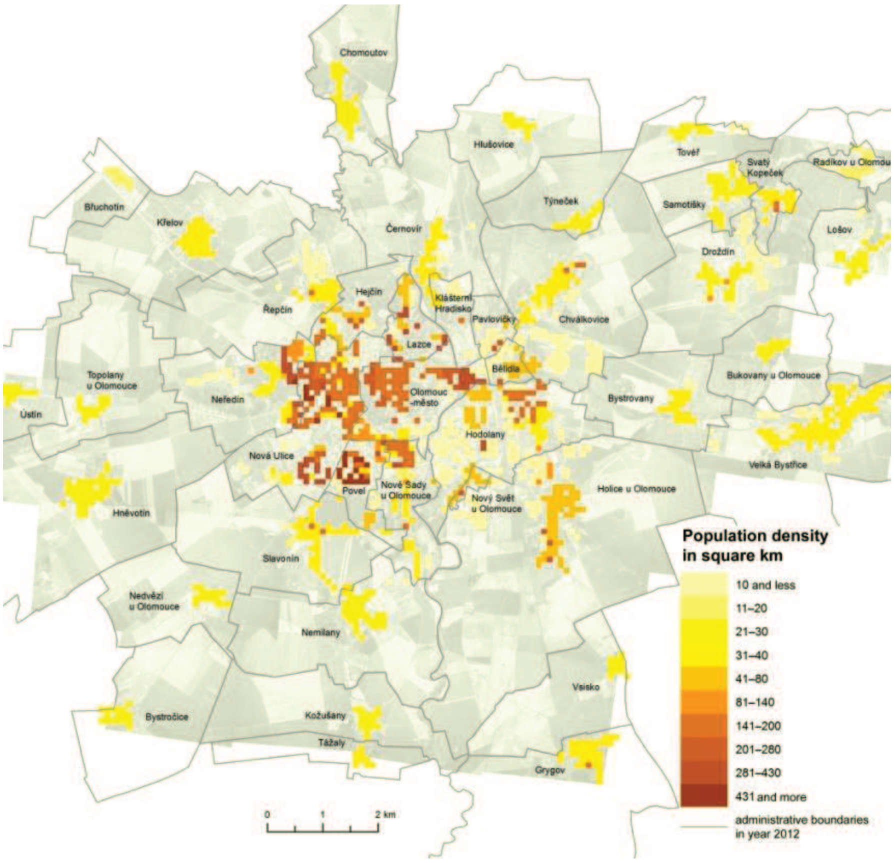

Fig. 4. Population density in Olomouc region in 1978

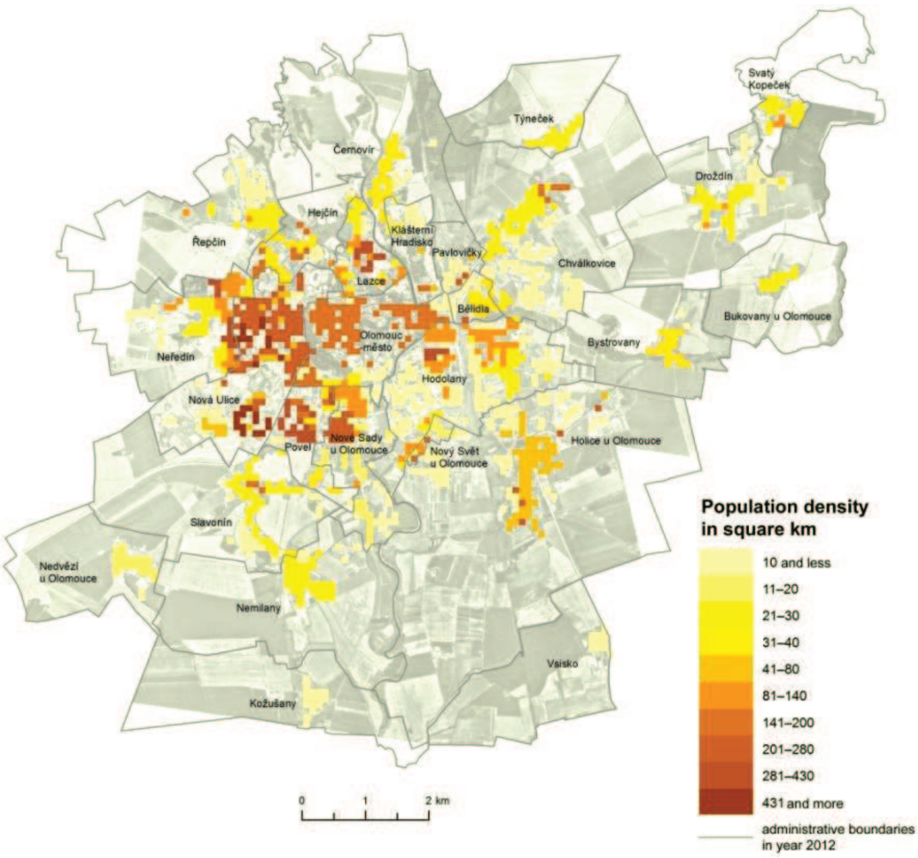

Fig. 5. Population density in Olomouc region in 1985

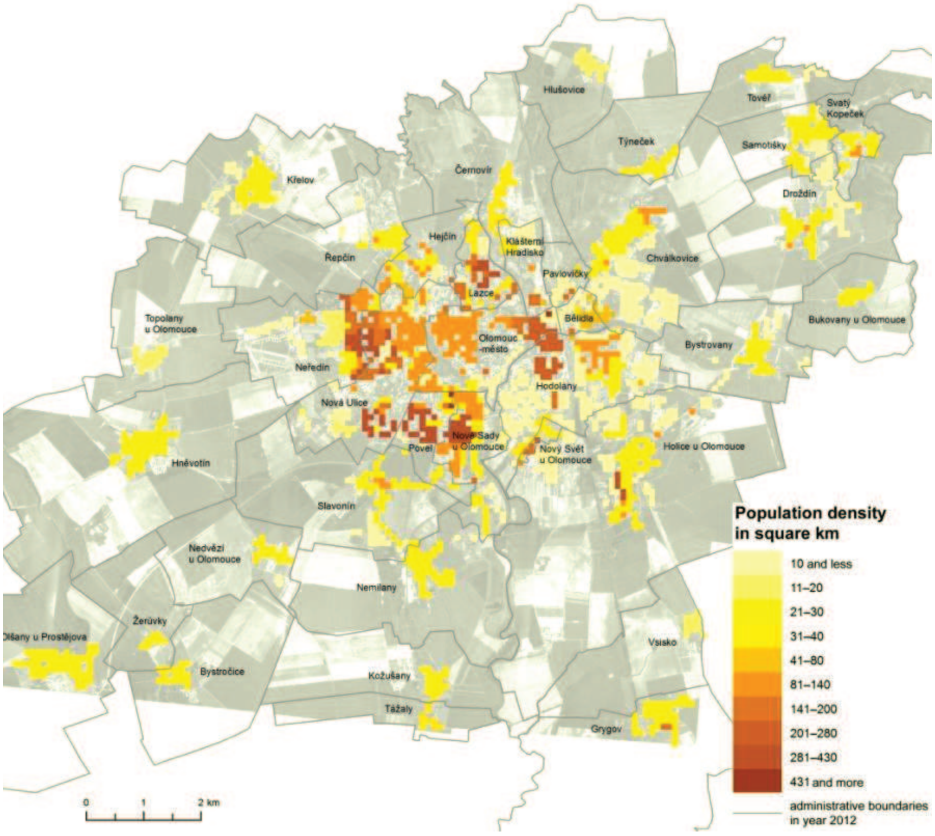

Fig. 6. Population density in Olomouc region in 1991

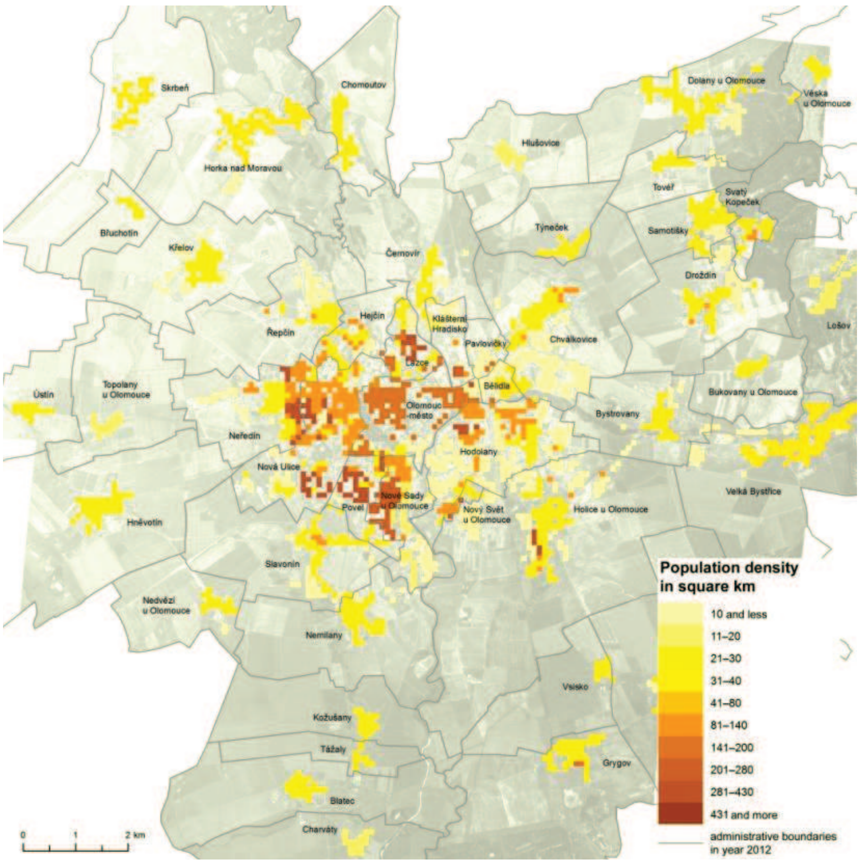

Fig. 7. Population density in Olomouc region in 1994

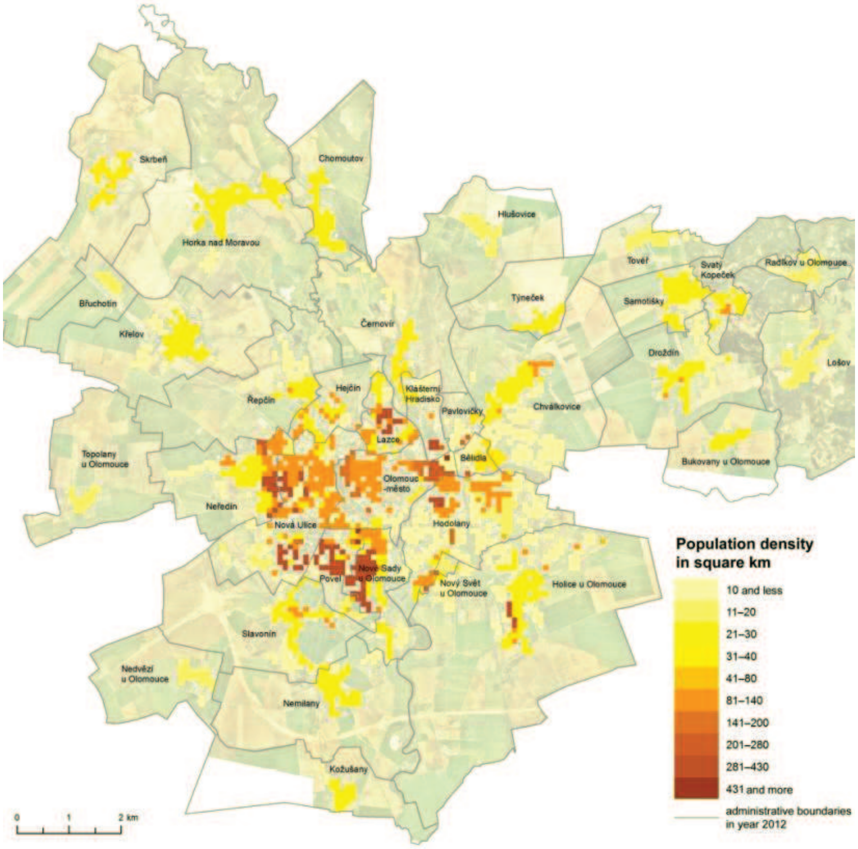

Fig. 8. Population density in Olomouc region in 2001

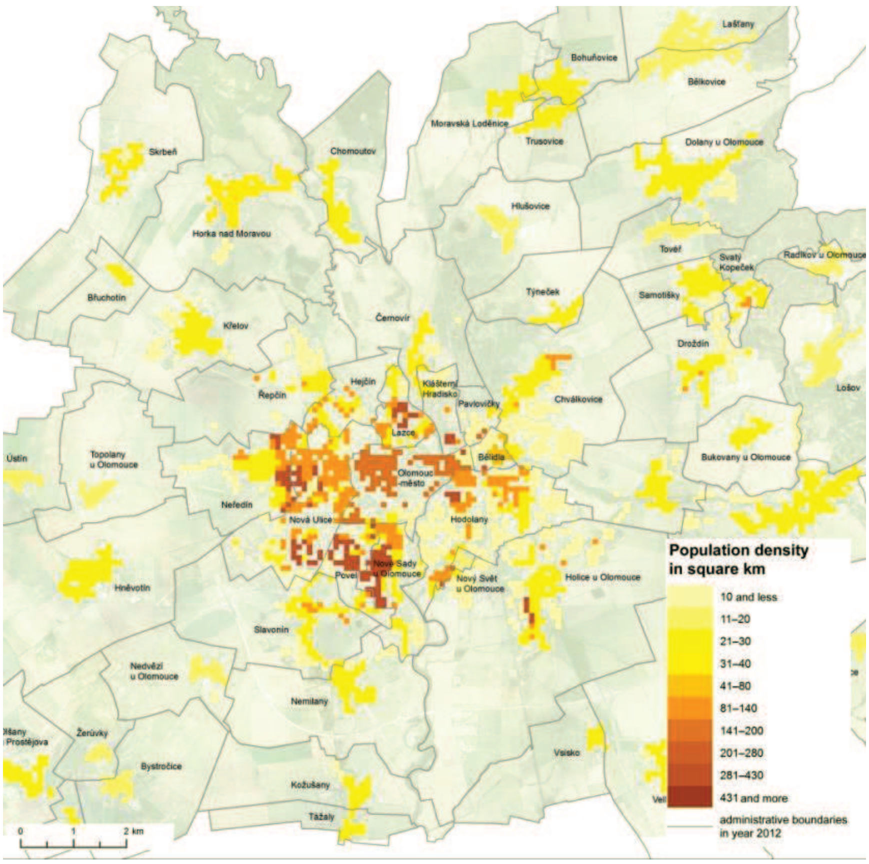

Fig. 9. Population density in Olomouc region in 2003

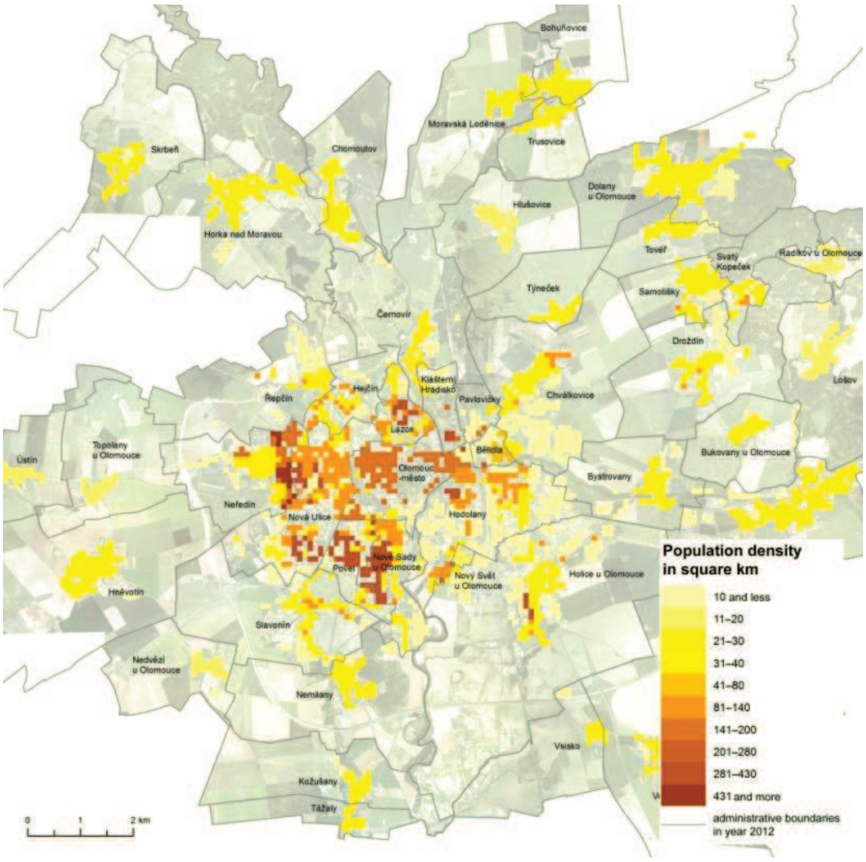

Fig. 10. Population density in Olomouc region in 2006

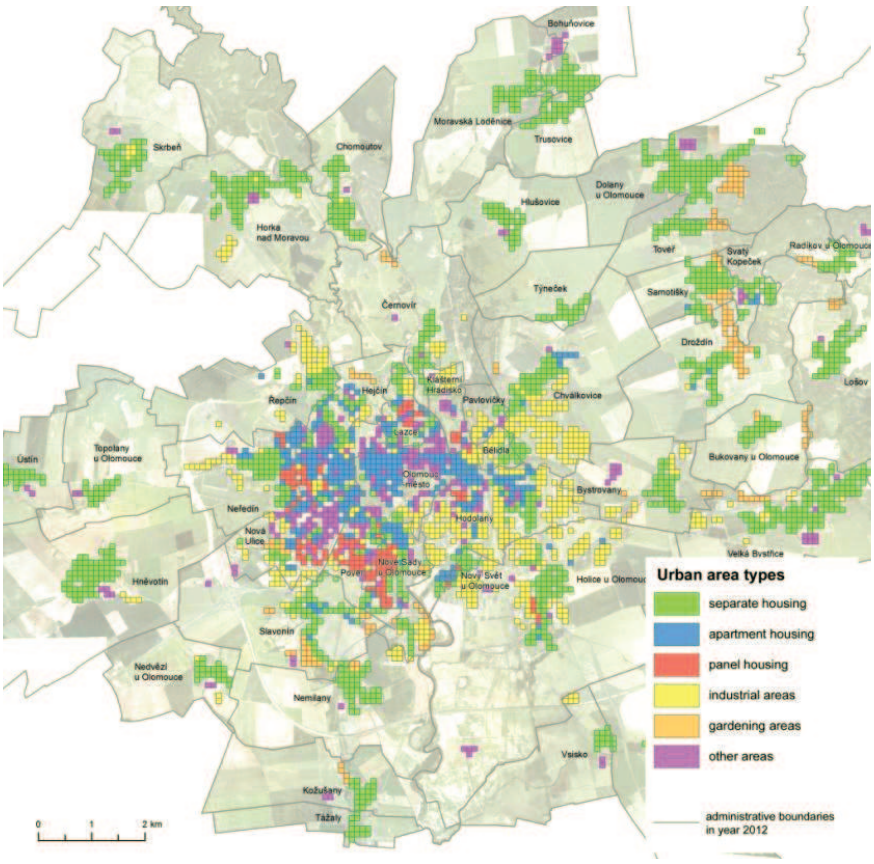

Fig. 11. Example of urban area types classification in 2006

Identification of urban development

In the resulting maps there can be identified certain developments in population density and in distribution of various urban area types in Olomouc. Population density is always related directly to the type of urban area in the locality; it is also not surprising that the lowest population density is in the southwestern part of Olomouc, where industrial sites are situated. The largest population densities are mostly in the residential buildings in the historic center of Olomouc.

At the beginning of the seventies there began the construction of panel houses in urban areas of Neředín, Nová Ulice area and others. On the map of year 1978 there can be seen that, especially in the southern part of Nová Ulice area has grown large panel housing. The industrial development can be identified in the seventies and eighties, mostly in Hodolany area and southern parts of Chválkovice area. In small villages around Olomouc there can be seen slowly growing of separate housing.

On the map of year 1985 there can be seen the emergence of two large panel housing estates. These settlements were gradually expanded to the south and along the housing estate in the Povel area. These locations become one of the most densely populated in the coming years. The increase in industrial development has slowed in the last years and there is not any significant increase in any type of urban areas.

Statistical evaluation

Statistical evaluation (Fig. 12) was performed for the center of the city, because all the necessary data (especially aerial photographs) were available for all processed years. On the graph, there can be identified the increase in size of the area of residential houses and the rise in the area of industrial areas. The low number of panel houses is due to the fact that the most of this area is the historic center of the city. There there can be also identified changes in urban area types (for example industrial areas are converted to residential housing, separate housing areas are converted to industrial areas, etc.).

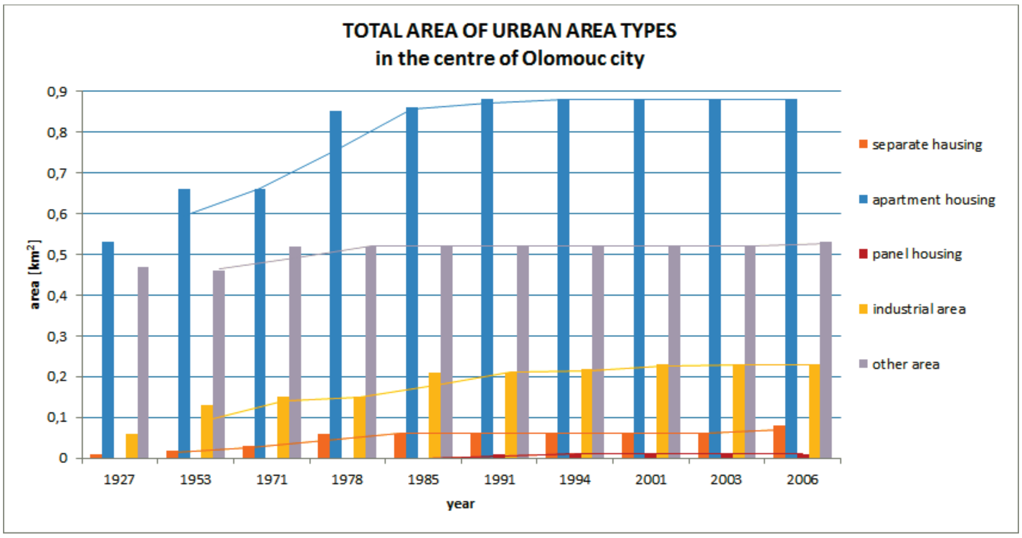

Fig. 12. Statistical evaluation of the urban area types in the city centre with trend lines

CONCLUSION

Method of dasymetric mapping based on the aerial photos was applied on the example of Olomouc city from period 1927 to 2006. The dasymetric mapping is a method of thematic cartography, which uses areal symbols to classify spatial volumetric data and is suitable for the population density visualization because of its ability to realistic spatial visualization. The same approach can also be used to monitor the development of the city in the long time period, applied is classification to different types of urban areas. To monitor such developments can be used aerial photographs in combination with statistical data related to the same time units, in which the aerial images were taken.

The methodology is unique because of the processed methods in a combination with several tools, that are usually used. A good indicator of the city development is besides the city population density also the type of buildings (residential buildings, industrial areas, etc.), which can be detected from aerial photographs. Detection of these areas and the subsequent application of statistical data are suitable for dasymetric visualization of the city development.

There were realized two sets of maps and animations of the outputs. In the first set of maps there is presented the population density, in the second set of maps there are presented urban area types. Both sets were processed in the period from 1927 to 2006.

ACKNOWLEDGMENTS

This contribution was made possible with the support of the Operational Program Education for Competitiveness – European Social Fund, project CZ.1.07/2.3.00/20.0170, CZ.1.07/2.2.00/28.0078 and project CZ.1.07/2.4.00/31.0010 of the Ministry of Education, Youth and Sports of the Czech Republic.

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ISBN 978-80-248-2974-6