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Research paper

Identification of land system transformations in the Rzeszów city square

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Abstract: The paper presents the results of a comparative study of the land system of the city square and adjacent buildings for Rzeszów in Poland. The study made use of a cadastral map at a scale of 1:2880 and a modern land and building record map. For the purpose of adjusting reference systems, the cadastral map recorded in the form of a digital raster image, in accordance with applicable provisions of polish law (Journal of Laws No. 263 §49), was subjected to a two-stage calibration. The first stage consisted in carrying out initial calibration with the employment of first-degree affine transformation. In the second stage, final calibration was performed using mathematical transformation that considered the distortions detected in the previous stage. The results showed shifts, consolidations, and divisions of land parcels with regard to the present state, and changes to property structure. The proposed method may prove useful for further research on historical urban system morphology, and on restoration and renewal of the urban tissue.

Keywords: city square, Rzeszów, cadastral map, land parcels, transformation

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1. Introduction

Historical and functional-spatial research on the Rzeszów city square focuses on the analysis of the appearance and structure of the frontage, the shape and form of the city square, and the area's origins and transformations. One major part of conducting research on the morphology of the urban tissue and recording data on the area concerns the geodetic and legal real estate boundaries. The first cartographic elaboration of the city of Rzeszów in Poland, apart from the Wiedemann plan, is the Austrian cadastre in the Lviv system. Due to its accuracy, the Austrian cadastral map constitutes a spatial database whose analysis can broaden the knowledge on spatial transformations of significant urban elements.

Transformation of coordinates between systems previously used, e.g. Austrian or local systems "PL-1965", and the "PL-2000" system is a problem often encountered during the implementation of geodetic and cartographic works. Some of the geodetic and cartographic resources and available studies, from which data from various types of cartographic studies are obtained, have just been developed in the "old" systems. Therefore, there is a need to transform them into "new", currently used, e.g. "PL-2000". The "PL-2000" system is implemented based on the spatial system ETRS89 (European Terrestrial Reference System 1989) adopted by the European Union and implemented via the EUREF Permanent GNSS Network of reference stations (EUREF). The ETRS89 is transferred to Poland and implemented in the form of the PL-ETRF2000 frame by the Polish Active Geodetic Network (ASG-EUPOS), which is characterized by a spatial configuration compliant with standards of European Position Determination System (EUPOS) [1,2]. ASG-EUPOS system services enable geodetic measurements using relative positioning methods using the Global Navigation Satellite System (GNSS) signals and determination of coordinates with centimeter accuracy in real time or in post-processing [3–5].

Traditionally, the method used for this purpose is the conformal Helmert transformation supplemented with the Hausbrandt post-transformation correction. It allows you to keep the existing catalog coordinates of empirical systems. Detailed algorithms of these calculations allow to achieve the accuracy required for geodetic and cartographic works. However, there is a need to introduce corrections resulting from differences between individual systems. That is, theoretical coordinate systems, determined on the basis of calculations, and their empirical equivalents, determined on the basis of measurements [6]. Numerical transformation algorithms are still being developed. An example is the m-estimation method, which eliminates the problem of gross errors not included in the Helmert transformation [7]. Another approach is the use of artificial intelligence methods and artificial neural networks [8–11]. The task of the network is to determine a pair of unknown coordinates (secondary system) on the basis of given coordinates (primary system). These studies were carried out, among others, by [12–15].

In the research presented in this article, it was decided to use the traditional approach, which turned out to be sufficient to solve the objective aim out in the article.

The aim of the article is to analyze cadastral maps for the area of the city of Rzeszów in terms of their accuracy and information content for the needs of modern planning and revitalization studies. Possibilities of using the transformation of coordinates as a multistage transformation process from the historical systems to those currently in force in Poland were also presented.

The city square is one of the most characteristic urban spaces. As a market place, the city square coexisted and developed together with the city being established in the 14th century. Its location resulted from favourable geographical position, at the intersection of trade routes from Cracow toward Rus, and from Lublin toward Slovakia and Hungary. The city square was initially surrounded by low wooden or, rarely, brick cellared buildings. The most characteristic building was the City Hall, in whose proximity were situated the market stalls, the weigh house, and the well. The turning point for the shape and form of the buildings was the great fire in 1842, after which damaged houses were replaced by brick tenements [16]. More destruction occurred during World War II, when heavy military equipment damaged the structure of cellars and foundations of tenements, thus making it necessary to demolish several buildings located in the west part of the city square. Following the war, numerous sewage system and water supply failures led to the subsidence of loessial soils, adding to the risk of building collapse. In 1960s, a restoration plan was developed, and twenty years later, a process was initiated that involved securing the resultant excavations, reinforcing the foundations, and renovating the tenements [17, 18]. The area of the city of Rzeszów and its commuting zones (CZ) is subject to changes in land cover and land use, research [19] shows that between 2006 and 2012 there was an increase in the area of class 1 – artificial surface at the expense of a decrease in area of class 2 – agricultural areas, semi-natural areas, and wetlands in functional urban areas of Rzeszów. In 2006, a high similarity between the Land Use Mix (LUM) of the CZ of Rzeszów and the balance of LUM in the CZ of Warsaw (the capital of Poland) was noted [20]. In the period 2006–2012, slightly smaller changes in the spatial entropy of the LUM system were determined in the area of the Reszów city than in its CZ [20], which may indicate greater changes in CZ than in the Rzeszów city and its historic center.

Currently, the city square along with adjacent buildings is one of the most atmospheric public spaces in Rzeszów and the centre of urban life. Such perception of the city centre is undoubtedly influenced by the unique, historical character of the public space, tightly surrounded by two- and three-story tenements.

2. Cartographic elaborations for the city of Rzeszów from a historical perspective

The Rzeszów area has very low map coverage. The first elaboration was the Wiedemann plan conceived in 1762, a bird-eye view of the city, which included the present historical centre: the Lubomirski castle, the main promenade (present 3rd May Street), the first churches, the Old Town and the New Town. The map contains a very characteristic presentation of objects and areas such as streets, parks, and water reservoirs. The space was mapped with the use of primitive "bird-eye" axonometry. Although such presentation is an interesting visualisation of the city space, as it shows approximate location and appearance of the objects and the area, it holds no value for analytical research on the size of cadastral parcels, and does not constitute comparative material for a detailed research on land planning.

There is no cartographic elaboration for the urban structures existing before 1762; the layout was reconstructed in the research work by contemporary academics [21, 22]. A great amount of historically significant information is contained in the Austrian maps of the Galicia from the years 1779–1783. The Mieg map is a source material that allows to evaluate historical urban systems, probable fortification locations, and other spatial elements [23]. The next cartographic elaborations are maps developed after 1817, by order of Emperor Franz II of Austria, which enforced the establishment of land cadastre. At that time, Poland did not exist on world maps; its south-eastern region was under Austrian rule, and was placed under the land cadastre system. The development of cadastral map for taxation purposes lasted from 1818 to 1864. However, the works were suspended due to the political events that took place in Europe in the years 1848–1849 (Spring of Nations). Following the revolutionary actions, serfdom was abolished in Austria. As a consequence, the entirety of works related to the development of cadastral surveys were finished in 1872; on their basis, land owners in the entire Austro-Hungarian monarchy became subject to taxation. The cadastral maps developed at that time were presented at the 1873 Vienna's World Fair [24].

The maps developed for the purpose of establishing land cadastre at the then area of Austro-Hungarian monarchy are, therefore, the first reliable cartographic elaborations for the city of Rzeszów. Due to their accuracy and quality, the maps may serve as a basis for the research on urban morphology with regard to the size and arrangement of land parcels. They constitute cartographic elaborations at a scale of 1:2880, and, along with the information contained in land records, allow to determine geometry and surface of the area (Fig. 1).

Fig. 1. Fragment of the cadastral map from 1849 (Source: State Archive of Przemyśl)

The oldest map available is the cadastral map from 1849. An analysis of its content reveals the division of frontages into narrow numerated land parcels. The boundaries of cadastral parcels are clear; in several spots, changes to the area were considered, such as demolition or new division of the then existing estates. Additions and land-use transformations were also marked on the cadastral map. The original map is physically damaged, frayed, with visible defects. In the following years, the cadastral map continued to be updated due to changes to property law. The after-war history of cadastral measurements was initiated by land and building cadastre decree issued in 1947. The decree, however, never came into force . In 1955, another decree on land and building record was issued [25]. On its basis, in the years 1956–1970, a countrywide record was carried out, although vitiated by numerous errors at both decision-making and executive levels [26, 27].

For morphological structure of the city square and adjacent buildings, the analysis should encompass streets, land parcels, and buildings. The cadastral map clearly shows an elongated coupled area: the Parish Square in the west, and the Old Town in the east. The main streets are circumferential, with the transit street along the Cracow–Lviv axis running through the southern part of the Parish Square, and subsequently crossing through the middle of the western frontage and the northern corner of the eastern frontage of the Old Town. The city square is of oblong trapezoidal shape, limited by the City Hall building from the west, with a mini-quarter designated by two buildings and three tight frontages of tenements. The land parcels adjacent to the city square are long and narrow. Main buildings, which cover about half of the surface, are situated mostly in the front of cadastre parcels, whereas backhouses and outbuildings are located in the back. The ground floor is generally used as service area, and the higher stories are used as residential space.

3. Research method

The area of the research encompasses the Rzeszów city square along with streets and frontages, and adjacent city centre buildings. The scope of the analysis was presented in Fig. 2.

Fig. 2. Fragment of land and building record map in the "PL-2000" system (Source: own elaboration)

In order to indicate changes to the boundaries of the real estate around the city square, a comparison was performed between the cadastral map of the former Austrian partition and the present land and building record map. The employed comparative method required, in the first place, the digitisation of the cadastral map and, subsequently, the transformation of coordinates from the original system to the local system and the "PL-2000" system. As a next stage, a comparison was conducted of the route of the boundaries, with the identification of changes and shifts; furthermore, an examination was performed of the changes to the surface area of land parcels with regard to the surface area of cadastral parcels. Particular stages of these works were presented in Table 1.

Table 1. Stages of converting analogue maps into digital images
(Source: own elaboration based on [24, 28, 29])

Stage I **Preparatory works**
Locating cadastral triangulation points in the analysed area
Identifying cadastral triangulation points with geodetic control network points
Determining the coordinates of cadastral triangulation points in the Catalogue [28] and indicating the corresponding coordinates of geodetic control network points
Scanning the cadastral map and calibrating the obtained map raster
Stage II **Transformation of the Lviv cadastral system into the "PL-1965" and "PL-2000" systems**
Indicating approximate transformation formulas of the "PL-1965" and "PL-2000" cadastral systems
Verifying the correctness of reference points – 2nd degree polynomial-conformal mapping formula
Initial transformation of cadastral map rasters into present spatial reference systems
Determining the coordinates of the cadastral map's section frame corners based on the map index
Calculating the coordinates of inch points on the cadastral map's section frames
Initial transformation based on the coordinates of the cadastral map's section frame corners and inch points in the section frames
Stage III **Conversion of the cadastral map into a digital image**
Identifying point pairs on the cadastral map's raster and on the land and building record map
Final transformation of the cadastral map's rasters into the adopted spatial reference system based on the adopted reference points, whose deviations do not exceed the allowed values
Comparing the transformed cadastral map rasters with the land and building record map
Determining the legal status of the real estate

4. Results and discussion

The analysis of shape and changes to the parcel system is one of the primary research methods for studying urban tissue transformations [30]. Sometimes, objections are raised that such approach toward the identification of research on urban structure is of two-dimensional character. Notwithstanding, the authors argue that this research method may prove useful, particularly in urban heritage analysis.

The comparison of real estate boundaries, one element of which is the map of the Austrian cadastre in the Lviv system, was preceded by the transformation of the cadastre into the present reference system, in order to enable its juxtaposition against the present land and building record map obtained from the cartographic resource.

The analysis made use of the cadastral map elaborated in 1928. The map index made it possible to read the cadastral coordinates of the map section corners on the basis of tabulated coordinate values, in accordance with Instruktion Grundsteuerkatasters issued in 1907 [31, 32]. These coordinates constitute the main reference points; the additional reference point is the tower of the Bernardine church in Rzeszów.

The first stage of transformation preparations was the scanning of the cadastral map of the Rzeszów city square area. The obtained map in raster form is a digital image that allows for storing and gathering data used by geodetic software. For the purpose of reconstructing the actual rectangular coordinate system, and eliminating errors and distortions, map calibration was performed in the EWMAPA programme. Calibration was carried out for three map sheets, which were fitted into the section frame corners and other reference points, e.g. the church tower. The process employed affine transformation, which – due to unequal spacing of the map along the X and Y axes and additional shearing – ensures a more flexible adjustment of the raster map into the secondary system with the use of the smallest square method. In affine transformation, points are transformed from the primary into the secondary system according to the following formulas (4.1, 4.2) [33]:

$$X = t_X + X_p \cdot k_X \cdot \cos\varphi_X - Y_p \cdot k_Y \cdot \sin\varphi_Y \tag{4.1}$$

$$Y = t_Y + X_p \cdot k_Y \cdot \sin\varphi_Y - Y_p \cdot k_X \cdot \cos\varphi_X \tag{4.2}$$

where: t_X, t_Y – displacement along the X and Y axes, X_p, Y_p – primary system coordinates, k_X, k_Y – scaling coefficient along the X and Y axes, φ_X, φ_Y – rotation angle along the X and Y axes of the primary system.

The results were subjected to the Hausbrandt correction, which consists in leaving the secondary system reference points in their pre-transformation form while assigning adjustments to the remaining transformed points using the following interpolation formulas (4.3, 4.4), according to [33]:

$$v_{Xj} = \frac{\sum\left[v_{Xi} \cdot \left(\frac{1}{d_{ij}^2}\right)\right]}{\sum\left(\frac{1}{d_{ij}^2}\right)} \tag{4.3}$$

$$v_{Yj} = \frac{\sum \left[v_{Yi} \cdot \left(\frac{1}{d_{ij}^2} \right) \right]}{\sum \left(\frac{1}{d_{ij}^2} \right)} \tag{4.4}$$

where: i – reference point index, j – transformed point index, v – transformed points corrections, d – distance between the reference point and the transformed point.

This leads to a conscious distortion of the original (affine) transformation results, which is required by the condition of constancy of reference point specification coordinates.

The obtained results were post-transformation coordinates with regard to reference points, where points 1001–1006 are section frame corners, and point 873 is the tower of the Bernardine church. The summary sheet of primary and secondary coordinates as well as deviations at the references point (dx, dy) was presented in Table 2.

Table 2. Coordinates prior to and after transformation (Source: own elaboration)

Point no.	Original coordinates [m]		Coordinates after transformation (without Hausbrandt correction) [m]		Hausbrandt correction [m]	
	x	y	x	y	dx	dy
873	23326.95	–146086.65	5545306.9713	7571606.6307	–0.0013	–0.0007
1001	23200.0000	–146400.0000	5545167.2493	7571298.7613	0.0007	–0.0013
1002	23200.0000	–145800.0000	5545191.9095	7571898.2564	0.0005	0.0036
1003	23200.0000	–145200.0000	5545216.5696	7572497.7515	0.0004	–0.0015
1004	22700.0000	–145200.0000	5544716.9903	7572518.2985	–0.0003	0.0015
1005	22700.0000	–145800.0000	5544692.3301	7571918.8034	–0.0001	–0.0034
1006	22700.0000	–146400.0000	5544667.6700	7571319.3083	0.0000	0.0017
1111	23326.95	–146086.65	5545306.9713	7571606.6307	–0.0013	–0.0007

The result of the transformations are rasters containing cadastral map information converted into the flat rectangular coordinate system marked as "PL-2000". The rasters were digitised, i.e. converted into vector form, which allowed to conduct operations necessary for obtaining comparative data (Fig. 3 and Fig. 4).

Having superimposed the cadastral map and the land and building record map, one can state that the boundaries between cadastral parcels and land record parcels generally overlap. The course of the streets shows shifts (cadastral parcel 4533 and land record parcel 985/2), extensions (a fragment of cadastral parcel 325 and the corresponding land record parcel 985/2), consolidations and divisions (consolidated fragments of cadastral parcels 325, 306, 4533 currently form record parcel 985/2). In a part of the square (cadastral parcel 905), a statue was erected to replace the well (cadastral parcel 904); the well

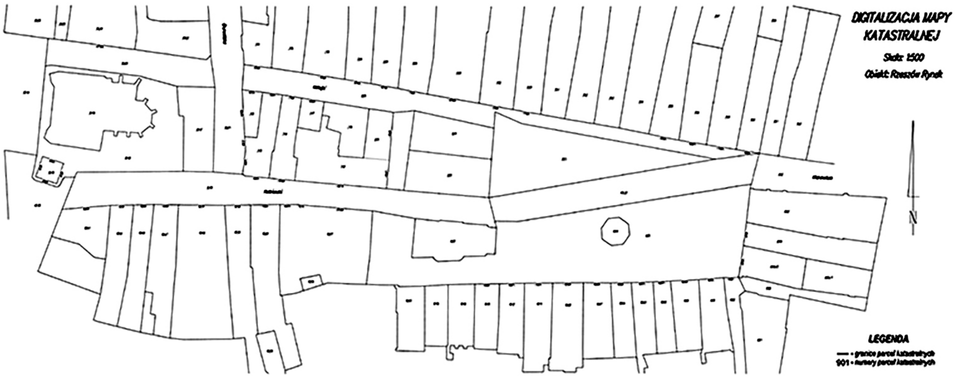

Fig. 3. Cadastral map after transformation into the "PL-2000" system. Source: own elaboration

Fig. 4. Land system transformations in the city square area. Cadastral map (green lines) overlaid with the land record map (red lines) (Source: own elaboration)

was reconstructed within the boundaries of the former communication route (cadastral parcel 4533).

The buildings situated within cadastral parcels 322 and 324 (the present land record parcel 986/1) disappeared. The parcels were consolidated, and partially transformed into streets. In the area that encompasses parcels 330, 331, 332, 352, 353, 354, 356, 358, 360, 361, and 362, one may observe a tendency toward division. This is probably due to the parcels' length, and the transformation of backhouses and outbuildings into a row of tenements serviced by Kopernik Street.

Another significant aspect of land system transformations within the Rzeszów city square is the surface area comparison between cadastral parcels and land record parcels. This allows to analyse changes to property structure granularity in the historical city centre area.

Although the research was conducted for all cadastral parcels and land record parcels within the area of the analysis, the present paper only discussed illustrative cadastral parcels, i.e. 312, 313, 314, 317, 318, 319, and 320. These parcels, situated between the present city square and the Parish Church, form a quarter which is the eastern frontage of the city square. A surface area comparison between selected cadastral parcels and land record parcels (Δp), along with relative error values, was presented in Table 3.

Table 3. Surface area comparison between cadastral parcels and land record parcels with difference and relative error values (Source: own elaboration)

Cadastral parcel number	Cadastral parcel area [ha]	Land record parcel number	Land record parcel area [ha]	Total area of land record parcels equivalent to cadastral parcels [m^2]	Difference of parcel area Δp [m^2]	Relative error [%]
312	0.0119	977	0.0116	116	3	2.52
313	0.0302	978	0.0309	309	–7	2.31
314	0.0275	979/1 979/2	0.0090 0.0179	269	6	2.18
317	0.0105	980	0.0110	110	–5	4.76
318	0.0578	982	0.0588	588	–10	1.73
319	0.0271	981/4 981/3 981/2	0.0032 0.0190 0.0054	276	–5	1.84
320	0.0194	976/1 983 985/1	0.0012 0.0132 0.0047	191	3	1.55
Minimum relative error [%]						1.55
Maximum relative error [%]						4.76
Mean relative error [%]						2.41

As shown in Table 3, the analysed changes to the surface area are significant. There is a clearly visible tendency toward the division of cadastral parcels into smaller land record parcels. This is probably due to the need for increasing density of the city centre, whose small-town character changed over time. The divisions in cadastral parcels are also indicators of development of the urban infrastructure. Differences in surface area between the former cadastral parcels and the present land record parcels (after summing up the areas of post-transformation parcels) range from 1.55% to 4.76%, with a mean of 2.41%, calculated based on the value of the percentage relative error (Table 3).

Evaluation and analysis of the morphology of historical urban tissue is a complex matter, since there are numerous elements and factors that impact the diagnosis of urban structure quality [34–40]. Apart from historical research on transformations and accumulations within the analysed area, and qualitative research on urban systems, it seems advisable to perform an evaluation of land systems [41–43]. An analysis encompassing changes to the boundaries of cadastral parcels, shifts, consolidations, and divisions seems to be of particular significance from the point of view of advancing knowledge on property structure transformations. Another major aspect of historical research is the analysis of coherence of cartographic elaborations, their accuracy, and conformity with the current state. Analyzes of this type are of great importance for the broadly understood construction industry, e.g. modeling of erosion processes [44, 45], transport [46], landslide processes [47–55], as well as assessment of the impact of the construction industry and the building materials industry on the natural environment in terms of sustainable development [56, 57].

5. Summary and conclusion

The conducted analyses of land systems of the Rzeszów city square made use of the Austrian cadastre map, which was compared with the present land and building record map. The analysis of both cartographic elaborations allowed to evaluate changes to the historical city centre area, from the beginnings of the cadastral map system until the present day. Following the transformation of the cadastral map into the present system, the cadastral map raster was overlaid with the land and building record map, which made it possible to accurately compare the differences that occurred within the property and street boundaries. It is worth noticing that the transformation of the former Austrian cadastre maps is a complex process, mainly due to the lack of an explicit mathematical description of the mapping, and the lack of preserved geodetic control network points. It seems that the adopted transformation model may become a standard for similar elaborations.

The conducted research shows high accuracy of cadastral maps. The cadastral map remains of relevance, as it mostly overlaps with the present land and building record map. The most frequently noted change is the division of property, which is a natural process related to increasing density of the city centre tissue. Despite slight differences in boundaries between the cadastral map and the land record map, it is the former that constitutes the basis for the land record modernisation process.

In the case of Rzeszów, modern land record maps do not refer the numbers of cadastral parcels, the majority of which are evidenced in land and mortgage registers. This issue is particularly important for the identification of areas covered by restoration and renewal projects, which refer to the data contained in cadastral maps. Transforming the cadastral map into the present spatial reference system allows for correct synchronisation of land parcel identifiers with land record parcels.

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Charakterystyka przekształceń układu gruntów rynku w Rzeszowie

Słowa kluczowe: rynek, Rzeszów, mapa katastralna, parcele, przekształcenia

Streszczenie:

W pracy przedstawiono wyniki badań porównawczych układu przestrzennego rynku miejskiego i zabudowy przyległej dla Rzeszowa w Polsce. W opracowaniu wykorzystano mapę ewidencyjną w skali 1:2880 oraz współczesną mapę ewidencyjną gruntów i budynków. W celu wyrównania układów odniesienia mapa ewidencyjna zarejestrowana w postaci cyfrowego obrazu rastrowego, zgodnie z obowiązującymi przepisami polskiego prawa – Dz.U. Nr 263 §49, została poddana dwuetapowej kalibracji. Pierwszy etap polegałna przeprowadzeniu wstępnej kalibracji z wykorzystaniem transformacji afinicznej pierwszego stopnia. W drugim etapie przeprowadzono ostateczną kalibrację za pomocą transformacji matematycznej uwzględniającej zniekształcenia wykryte w poprzednim etapie. Wyniki pokazały przesunięcia, konsolidacje i podziały działek w stosunku do stanu obecnego oraz zmiany w strukturyze własności. Zaproponowana metoda może okazać się przydatna w dalszych badaniach morfologii historycznego układu urbanistycznego oraz rewaloryzacji i odnowy tkanki miejskiej.

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