CIVIL ENGINEERING JOURNAL

Article no. 11

THE CIVIL ENGINEERING JOURNAL 2-2024

POSITIONAL ACCURACY OF CADASTRAL MAPS DIGITISED FROM THE STABLE CADASTRE SYSTEM

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ABSTRACT

The accuracy of positional data in cadastral mapping is crucial for various technical activities within the cadastre and related decision-making processes. With digital maps becoming ubiquitous in cadastral operations, assessing the positional accuracy of cadastral maps digitised from stable cadastre systems has become essential. These maps, categorised as DKM and KMD, present different challenges in determining their overall positional accuracy. While DKM maps offer high accuracy, KMD maps, derived from stable cadastre systems, pose challenges due to their varied origins, including potential positional errors inherited from historical data.

This study proposes a methodology for assessing the positional accuracy of KMD maps by comparing digitised boundaries with actual field measurements. The evaluation considers factors such as cadastral area characteristics, available survey data, and the timing of digitisation efforts. The study aims to categorise objects based on their positional accuracy by analysing shifts in boundary points and building positions.

Results from testing in selected cadastral areas reveal varying degrees of accuracy in KMD maps. While some areas demonstrate high accuracy, others exhibit significant positional inaccuracies, particularly in peripheral regions or linear parcels. The study suggests that areas outside built-up areas may require immediate remapping to ensure accuracy.

Overall, the findings highlight the importance of assessing and improving the positional accuracy of cadastral maps to enhance their utility in land management and decision-making processes. Further research could focus on developing automated methods for detecting and correcting positional errors in digital cadastral maps.

KEYWORDS

Cadastral mapping, Positional accuracy, Digital maps, Stable cadastre system, Land parcel, Boundary refinement, Geographic information systems

POSITIONAL ACCURACY OF CADASTRAL MAPS DIGITISED FROM THE STABLE CADASTRE SYSTEM

The quality of the positional data is essential for using the existing cadastral mapping work in all technical activities within the cadastre [1] and in cadastre-related activities where cadastral data are used as support for further decision-making. At present, it is possible to encounter maps in digital form in virtually all cases in the cadastre [2]. These can be divided into maps of high positional accuracy, marked DKM, which have undergone either a new mapping or a redrawing based on the cadastral map in S-JTSK on a previous numerical measurement basis. These maps constitute approximately half of the mapping operation and need not be considered further regarding their positional accuracy. In the second case, these are KMD maps created by reworking from the stable cadastre system [3]. The very principle of creating KMDs makes it impossible to determine the overall positional accuracy of such a map in any simple way. This map is partly made up of detailed points

obtained from previous measurements and partly of vectorisation of the original map data converted into raster form. The origin of the stable cadastral map dates back to the first half of the 19th century so that numerous positional errors may be preserved in these maps. The situation is complicated because each location with a digitised cadastral map may be of varying quality.

Its influence may be the structure and shape of the cadastral area, the amount of available data from previous surveying works or even the scattered or coherent nature of the intravillans in the course of refining transformations of map data. Another quality factor may be the time when the restoration took place, whether at the beginning of the ongoing digitisation or rather towards the end of it when the processor has already gained some experience. The last and most important influence on the quality of the resulting digitised map has always been the processor of the renewal, its diligence and expertise [4].

The stable cadastre system was introduced in all the crown lands of the Habsburg monarchy by the relevant patent as a means of maintaining the land tenure agenda. In most of them, the cadastres of the countries divided after the First World War underwent different developments. However, they retain some common features from the first hundred years of their joint administration.

In Austria, the home country of these cadastral inventories, there have also been efforts in recent years to establish the quality of the cadastral maps, and further steps in the refinement and development of the entire register may follow. There are conferences on this topic, e.g., in Austria, Croatia, Hungary, and Czechia. As can be seen from selected papers, also in Austria [5] or Slovakia [6], attempts to quantify the residual errors of cadastral maps are being made by comparing identical points with reality or attempts to assess the overall quality and usability of the graphical part of the cadastral maps. Polish colleagues [7], among others, attempt to compare the state of cadastres in post-Habsburg countries and show common and different elements of the related cadastral systems.

METHODOLOGY FOR DETERMINING THE POSITIONAL ACCURACY OF A KMD MAP

The positional accuracy of the map can be obtained, for example, by comparing the position of individual breakpoints of land boundaries before mapping with their actual position in the field. As each digitised cadastral map may be of different quality, it was decided to conduct testing in several territories and then evaluate the conclusions considering several factors.

Coordinates determined by mapping have significantly higher accuracy. Therefore, the coordinate differences can be used as true coordinate errors according to the statistical principle. The distance of the identical point in the digitised map (i.e. the image of reality) with its position in the digital map after the mapping, i.e. with its actual position in the field, was chosen as the tested element. In other words, the offset of the position of the refractive point of the parcel shown on the map before mapping with its position in reality shown on the map after the new mapping. This has always been consistently done within each test site for as many points as possible that can be declared identical. Thus, apparently corrected boundaries were not chosen for comparison, where a seemingly straight section of the boundary was drawn with several new breakpoints after mapping and the boundary did not correspond in shape to its course before mapping. Such cases are possible in a new mapping. However, in addition to the new mapping, they can also be dealt with by a procedure where the situation is surveyed and entered in the cadastre using a geometric plan and related deed. As far as buildings are concerned, the methodology is similar, and all buildings that have been rebuilt in any way have been ignored in the assessment of displacement. If a building showed only curvature or displacement in any direction but its perimeter shape was consistent with the condition before the mapping was carried out, such a building was surveyed, all its fracture points were examined, and its displacement monitored. In the case of linear parcels, which may include roads, paths and other communications, as well as watercourses, rivers or streams, the displacement of the line position was measured as a test feature where specific fracture points could not be identified (for instance, see Figure 1).

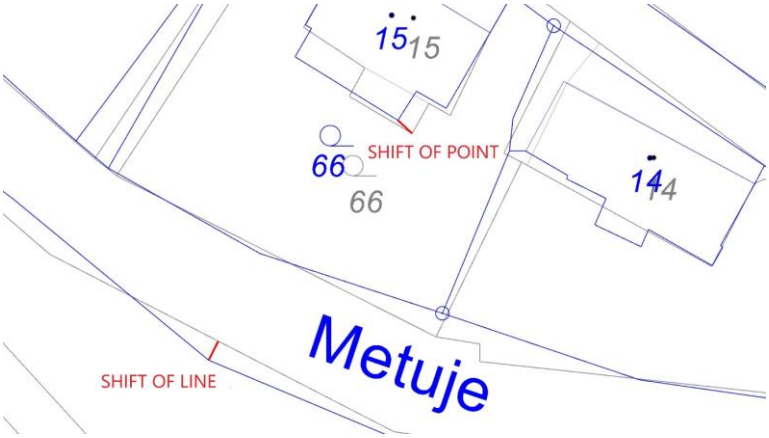

Fig. 1 – Example of a measured displacement of the rebuilt building (No. 15) and the watercourse (the Metuje River):

The individual displacements were then evaluated according to different types of objects, namely:

1. buildings,
2. plots,
3. line plots,
4. detailed points.

Furthermore, three intervals were selected, defining the range where the tracked object was evaluated either as positionally sufficient accuracy or as intended to be refined or corrected. The evaluation was therefore carried out considering the current possibilities of cadastral management and boundary refinement [8]. Only an object was selected as an object of sufficient positional accuracy if the displacement of all refractive points of the object under study lies in the interval zero to 0.28 m, where the boundary limit was chosen as the size given by the coordinate error limit of the detailed point with quality code (QC) 3. Such an object, be it a building, a parcel or a linear parcel, can be evaluated as an object whose position remained unchanged after the new mapping. The object to be refined has been determined by moving at least one refractive point of the surveyed object to the distance given by the refinement parameter for the boundary shown by quality code 8, i.e. to a distance of 2.82 m. All objects with a displacement of at least one of their breakpoints beyond 2.83 m were then identified as objects to be repaired.

Building, parcel and linear parcel objects were divided into intervals according to whether at least one point on their perimeter was already in the "worse" interval of the assessed accuracy. In order to avoid some distortion of the overall accuracy of the study area if most of the displacements on the surveyed object lay in an interval close to zero, and continually one inaccurate breakpoint would significantly worsen the resulting number of surveyed parcel or building objects, a variant of the single detailed point as such was added as a separate category.

To better visualize the displacements and conclude, it was decided to sort the displacement data for the selected object category "detailed point" even more according to their frequency in intervals of 0.40 m, which is close to multiples of the size of the limiting positional error according to the cadastral decree. The results clearly showed the quantity and size of displacements of identical points in individual territories. It is thus evident at a glance which cadastre units show the highest inaccuracies in the originally examined digitised cadastral map.

In addition, in determining the displacement of individual points, the interval of positionally sufficient accuracy has been extended by the category of so-called "technically perfect points" in the interval 0 to 10 cm since 10 cm is the distance from which broken boundaries and protrusions on buildings are displayed on the cadastral map.

The critical value has been set to establish a limit from which shifts of identical points on the map before and after mapping will be regarded as gross errors in position that cannot be refined

even with the consent of the owners. A more apparent numerical limit would be to set a specific integer figure that is easy to represent, such as 3.00 m, which is what the distance of 2.82 tends to be in practice. Similarly, the limit was set by looking for an interval of still recognisable points that did not need to be re-surveyed as part of the new cadastral survey. This is also why a specific interval of 0.00 to 0.10 m was set for monitoring the displacement of technically perfect points, completely unrelated to the values of the quality characteristic codes 3 or 8. Another evaluation interval bounded by a limit value of 0.28 m, identical to the value of the coordinate error limit, is already on the edge of perceiving points as identical. In this situation, it can be argued that identical points beyond this distance should already be redetermined in the detailed measurement of the new mapping. A position error limit of 0.40 m is literally no longer appropriate because a significant number of insulated corners of buildings would fit behind the positionally accurate points.

Priority was given to the survey to reach conclusions on the technical necessity of the new cadastral mapping. For these reasons, in further research, it would be advisable to adjust the intervals completely without reference to the values of mean errors according to the currently valid cadastral decree but rather with regard to the current measurement possibilities. Thus, the intervals should be adjusted with the limit criteria of 0.10 m as technically perfect, 0.25 m as sufficiently accurate and greater than 1 m as inaccurate. In such a case, information on the possibility of the owners' refinement of these boundaries would then drop out.

Tab. 1 - The overall table for the methodology of determining the positional accuracy of the map according to the surveyed objects

Object	Technically perfect	Of sufficient accuracy	Intended for refinement	Intended for repair
Building		0.00–0.28 m	0.29– 2.83 m	more than 2.83 m
Plot		0.00–0.28 m	0.29– 2.83 m	more than 2.83 m
Line plot		0.00–0.28 m	0.29– 2.83 m	more than 2.83 m
Point	0.00–0.09 m	0.10–0.28 m	0.29– 2.83 m	more than 2.83 m

The quality of the digitised cadastral map before mapping was determined by the percentage frequency of individual objects compared to the total number in the mapped area.

This procedure gives a very illustrative overview of the positional accuracy of the digitised cadastral map of the area. It is, of course, possible to arrive at one particular figure, either the average displacement or the maximum displacement of a control point. However, given that the quality factors described above affect each cadastral area separately, this is not essential. The methodology is based on the fact that we are using the map after the new mapping, i.e. after the boundary survey, as a comparison file. We obtain the actual difference in the boundary position agreed by the owners and the boundary registered in the cadastre before the mapping. Thus, it can be expected that, in the case of a sufficiently large number of identical points, we approach a specific and realistic result of estimating the positional accuracy of a particular territory.

Tab. 2 - Analysis of detailed point shifts in individual cadastral areas

Cadastre unit	Renewal by reworking	Renewal by mapping	Description of the territory	Cadastral office
Maršov nad Metují	28.04.2009	16.07.2020	built-up part of the village and part of the extravilan	Náchod
Levín nad Cidlinou	23.11.2009	09.07.2018	built-up part of the village *	Hradec Králové
Bělý	19.04.2010	01.12.2021	built-up part of the village	Náchod
Vinice v Podkrkonoší	14.04.2016	12.10.2021	built-up part of the village *	Jičín
Vlásenice u Makova	18.12.2013	15.12.2021	built-up part of the village *	Tábor
Skoranov	21.12.2009	18.11.2020	built-up part of the village	Chrudim
Sedlatice	27.11.2013	10.11.2023	built-up part of the village *	Jihlava
Divnice	12.01.2009	29.11.2023	built-up part of the village *	Valašské Klobouky

* the area was solved after comprehensive land development

Table 2 lists the cadastral areas selected for testing positional accuracy. The areas were chosen because they were different sites, fell under the jurisdiction of different cadastral authorities, were developed at different times, and at least some area covered the extravillage.

The initial assumption was that KMD-type maps produced during early digitisation might have some inaccuracies, for example, because of the initial experience gained in the production of KMDs through reworking. In the mapped area, including part of the extravillage, it was assumed that the inaccuracies of the KMD map type would be significantly more extensive and more frequent outside the municipality's intravillage due to the insufficient number of identical points for refining transformations in the KMD production.

For testing, freely available cadastral maps [9] in the cadastral exchange format were used on the website https://services.cuzk.cz/. The survey of the positional accuracy of the digitised cadastral maps was carried out only on maps originating from the stable cadastre at a scale of 1:2880.

Tab. 3 - Objects analysed in each location

Cadastre unit	Buildings	Plots	Line plots	Total number of points
Maršov nad Metují	50	90	14	657
Levín nad Cidlinou	41	62		302
Bělý	123	154	7	995
Vinice v Podkrkonoší	42	46		292
Vlásenice u Makova	98	122	11	792
Skoranov	77	113	6	551
Sedlatice	47	60		305
Divnice	265	358		1768
Total objects	743	1005	38	5662

RESULTS

The following graphs show the frequency of shifts of detailed points sorted in intervals of 0.4 m. They may represent a clue indicating significant shifts and large positional inaccuracies of the original map within the particular areas.

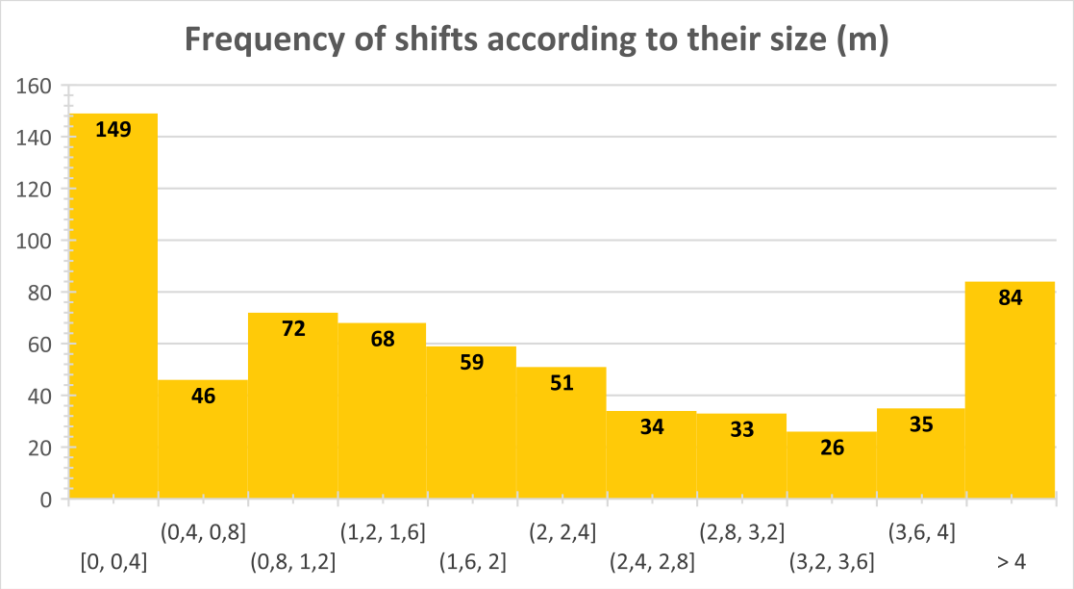

Fig. 2 – Maršov nad Metují (Cadastral Office for Hradec Králové Region)

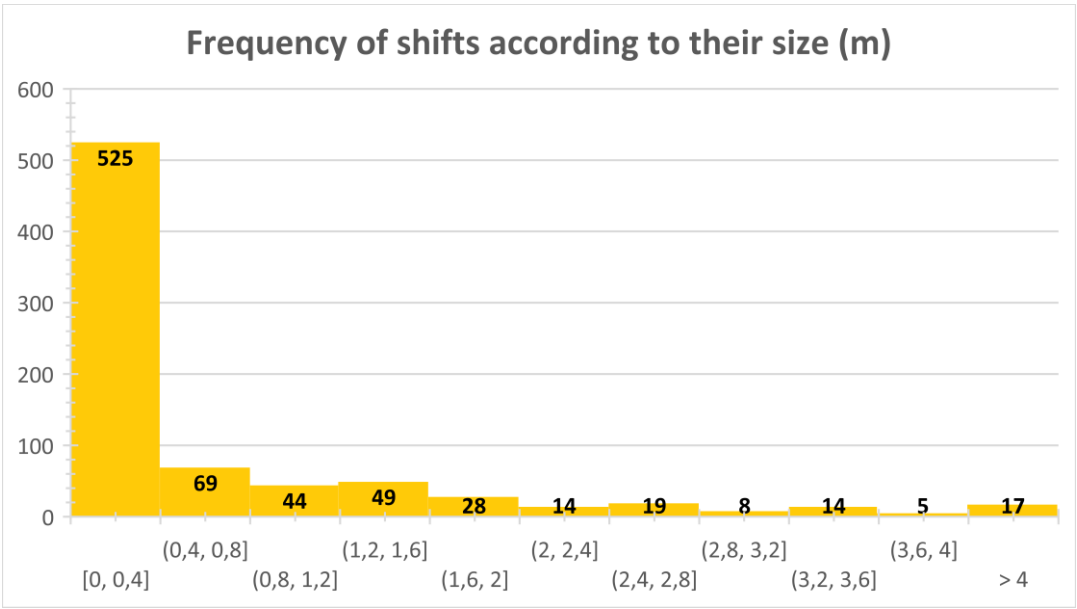

Fig. 3 – Vlásenice u Makova (Cadastral Office for the South Bohemian Region)

The graphs of the frequency of displacements in Figure 3 show that most of the points lie in the first interval up to 0.40 m. In these cases, the positional accuracy of the digitised cadastral map is relatively high.

By testing eight selected areas, many of the KMD-type maps proved to be surprisingly positionally accurate. Most of the detailed points meet the parameters for QC 3 points, and the remaining points could be refined with the owners' consent if they were interested.

Tab. 4 - Summary of the analysis of shifts in the test areas

Cadastre unit	Average shift (m)	Maximum shift (m)	Points of sufficient accuracy (%)	Points to be refined (%)	Points to be corrected (%)
Maršov nad Metují	2.00	11.09	20.4	52.5	27.1
Levín nad Cidlinou	1.12	6.39	27.8	65.2	7.0
Bělý	1.09	7.63	39.0	51.5	9.5
Vinice v Podkrkonoší	0.36	2.63	65.4	34.6	0.0
Vlásenice u Makova	0.65	9.4	62.5	32.1	5.4
Skoranov	0.56	7.45	69.0	26.1	4.9
Sedlatice	0.37	3.29	70.8	28.2	1.0
Divnice	0.52	7.74	61.1	36.2	2.7

At first glance, the grey-shaded cadastre units have an unexpectedly high positional accuracy. Almost two-thirds of the surveyed points show only a slight shift of an identical point, between 0 and 28 cm from its recorded position in the KMD. Even the size of the average shift confirms the unexpectedly high positional accuracy of most of the surveyed areas. The maximum shift's magnitude indicates the gross error that may occur in a given area. The very high maximum displacement at Maršov nad Metují is clearly also due to the mapping of the extravilane and linear parcels. The lower positional accuracy of the areas digitised in the early years is also confirmed. In all the grey-shaded areas, we can speak of relatively good-quality KMD maps. However, some parts of peripheral locations or blocks of parcels may show rough shifts of up to several metres (as in the case of the cadastral area of Skoranov and Vlásenice u Makova).

The best-quality maps (Vinice v Podkrkonoší and Sedlatice) of the surveyed areas show a tiny average shift (0.36 and 0.37 m), a maximum shift ideally within the limiting deviation for boundary refinement, and a high frequency of sufficient-accuracy points (65% and 70% of the total number of surveyed points).

Comparative charts of all cadastre units (c. u.) follows.

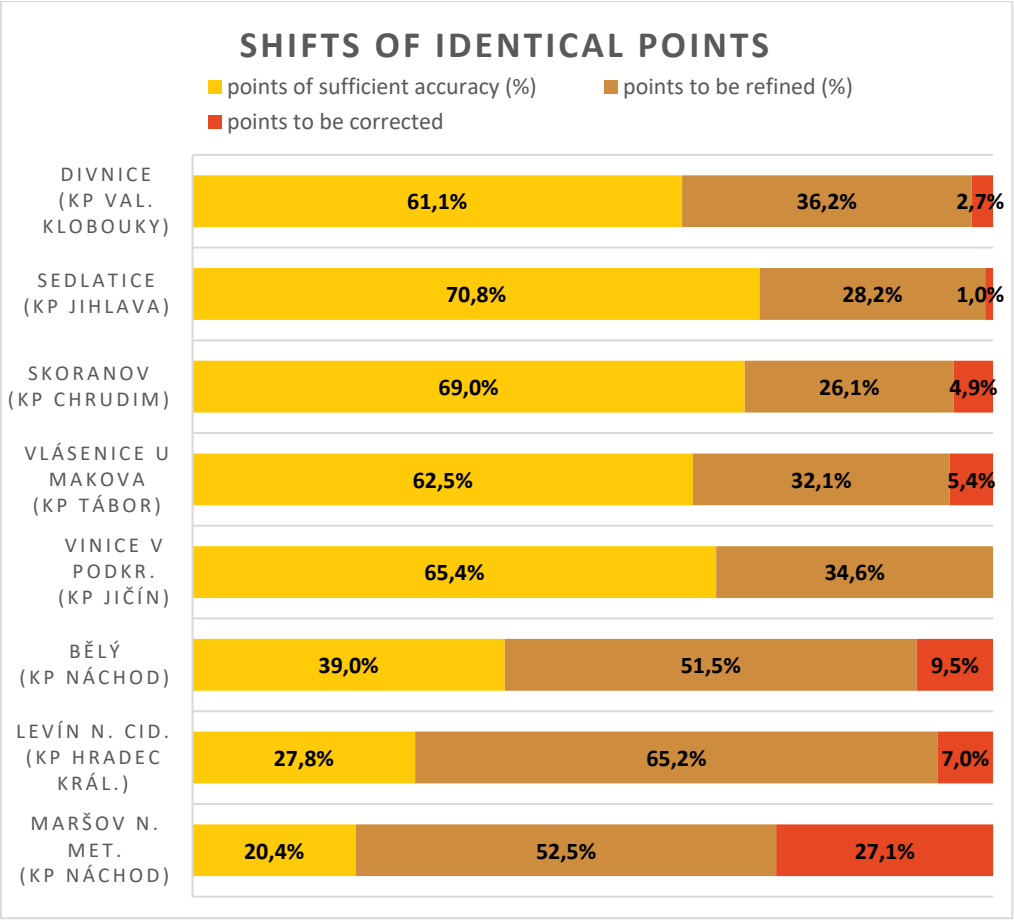

Fig. 4A – Comparative charts of the subject cadastral units

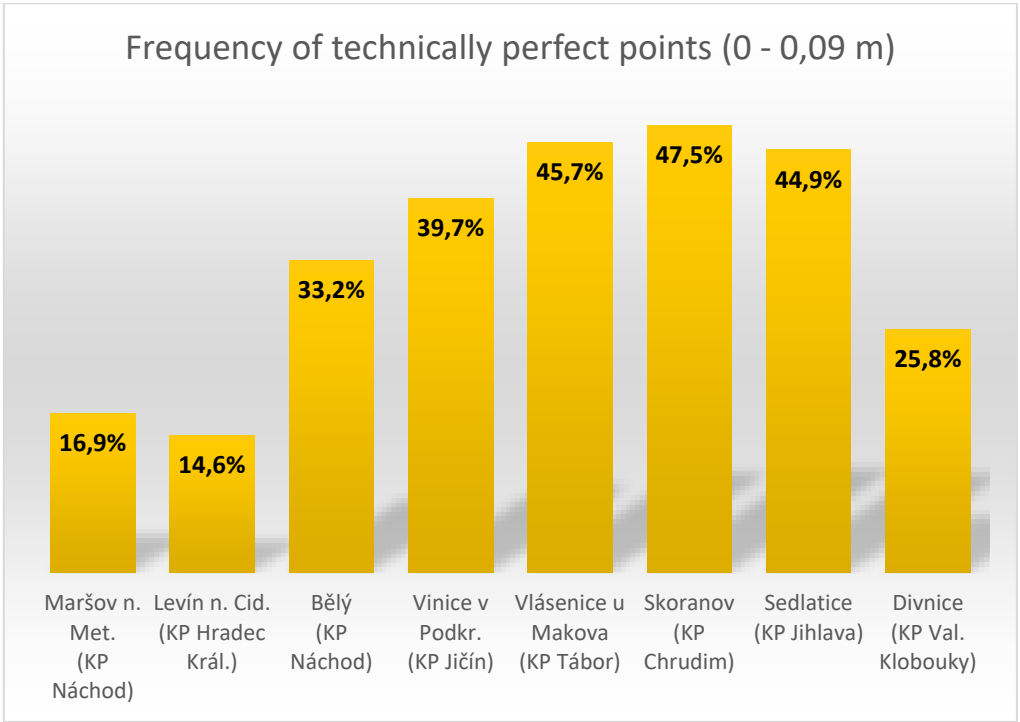

Fig. 4B – Comparative charts of the subject cadastral units

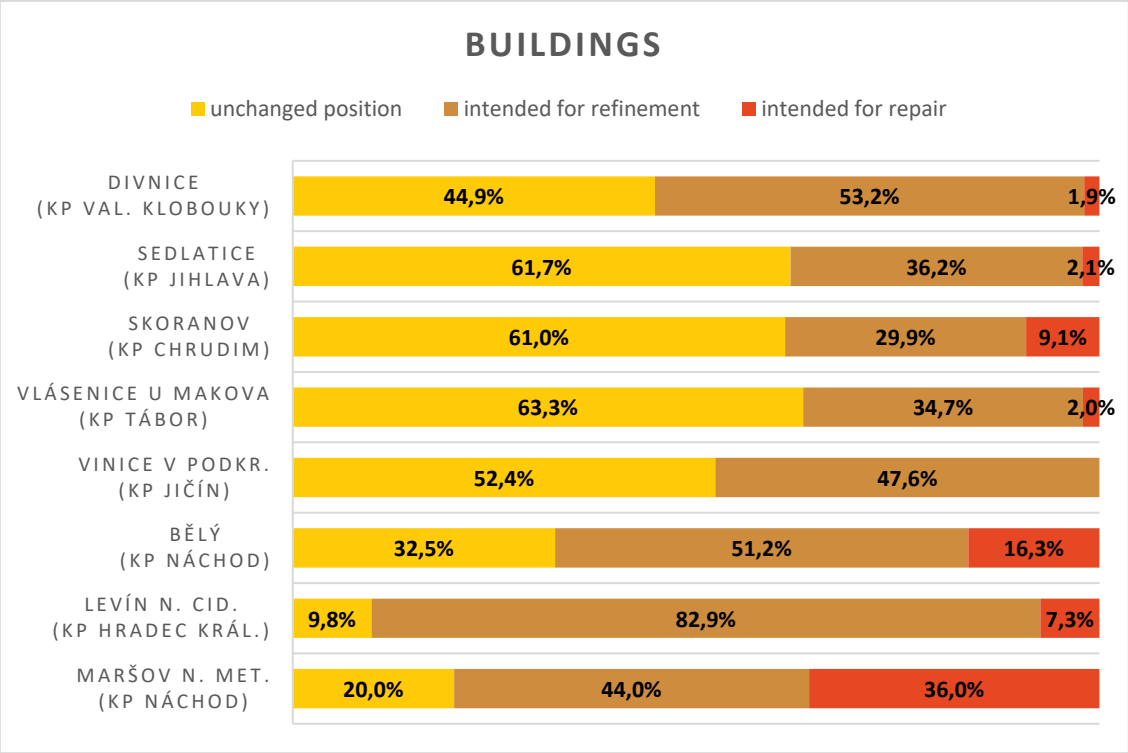

Fig. 4C – Comparative charts of the subject cadastral units

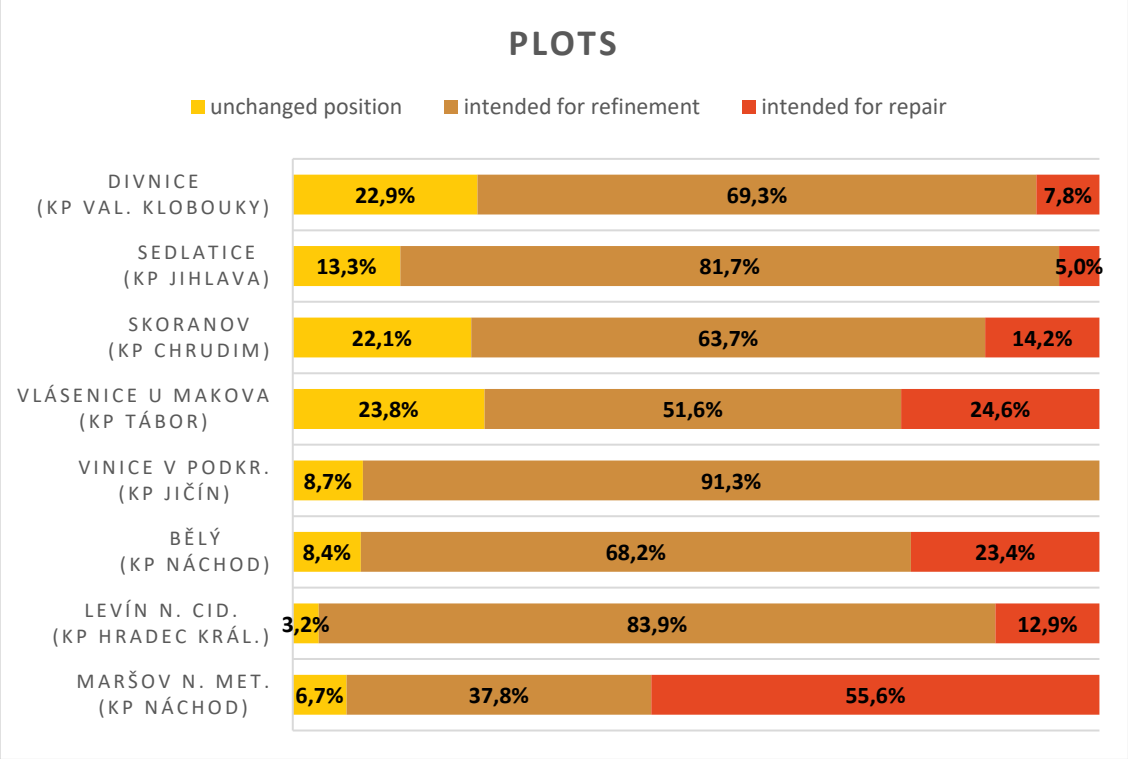

Fig. 4D – Comparative charts of the subject cadastral units

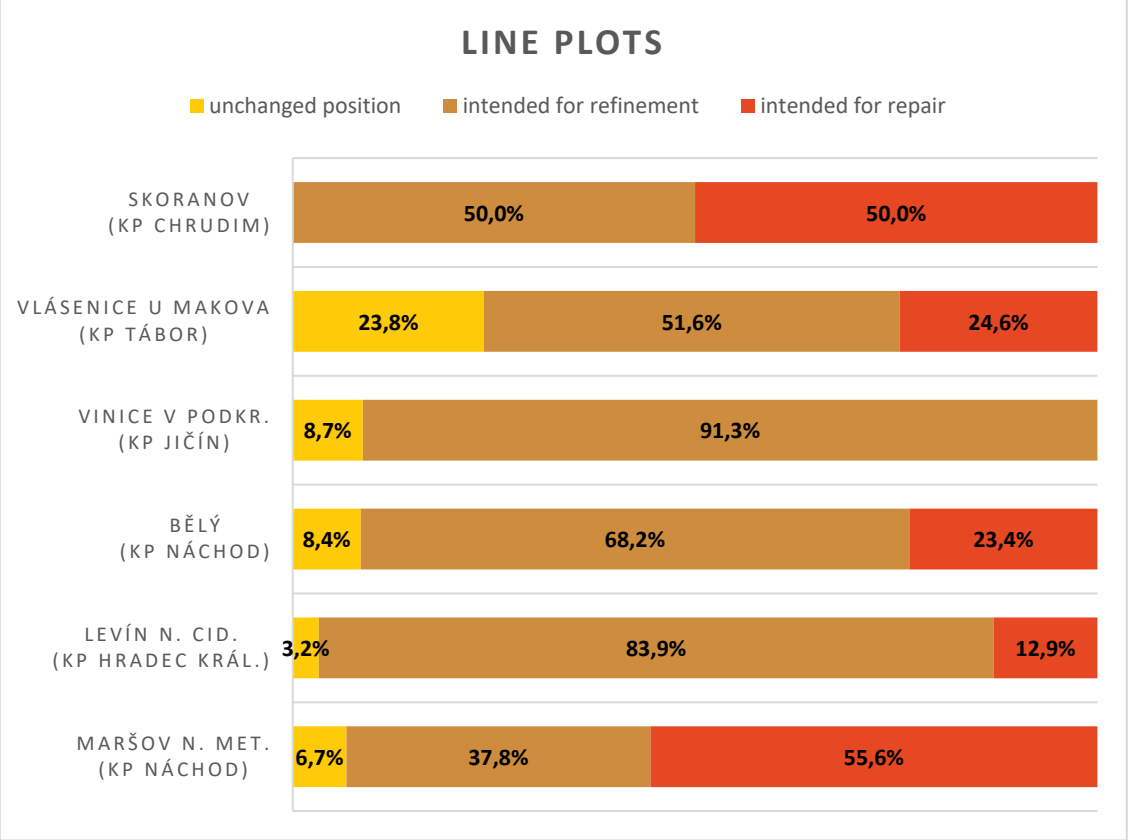

Fig. 4E – Comparative charts of the subject cadastral units

CONCLUSION

Testing of the displacements of detailed points before and after the mapping clearly confirmed that the digitised cadastral maps always show a certain number of detailed points whose displacement from the actual position is significantly greater than the distance that can be considered as a limiting condition for the refinement of the boundary by the owners. In particular, in areas that extend outside the built-up area of the municipality, this may involve up to one-third of the measured points. In such a location, it makes sense to carry out a new mapping as soon as possible. At the same time, however, the testing has surprisingly revealed a significant number of detailed points that, in the existing cadastral maps, meet the parameters for a detailed point with quality code 3 with a mean coordinate error of mxy = 0.14 m. In addition, a relatively large number of detailed points are technically perfect because their image on the map lies within 0 to 10 cm of the actual position. In these cases, we can already speak directly of a coincident point. The only reason for the change in its position in the new mapping is that the connection to the coordinate system is different, or the prism is attached to the fence post differently, etc.

Specific objects in the cadastral map are linear plots on one side and buildings on the other side. In the case of buildings, these are very often oversized buildings, which in the end only cause a shift in the map by insulation. Another widespread case is the exact position of the main building extended by a specific annexed part, and only the last group are twisted or positionally differently shifted buildings. These are always in the minority. Very often, one can also encounter a correctly depicted part of a building clearly visible from the road with one or more corners in the back part towards the yard or garden wrong, which logically could not be oriented when the digitised map was created and was therefore only vectorised using the refined grid of the previous land registration map.

In the case of linear parcels such as roads, paths, streams or rivers, whether they are located in the intravilane or extravilane, the cadastral map produced by the reworking of the stable cadastre is significantly inaccurate.

The following (Figures 5 - 10) are examples of the shift of the position of the objects under study in selected cadastral areas. The original cadastral map created by the reworking (KMD) is in grey, and the new digital cadastral map, after mapping used for accuracy testing, is in blue. Geostore V6 software was used for the analysis.

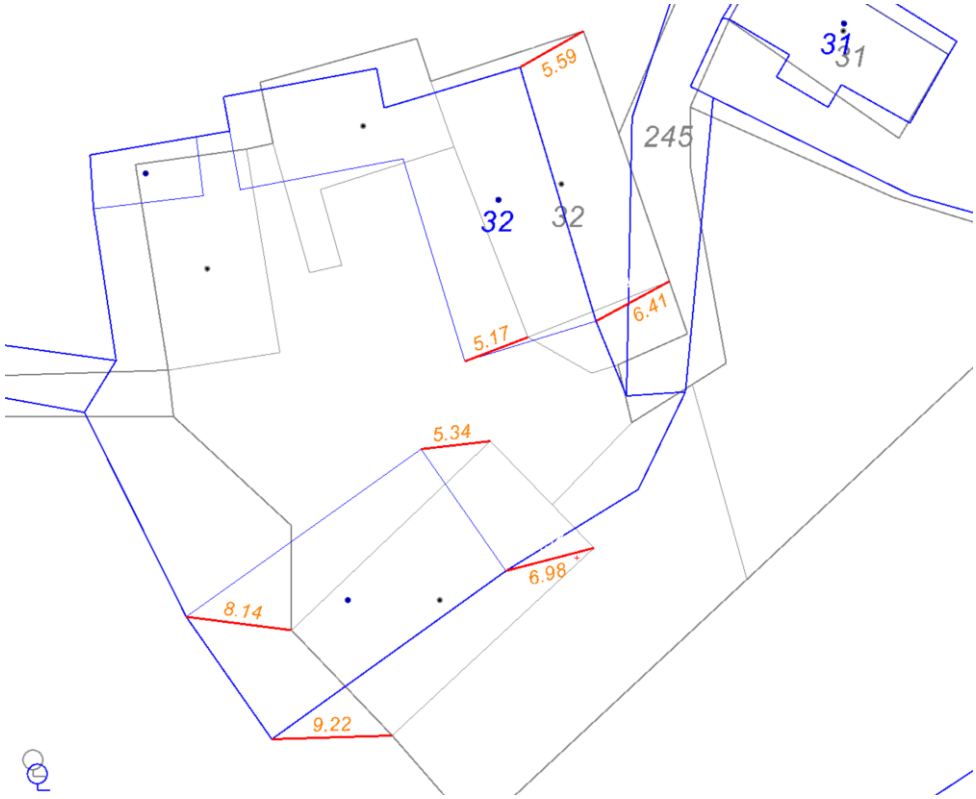

Fig. 5 – c. u. Maršov nad Metují – gross error of curled and displaced homestead in KMD map

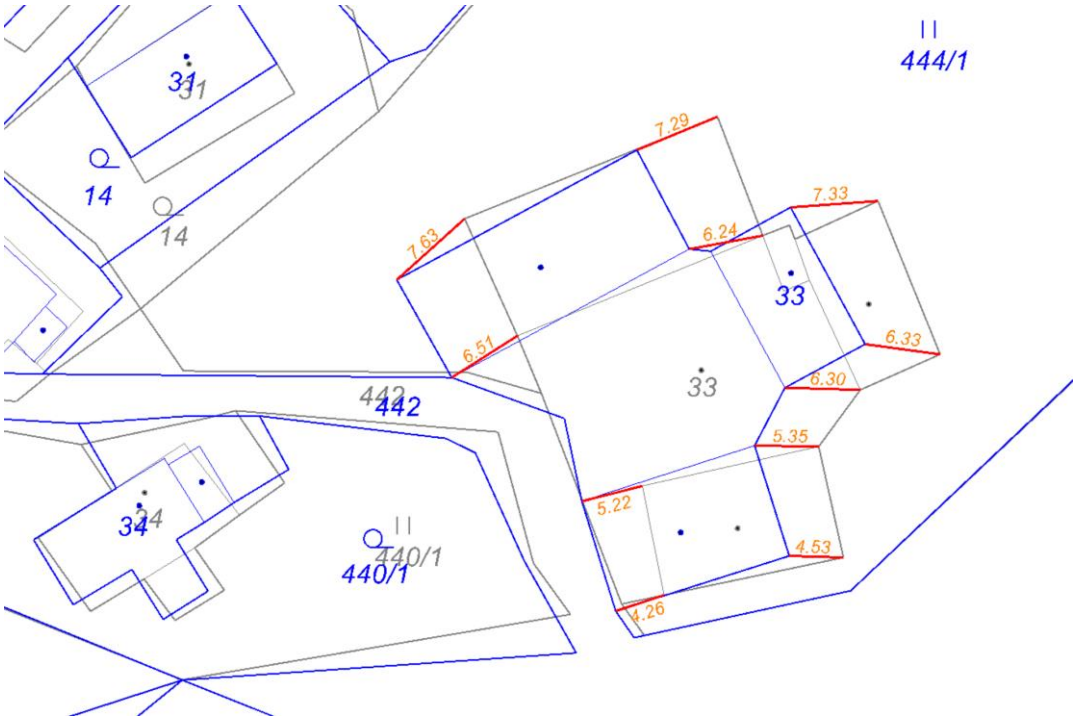

Fig. 6 – c. u. Bělý – an example of a twisted building and a gross error in position (No. 33)

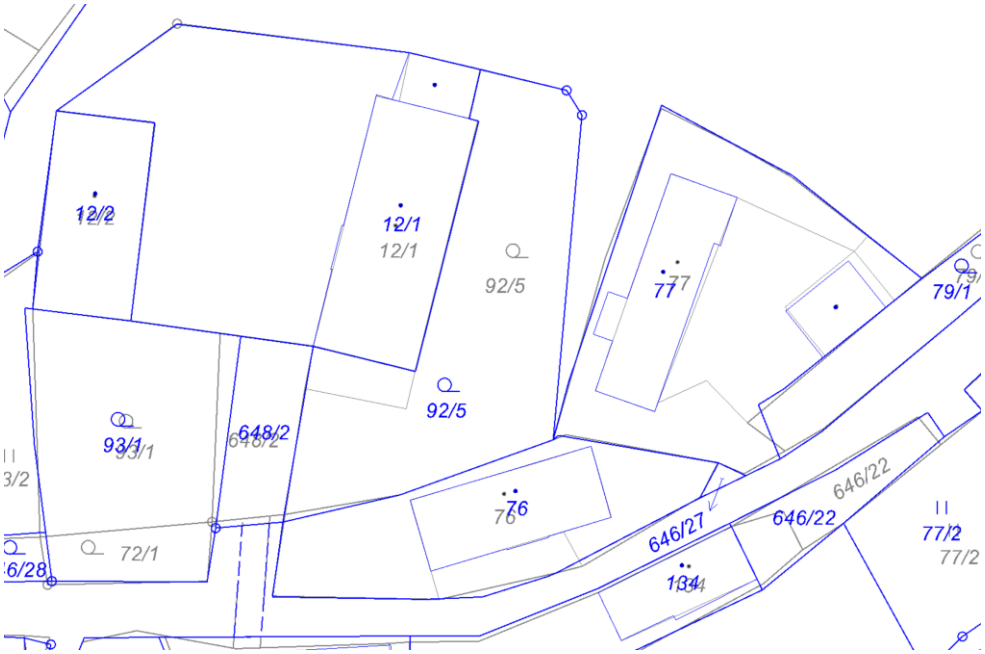

Fig. 7 – c. u. Bělý – positionally accurate sample of KMD map

Fig. 8 – c. u. Vinice v Podkrkonoší – positionally correct property boundaries in KMD

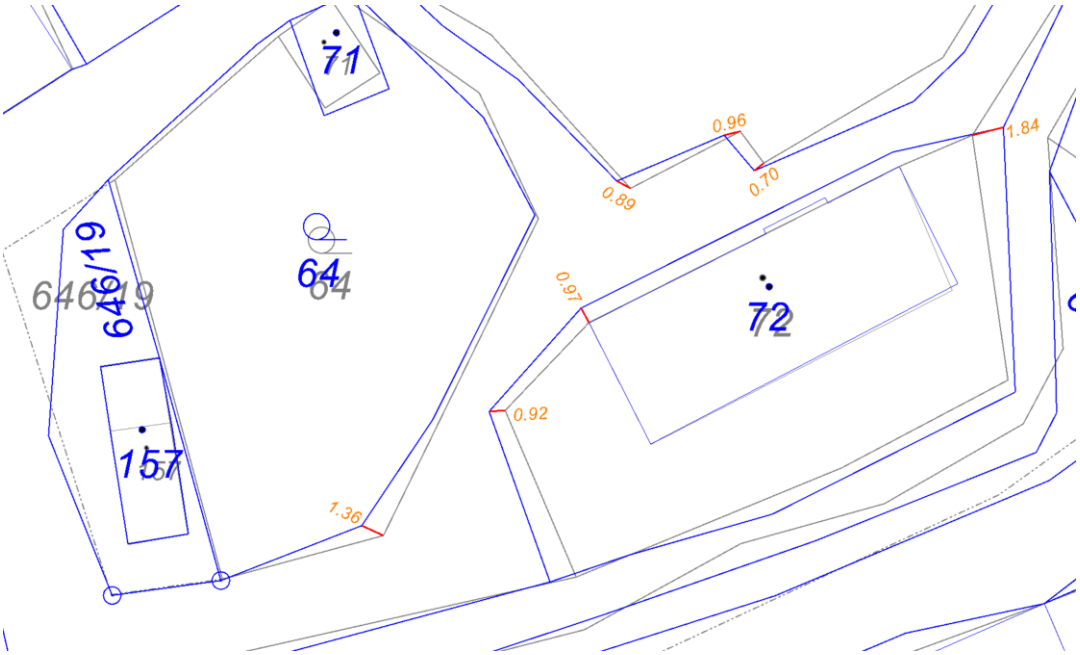

Fig. 9 – c. u. Bělý – boundary shifts within the "refinement" derogation

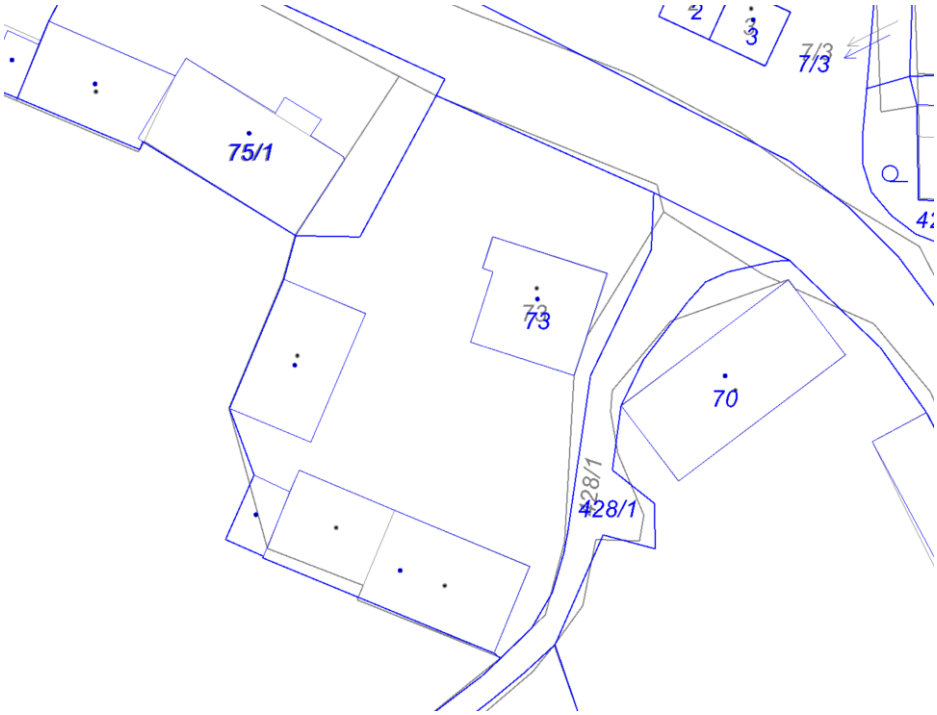

Fig. 10 – c. u. Vlásenice u Makova – correctly displayed buildings and error in the road rendition (No. 428/1)

DISCUSSION

This article deals with an unpublished topic and is an original topic for which there are no previous sources to build on. It is an innovative theme, and the aim is not only to provoke a discussion on the positional accuracy of digitised cadastral maps but, in particular, to approach the question of the need for new cadastral mapping from a technical point of view as a next step. The reason why the area of the positional accuracy of cadastral maps created by the redrawing from the stable cadastral system has been rarely addressed in the long term may be precisely because the maps are gradually being replaced by new mapping [10]. However, the pace of mapping is so slow that the use of these data is suggested for research into the actual positional accuracy of digitised cadastral maps.

REFERENCES

[1] Act on the Cadastre of Real Estate (Cadastral Act), No. 256/2013 Coll.

[2] Digitisation of cadastral maps and further procedure of cadastral register renewal (in Czech). Online. ČÚZK – Státní správa zeměměřictví a katastru. 2023. Available at: https://www.cuzk.cz/Katastr-nemovitosti/Digitalizace-a-vedeni-katastralnich-map/Digitalizace-katastralnich-map/Digitalizace-katastralnich-map.aspx [cit. 2024-05-25].

[3] Instructions for the Cadastral Register Restoration and Transfer, No. ČÚZK-01500/2015-22

[4] Outlook for the Activities of Cadastral Offices in the Field of Technical Data Management until 2030 (in Czech). Online. ČÚZK – Státní správa zeměměřictví a katastru. 2019. Available at: https://www.cuzk.cz/Katastr-nemovitosti/Digitalizace-a-vedeni-katastralnich-map/Vyhled-cinnosti-KU-v-oblasti-spravy-TU.aspx [cit. 2024-05-25].

[5] Navratil, G., Hafner, J. and D. Jilin (2010). Accuracy Determination for the Austrian Digital Cadastral Map (DKM). Fourth Croatian Congress on Cadastre with international participation –Proceedings. Zagreb, 2010. pp 171–181. ISBN 978-953-97081-8-2.

[6] Seidlová, A. and J. Chromčák (2017). Types of Cadastral Maps in Slovak Republic and Accuracy of the Land Area. RSP 2017 – XXVI R-S-P Seminar 2017 Theoretical Foundation of Civil Engineering. MATEC Web of Conferences, vol. 117. DOI: 10.1051/matecconf/201711700148.

[7] Karabin, M., Luczynski, R. and M. Karabin-Zych (2017). A Cadastral Map in Poland – the Proposal Based on Analysis of Cadastral Maps in Selected Countries. SGEM Conference Proceedings, Vol. 17, Issue 22. DOI: 10.5593/sgem2017/22/S09.002. ISSN 1314-2704.

[8] Decree on the Cadastre of Real Estate (Cadastral Decree), No. 357/2013 Coll.

[9] Services of the map server – cadastral map data (in Czech). Online. ČÚZK – Mapový server ČÚZK. 2023. Available at: https://services.cuzk.cz [cit. 2024-05-14].

[10] Overview of completed and planned operate renewals by mapping and revisions (in Czech). Online. ČÚZK – Státní správa zeměměřictví a katastru. 2020. Available at: https://services.cuzk.cz/prehled-mapovani-a-revize/mapovani-dokoncene [cit. 2024-05-14].