IMPROVEMENT OF ZKP – HOMOGENIZATION//membrane method

1. Introduction

A land cadastre display – ZKP is an image of form and mutual position of plots and provides information about the existence of a plot and its environs. Poor positioning accuracy and precision as well as non-homogeneity of the graphical part of the Land Cadastre or land cadastre display has long been considered a serious problem. At the same time, there occur doubts on the applicability of the land cadastre display as the fundamental basis for other records of the area. Due to the issues described above, the Surveying and Mapping Authority of the Republic of Slovenia decided to improve the positioning accuracy of the land cadastre display (the graphical part of the Land Cadastre), namely by using the so-called membrane method.

2. Non-homogeneity of the graphical part of the Land Cadastre or land cadastre display

In the Republic of Slovenia, the Land Cadastre is the fundamental spatial record to many other records related to the land and thus its data quality is particularly exposed to scrutiny. With the increasing number of spatial data users, in particular the quality of the graphical part of the Land Cadastre is becoming ever more important. However, in the recent decades its quality has not follow quick dynamics of changes and development of the environment.

The reasons for poor positioning accuracy and precision as well as the non-homogeneity of the land cadastre display is dealt with separately for:

- **The period prior to the digitalisation of cadastral plans**
  Its origins in Slovenia dates back to the second half of the 18th century. First measurements were conducted without observing the rules of geodetic measurements, i.e. with no determination of a Geodetic datum and no use of projections.

  In 1927, a new coordinate system with the Gauss-Krüger projections was introduced to Yugoslavia representing a mathematical basis of numerical measurements through trigonometric numerical and control networks. Since then, various numerical methods of geodetic measurements (orthogonal, tachymetric and photogrammetric) were used to maintain the Land Cadastre.

  Between 1945 and 1991, several new cadastral measurements of the urban areas were carried out and the land consolidation was conducted. The Land Cadastre in the nationalised areas was very poorly maintained in that period. After the Second World War, the Military Geographic Institute carried out the renovation works and measurements of the triangulation network. In 1948, the first order network for the entire territory of Slovenia was calculated and thus a coordinate system named D48 ("Datum48") (Delčev, 2014) was established.

  In the areas where no new cadastral measurements have been carried out, the cadastral plans of graphic measurements are the basis of the land cadastre display of today. The positioning accuracy of the land cadastre display in these areas is thus conditioned by the quality of analogue plans.

- **The period after the digitalisation of cadastral plans**
  In 1991, Slovenia became independent and the Land Cadastre underwent some changes. The digitalisation of the cadastral plans started to be conducted rapidly resulting in a continuous vector layer within the cadastral communities that was approximately transformed to the then D48/GK national coordinate system. Some major errors were eliminated, such as the land plots without the land plot numbers, overlaying of polygon borders of land plots, several discrepancies at the borders of cadastral municipalities, while at the same new, mostly topological errors occurred (overlaying of land plots, gaps between land plots, etc.) also within the cadastral communities.

- **Maintenance of the graphical part of the Land Cadastre (cadastral plans)**
  The method of maintaining the graphical part of the Land Cadastre, in particular the paper method, has a great impact on the poor positioning accuracy and precision as well as the non-homogeneity. The maintenance of the graphical part of the Land Cadastre today:
  - **86% *the paper method;***
  - **11% *the coordinate method;***
  - **3% *the combination of both methods*** (Areas of the coordinate cadastre are maintained through the paper method and the coordinate method.

Due to the need to renew the graphical part of the Land Cadastre and the indicated requirement of establishing the multi-purpose cadastre, the Surveying and Mapping Authority of the Republic of Slovenia began to establish the Central base of real estate. A part of the Central base of real estate will also be an improved graphical part of the Land Cadastre. The improvement of the positioning accuracy of the graphical part of the Land Cadastre will be carried out by using the ***membrane method***. For this purpose the Systra software package is used (technet GmbH). The applicability of the membrane method was tested and analysed in the area of the Črešnjice cadastral community. In March 2016, the Surveying and Mapping Authority of the Republic of Slovenia founded a project group to conduct the second test in the area of the Municipality of Novo Mesto, which includes **31** cadastral community, prepare a methodology to improve the graphical part of the Land Cadastre and coordinate and control the implementation of the improvement.

3. Homogenization/membrane method

A graphical part of the Land Cadastre represents an elastic membrane. Points identified and measured in nature are represented by pins on which this elastic membrane is fitted in order to be extended or contracted under the introduced local conditions (perpendicularity, linearity and parallelism) and thus adjusted to the actual situation in nature.

By using the membrane method transformation and improvement are carried out iteratively in several steps.

1. ***step: Transformation of the graphical part of the Land Cadastre from D48/GK in D96/TM***
   As a model of transformation, the Triangle-based piecewise affine transformation was selected to be implemented separately from the adjustment and homogenization. The procedure of such transformation is tested and automated, and there is no need for on-site measurements. The transformation is continuous and reversible. The positioning accuracy is not improved by the transformation, major errors remain and there is also no information on the data quality after the transformation. The above-mentioned deficiencies will be eliminated iteratively through adjustment and homogenization.

Deviations caused by the Triangle-based piecewise affine transformation:

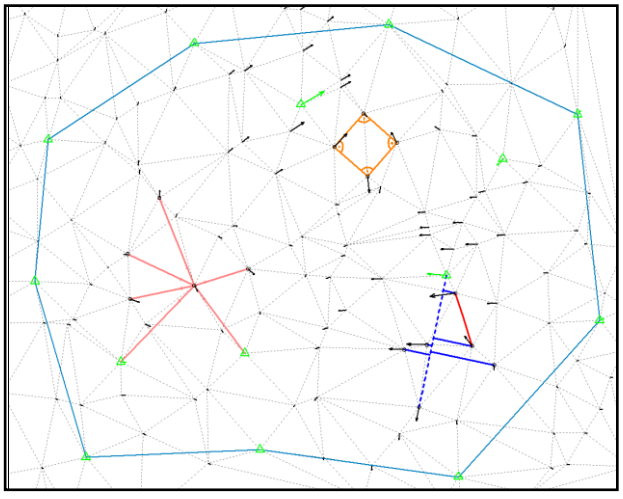
- maximum surface deviation is 0.0085%
- maximum length deviation is 0.0065% (65 ppm)
- maximum angle deviation is 15.0'' (not causing non-perpendicularity of buildings)

However, it is a question of sequence, namely whether to carry out the transformation in the new coordinate system (D96/TM) first and than perform the improvement in the new coordinate system, or to carry out the improvement in the old coordinate system (D48/GK) first and then transform the already improved cadastre in the new coordinate system. Currently, there is no answer to this question, since an uninterrupted and regular maintenance of the Land Cadastre should be provided during the period of improvement.

2. ***step: Calculation of approximate values of coordinates, the first step of adjustment – adjustment of transformation and detection of major errors***
   As a first step the approximate values of the unknown coordinates are determined (all break points of the plot borders) that serve as default values in the next step of adjustment. Detection and elimination of major errors are executed in several iterations (Data Snooping). In this regard the standardised correction – NV is calculated providing the relation between the standard deviation of observation and standard deviation of the observation correction or revealing whether the observation is highly erroneous (NV<2.5 – no major errors; 2.5<NV>4.0 – possible presence of major errors, and NV>4.0 – high probability of the presence of major errors). All observations marked as highly erroneous are eliminated from further processing.

3. ***step: Inclusion of GNSS observations and the data of previous measurements (detailed reports)***
   By including GNSS observations that in addition to the existing land register points and ''points of the geodetic network'' represent linking points and by including the data of previous measurements (detailed reports) and additional onstraints of perpendicularity (objects), linearity and parallelism (roads, watercourses, etc.), the geometric of topological restrictions are defined. To put is simply, the additional restrictions of the extension of membrane are determined.

4. ***step: Adjustment with homogenization (membrane method) of the TIN model***
   A graphical part of the Land Cadastre represents the membrane. The corrections of the linking points coordinates cause deformation of the membrane by taking into account the correlation. The result is determined coordinates of all points in the observed area.

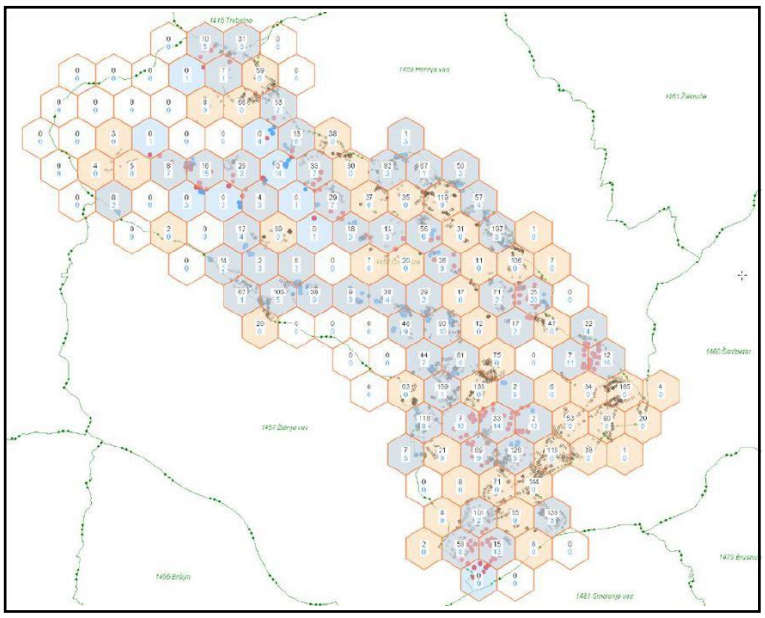


4. Improvement of the graphical part of the Land Cadastre in the Črešnjice cadastral community

The Surveying and Mapping Authority of the Republic of Slovenia in cooperation with the Land Survey Institute and the Faculty of Civil and Geodetic Engineering tested and analysed the applicability of the proposed transformation model and the improvements of the graphical part of the Land Cadastre by using the membrane method. The Črešnjice cadastral community was selected as a test area. The improvement took place in the second half of 2015.

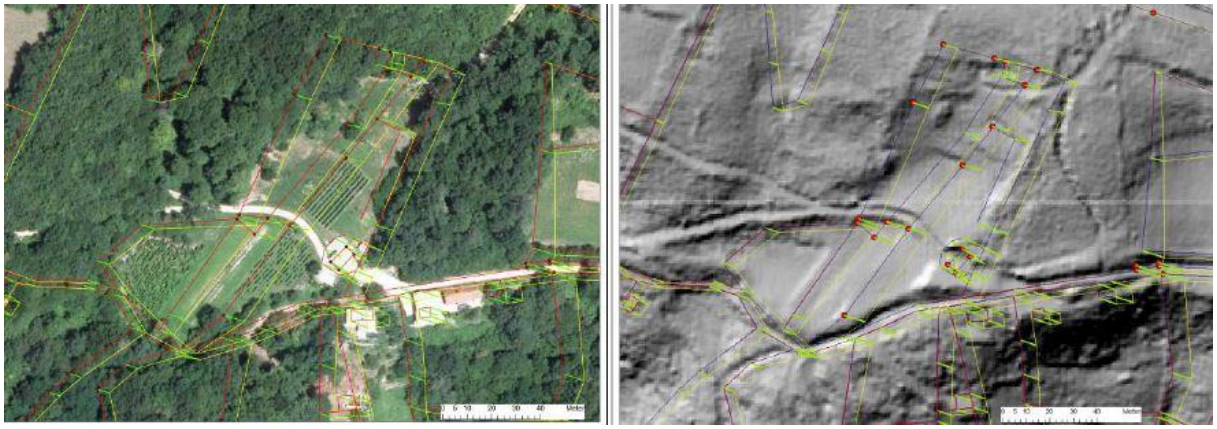
The course of the project of improvement

- In the first phase of the project, the preparation of data was carried out comprising the analysis of the existing land cadastre and ''geodetic'' points and the calculation of the previous measurements (139 detailed reports).
- In the continuation, the entire cadastral community was overlaid with a uniform grid of hexagons (hexagonal comb) with the purpose to identify the areas without linking points. Additional 368 linking points were determined in the area without linking points by the on-site measurement.



- After the finished preparation, the processing of the input data started:
  - transformation into the new coordinate system (D96/TM);
  - calculation of approximate values of the positions of points (all breaking points of plot boundaries);
  - adjustment of the transformation and detection and elimination of major errors;
  - homogenization with the membrane method.

- The result of the improvement (after homogenization) are adjusted positions of the existing land cadastre points and corrected and adjusted positions of all other breaking points of plot boundaries.



Yellow – prior to homogenization
Red – after homogenization

- Finally, control was executed. It included 40 reliably measured points that had not been used as linking points in the adjustment and homogenization. An average deviation between the measured and homogenised coordinates was 1.44 m.

5. Conclusion

The Surveying and Mapping Authority of the Republic of Slovenia made a decision to use the Triangle-based piecewise affine transformation to transform the graphical part of the Land Cadastre from D48/GK/ to D96/TM. In 2014, the control and verification of this model were performed in the area of 10 cadastre communties. To improve the graphical part of the Land Cadastre, the membrane method, which is a part of the Systra software package, will be used. In 2015, the membrane method was tested and analysed in the area of the Črešnjice cadastral community.

In this year, the transformation and improvement of the graphical part of the Land Cadastre is planned to be carried out in the area of the entire Municipality of Novo Mesto, which includes 31 cadastral communities. The main goal is to test and verify the combination of both models in a wider area (Triangle-based piecewise affine transformation will be applied for the transformation, while the membrane method will be used for the improvement).

Transformation and improvement of the Land Cadastre are a major expert challenge. Experts point out that the implementation of such extensive and important task takes time. In addition to the execution of transformation and homogenization, the preparation of data is also an important and lengthy part of the project of improvement which comprises the analysis of the existing land cadastre points and points of geodetic network, calculation of all previous measurements (detailed reports) and their conversion to required formats, and on-site measurements of missing linking points. It will take at least a decade, in order to provide quality of the task performed in the entire area of Slovenia. How much time and how many assets will be reserved for the improvement will be a political decision, for which we hope that it shall be more of an expert quality than economically efficient one.

Challenges for the future:
What should be the method of maintaining the graphical part of the Land Cadastre after the performed improvement?
Currently applicable method of maintenance, paper method and adjustment of the environs, is based on conserving relative geometric relations, i.e. within the measurement, and is probably not the most suitable in terms of the environs. In the future, the method of

maintenance will have to observe relative and absolute geometric relations or the impact of and on the neighbouring points (correlation)!

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