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Research paper

Quantifying space for the accommodation of stratified property

Szczepan Budkowski[1]

Abstract: The transformation of cadastral systems from a flat projection paradigm to multidimensional registration is not merely a technological issue, but primarily an epistemic one – it concerns the conceptualization of property as an entity extending in space and time. This article attempts to answer the question of how a system based on the Roman principle of superficies solo cedit can be adapted to a reality in which ownership relations do not overlap hierarchically but interpenetrate vertically, hybridly, and dynamically. The author argues that the problem concerns not only the registration of bridges, tunnels, or underground infrastructure, but also the redefinition of the unit of legal space itself. The proposed algorithm for quantifying areas, therefore, does not serve solely the selection of pilot areas but serves as a tool for diagnosing the "structural resistance" of space to the prevailing cadastral model. The results of analyses conducted within Krakow's city center demonstrate that the boundary between what is legally possible and what is spatially necessary is shifting. The article postulates that the implementation of a layered cadastre should be understood not as a reform of the register, but as a change in the ontology of ownership – from surface to volumetric, from permanent to time -space, from single-purpose to relational.

Keywords: land and building records, 3D cadastre, ownership, spatial plot, SMART Cadastre, CityGML

[1]PhD., Eng, University of Agriculture in Krakow, Faculty of Environmental Engineering and Land Surveying, Balicka 253A, 30-149 Crocow, Poland, e-mail: szczepan.budkowski@urk.edu.pl, ORCID: 0000-0002-1806-1173

1. Introduction

The real estate cadastre, as an official register collecting information about real estate, should provide reliable data on the legal and physical status of real estate, which is necessary for the purposes of management, administration, planning and fiscal policy.

Considerations in this area emphasize the need to create a cadastre of the future that would be able to constitute a component of analytical systems enabling the development of information technologies in concert with growing socio- economic demands [1–9]. The system would be coupled with augmented reality technology, which superimposes the real world on the virtual world. Its basic concept is the ability to present relevant information contained in IT systems in the real world. The process of integrating augmented and virtual reality should not only consider volumetric plots but also record the rights associated with these properties, along with their temporal and spatial nature [10–24].

One of the stages of the development of the conceptual cadastre model was the ISO 19152 standard" Geographic Information - Land Administration Domain Model (LADM), which was published by the Polish Committee for Standardization under the number PN-EN ISO 19152:2013-05E. The existing standard provides a common, standardized, global descriptive and semantic dictionary defining the creation of a reference register model that contained information on entities, spatial elements such as type, area, volume assigned to real estate, as well as standardized terminology. The most important part of the standard should be considered the one that referred to its multidimensionality, assuming the existence of spatial units, which included three-dimensional parcels whose boundaries were determined by planes [25–40].

Analyzing the current discussion, it should be noted that researchers from around the world emphasize the need to modify existing cadastral systems in the direction described above. This seems unquestionable and anticipates the future. Relatively few researchers, however, consider the issue of siting such a modified system, emphasizing its complex nature and the enormous social and economic costs [40–54]. Against this background, this paper aims to synthesize the technical and legal prerequisites for accommodating stratified (layered) ownership within the Polish cadastral environment; propose a transparent, reproducible framework for spatial quantification of areas where the demand for 3D/4D land administration solutions is likely to be highest; and demonstrate the approach through a district-level case study of the City Centre cadastral unit in Kraków. The research question is whether a multi-criteria spatial quantification, grounded in cadastral and urban-form characteristics, can support prioritisation of areas for pilot implementation of stratified property solutions, while explicitly acknowledging legal constraints and the need for future replication.

2. Materials and methods

This manuscript follows the ongoing international trend of developing multidimensional (3D/4D) cadastral concepts. The study combines a structured literature review with an empirical case study. The case study is used to operationalise an algorithmic attempt to quantify, at the district level, areas that could potentially accommodate multidimensional cadastre solutions in practice. Cadastral and ancillary spatial data were provided by the Kraków City Hall for research purposes. Because the empirical component is limited to a single urban context, the resulting prioritisation map should be interpreted as locally valid; external validity requires replication in other cities and morphological/legal settings.

The City Center, a cadastral unit of the city of Krakow, is located in the central part of the city and consists of 34 districts of varying sizes (Fig. 1).

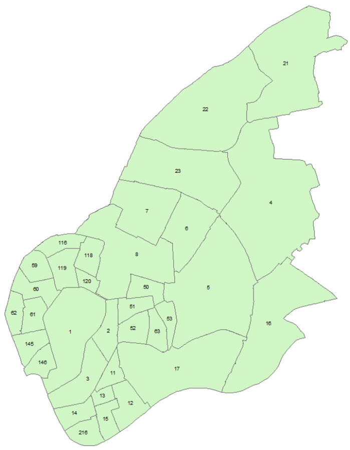

Fig. 1. Division of the cadastral unit into districts, source: own study

It encompasses areas with the highest development intensity, a concentration of historic buildings, and peri-urban services. It is characterized by the greatest cadastral and legal complexity, with a high proportion of historic buildings. In terms of land use, the area consists primarily of residential and built-up areas. Green spaces are located primarily within the Planty Park and landscaped green areas, such as parks and city squares (Fig. 2).

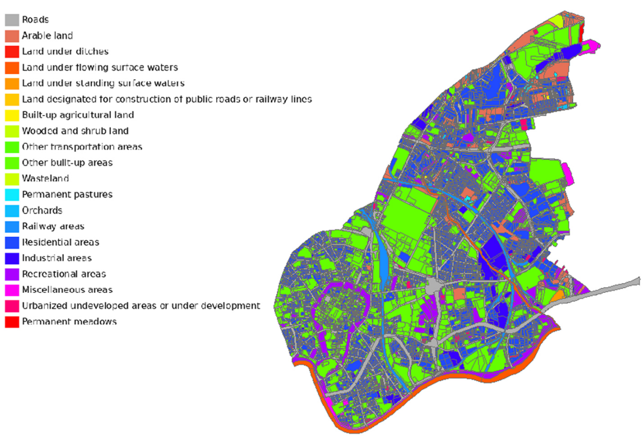

Fig. 2. Land use structure, source: own study

Analyzing numerous literature sources on multidimensional cadastre, it should be noted that the latest research trends are focused on the possibility of producing digital data, which, in line with emerging technologies, have the potential to become useful for a variety of applications [35, 42–44, 46, 49]. For over a decade, the concept of creating and subsequently developing a 3D cadastre has been associated with land management systems. The goal was not only to correctly represent buildings and objects on maps, but also, and even primarily, to create a system that would enable efficient vertical investments and the most reliable security of ownership, as land rights.

Considering that some researchers view a 3D cadastre not only as a designated airspace (3D parcel) but also as a system for representing layered rights and limited property rights (sometimes limited by the period of exercise), this implies another evolutionary step and necessitates the registration of time as another variable. This perspective is shared by many academic researchers, who thus diagnose the need to create a 4D cadastre. This milestone is another, but not the only, step, as there are also works postulating the modeling of graphical content resulting from the symbolization process. These researchers use CityGML, which models the classes and relationships of urban objects along with geometric, semantic, and visual characteristics. Such solutions allow for encoding not only the reality of geospatial space but also some information about its representation. However, the CityGML model can encode spatial information in a limited way, and this is one of the reasons why researchers are attempting to extend the original CityGML model to complement it. For example, proposals by some researchers [16, 27, 32, 39, 45] include the CityGML model extended with the 3D CityDB solution, which uses other data formats for visualization and mapping.

The literature review allows us to diagnose yet another solution, which is based on the use of IFC (Industry Foundation Classes) as an open standard for digital modeling of building information (BIM) - Building Information Modeling [3, 7, 16, 25, 32]. This information allows for the integration of the created BIM models with GIS and cadastral systems, which enables the implementation of detailed spatial analyses and management not only of buildings as "cuboid" solids, but above all allows for the assignment of rights also within these objects, e.g. to common areas or elements of the site infrastructure, including connections and technological channels located within the facility. Information that can also be integrated with the cadastral system includes height and the number of storeys. IFC allows for tracking changes over time, and therefore serves as a multi- (at least four-) dimensional cadastre.

The challenge of creating such a detailed spatial information system must, according to researchers, be supported by BIM (Building Information Modeling), which, as a process of digitally modeling building information, integrates geometric, functional, and technical data into a single, coherent model. BIM can also include information on costs and component values, allowing for the expansion of the cadastral system with new dimensions. The integration method, also presented schematically [10], is the author's own proposal.

3. Findings

3.1. Multidimensional cadastre in the world

The most mature form of evolution of the cadastral system was defined as SMART Catastre. as an element of participation in modern spatial description. This idea is an original proposal and presents the system as transcending the current state of knowledge, relational and synergistic, which, due to the information held, will have the potential to be used for other purposes, even those unknown today and currently difficult to define, which may indicate added value not directly resulting from the nature of the register [10]. Such a multi-purpose, multi-dimensional, relational and synergistic cadastre system should demonstrate integration capabilities with other systems to enable the use of augmented reality's advantages not only for visualization purposes, but also for conducting spatial analyses that are not yet available today or extremely complex to implement (Fig. 3)

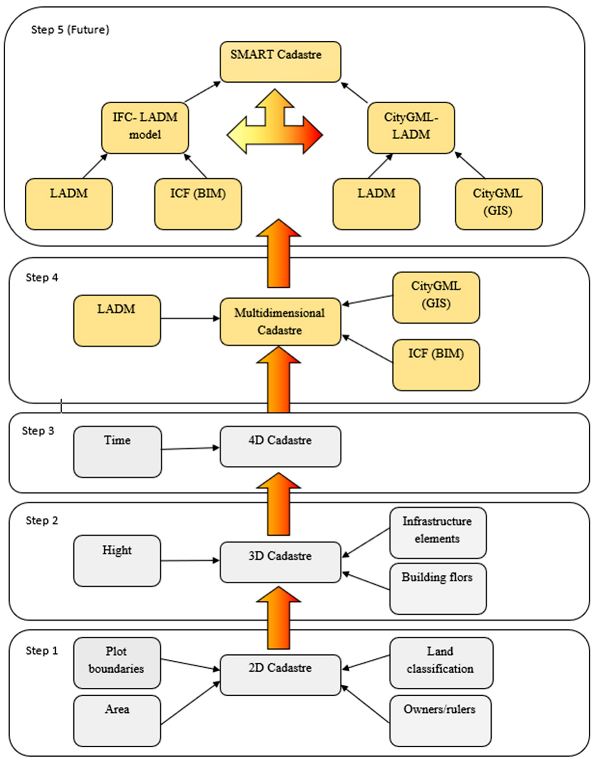

Fig. 3. Evolution of the cadastre concept based on the literature (steps 1-3) and authorial synthesis of the integration of LADM, IFC (BIM), and CityGML (GIS) towards the SMART cadastre concept (steps 4-5). Gray indicates state-of-the-art solutions, while amber indicates the contribution of this study, source: own study

3.2. Multidimensional point cadastre

The point-based approach involves registering a multidimensional cadastre for selected, key objects of particular spatial significance. This may include multi-story buildings, historical monuments, infrastructure complexes, or strategic urban areas such as business centers.

Beyond the legal and technical aspects, it is also necessary to emphasize the need for proper registration of ownership relations, which cannot be represented on two-dimensional maps. Below are selected objects within the city of Krakow, the research area, whose ownership relations are not correctly represented on two-dimensional maps. The selected objects are representative of specific groups of objects, including bridges, tunnels, viaducts, buildings, and slender structures. This is another argument (beyond investment) supporting the implementation of multidimensional cadastre solutions.

a) **Registration of bridges, tunnels and viaducts**

– The registration of bridges, tunnels, viaducts, and overpasses is one of those that cannot be properly represented on two-dimensional maps. One example is the Dębnicki Bridge in Kraków. The ownership relations presented on the two-dimensional map do not record the existence of the bridge, which, unlike flowing water plots, has a different ownership structure. Flowing water plots, according to Polish law, are owned by the State Treasury and are managed by the State Water Management Company (Polish Waters) (light pink). The road above the water is owned by the Municipality of Kraków, and the road is managed by the Kraków City Road Authority (light yellow) (Fig. 4).

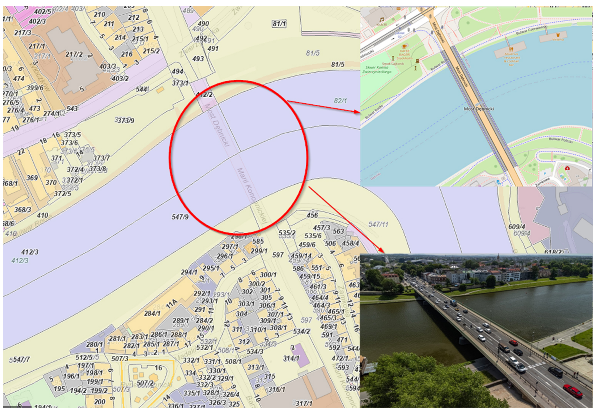

Fig. 4. Dębnicki Bridge in Kraków, ownership structure and site plan; source: prepared based on the Kraków Observatory

– Another example is the overpass on Wita Stwosza Street from the Galeria Krakowska shopping center and the viaduct above the railway line. As can be seen in the maps presenting the ownership structure, the road running along the top of the viaduct and the viaduct are not included. Light pink represents State Treasury land, while dark pink represents land owned by the State Treasury and managed by a PKP Group company. Additionally, the road running along the viaduct is municipal property and is transferred to the Krakow City Road Authority. Such complex ownership relations prevent proper display on two-dimensional maps, although their presentation complies with current legal regulations (Fig. 5).

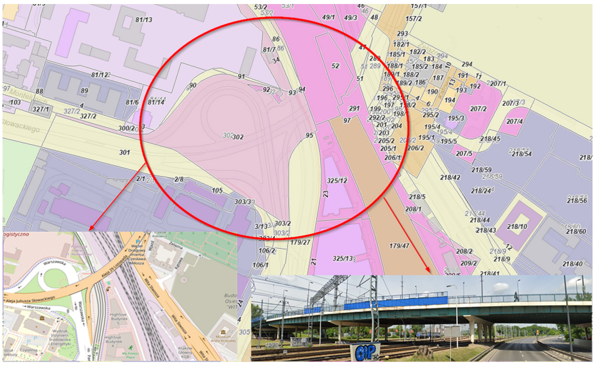

Fig. 5. Overpass on Wita Stwosza Street next to Galeria Krakowska, ownership structure and site plan; source: prepared based on the Kraków Observatory

Taking into account not only the current registration problem, in the authors' opinion, it would also be necessary to take into account future potential city development plans, which focus on the area of maximum vertical exploration. Therefore, the problem of registering existing facilities seems to be a secondary issue, due to previously existing problems with vertical use in the context of developing extremely attractive urban spaces. The current considerations in this area assume the construction of commercial and service facilities directly under or above overpasses, decorated with greenery (the concept of green overpasses). This involves regulating complex ownership issues, which in the Polish legal system are considered a norm of iuris congentis nature (mandatory), comes down to the need to respect the Roman law principle of superficie solo cedit. This means that the currently constructed legal system prevents deviations from this principle, as a result of which investors are unable to implement vertical investments, for example, by utilizing the spaces between viaducts. This development concept emerged in the finals of the international two-stage competition titled "New Life Between Viaducts".

b) **registration of building objects**

An example of a building with a modernist shape is the newly constructed Novum building at 20 Rakowicka Street. As can be seen in the photograph and the completed implementation concepts, the building is not a uniform cuboid shape and has a complex geometry. Therefore, its representation on a two- dimensional map is quite problematic. Collecting geometric data about the building is not the only problem that can be encountered during the proper registration stage. Another problematic issue is the information about descriptive attributes including the number of storeys, as the building's shape is not uniform in this respect and has a variable number of storeys. The situation is similar with underground parking lots, which do not align with the building's surface, and below it, the number of storeys is not uniform throughout the entire area (Fig. 6).

Fig. 6. Novum building at 20 Rakowicka Street; source: own study based on the Kraków Observatory and GSBK

The analyses conducted allow us to draw partial conclusions, which indicate that currently registered objects are not represented correctly on property maps. It is also possible that objects listed in the land and building register are incorrectly presented not only in terms of object geometry but also in terms of descriptive attributes. Considering the above, it should be stated that the introduction of layered property registration solutions could provide a remedy for the currently identified problems. An undoubted advantage of such a solution is the ability to selectively and precisely process data for selected, key objects. This approach, of course, has an impact on costs, which in this case are reduced to a bare minimum due to the reduction of surveying and technical work. Focusing on selected objects or small, limited locations (real estate, plot) also allows for relatively rapid achievement of the desired effects of implementing such solutions. A professionally conducted analysis cannot, of course, focus solely on the advantages of the proposed solutions. Among the proposal's shortcomings, the lack of spatial coherence of the managed resource can be identified, which can lead to difficulties in integrating data at the district level, and even further down the line, at the individual and national levels. Registering only selected objects from the spatial landscape will also prevent the full potential of a multidimensional cadastre from being fully utilized, for example, in the context of spatial planning or conducting advanced spatial analyses using artificial intelligence solutions.

3.3. Multidimensional area cadastre

Regardless of the layered property solution, multidimensional cadastre, or SMART cadastre used, spatial allocation seems crucial. Research conducted in this area in Poland and internationally indicates that registration in a layered system would primarily apply to slender objects, tunnels, and bridges, a view also confirmed by the authors' own research. This perspective would allow for the formulation of a view postulating selective, and specifically point-by-point, implementation of layered property solutions [28]. The analyzed literature sources present shortcomings in this regard, as the research conducted is essentially limited to the above formulation, reducing the weight of the considerations to irregularities on 2D maps, which result from the incorrect representation of such objects on currently used maps. The author of this manuscript diagnoses the need to supplement the current considerations, bearing in mind that the literature contains only partial studies that limit themselves to establishing a set of objects that could constitute a pretext for implementing multidimensional cadastre solutions. However, currently available research has not identified any publications establishing objective data metrics that could be decisive in verifying the feasibility of implementing a multidimensional cadastre. Previous studies have typically been conducted on selective sites, and the data collected for analysis were often descriptive in nature, thus presenting a significant degree of uncertainty in assessing the actual situation. Therefore, it was decided to conduct an analysis based on which a proposal for an objective algorithm was developed to verify the feasibility of accommodating solutions for modern spatial description - a smart cadastre.

A literature review typically leads to a conclusion, where the main focus of the discussion is on the cadastre's functioning, its integrity with other systems, its evolution, the possibilities of object registration, the use of BIM or GIS technologies, etc. Considering the literature search, the topic of the cadastre is rarely reduced to its spatial allocation capabilities. Even if it is, it is primarily through the selection of selected objects whose potential registration in a multidimensional space would solve the problem of presenting correct ownership relations. While this issue is certainly important from a scientific perspective, in the author's opinion, it certainly cannot and should not constitute the core of the ongoing discussion on the implementation possibilities of vertical ownership. Also significant are the potential development possibilities, for which the most important factor should be an investment impulse, intended not only to utilize the vertical space of an attractive urban fabric but also to finance the investment by establishing a mortgage on such a defined legal structure. The existence of a legal entity of a spatial and vertical nature may be the subject of economic transactions, which would also involve the need to regulate relations between neighbouring properties.

A natural consequence of this approach is the area-based approach, which should be identified with the possibility of allocation to specific spatial units larger than a plot, such as districts, city administrative boundaries, or cadastral units. The area-based approach results in comprehensive data collection capabilities, which directly translates into spatial management capabilities, including the various uses and complexity of infrastructure facilities. A holistic approach also allows for increased data harmonization and interoperability within a cadastral unit. Linking data with fixed- structure spatial information systems (GIS) can encourage their use in the context of spatial development, advanced spatial analyses, or fiscal policy. The register's universal design can also imply a strong gravitational potential for investors, who are already declaring their willingness to allocate funds for vertical development projects. However, this solution is not without its drawbacks. Leaving aside the issues of changing regulations and adapting them to the new legal situation, it is important to note the high implementation costs and the relatively long implementation time. It is also worth noting that attempting to implement such a complex undertaking, both legally and technically, may end in failure. Therefore, the solution recommended by the author of this manuscript is to analyze areas that are crucial for the application of multidimensional cadastre solutions. To this end, it was decided to attempt to quantify space using an algorithm that included:

a) Defining input spatial data:

The input spatial data is a set of criteria Ki for each analyzed area Aj. For n criteria and m areas, the results are as follows Eq. (3.1):

$$K = \{K_1, K_2, \ldots, K_n\} A = \{A_1, A_2, \ldots, A_n\} \tag{3.1}$$

Each i-th criterion K is a spatial function $f_i = (x, y)$ that assigns a value to each point or unit of area (x, y).

b) Standardization of criteria

Due to different scales of criteria, their values are normalized in the range [1] using min-max scaling Eq. (3.2):

$$K_i^{\text{norm}}(x, y) = \frac{K_i(x, y) - \min(K_i)}{\max(K_i) - \min(K_i)} \tag{3.2}$$

Where $\min(K_i)$ and $\max(K_i)$ denote the minimum and maximum value of the criterion, respectively K_i

c) Evaluation of criteria

Each criterion is assigned a weight w_i, where Eq. (3.3):

$$\sum_{i=1}^{n} w_i = 1, w_i \geq 0 \tag{3.3}$$

d) Aggregation function

The final value for each area is calculated as the sum of weighted, normalized criteria Eq. (3.4):

$$S\left(A_j\right) = \sum_{i=1}^{n} w_i \cdot K_i^{\text{norm}}(A_j) \tag{3.4}$$

Where $S\left(A_j\right)$ is the cumulative result of area A_j,
$K_i^{\text{norm}}\left(A_j\right)$ is the average value of the $K_{i\ \text{criterion}}$ in the area(A_j)

e) Quantification of areas

Areas are quantified based on values $S\left(A_j\right)$, which are categorized into the following decision thresholds:

- $S\left(A_j\right) \in [0, 0.4]$ low priority
- $S\left(A_j\right) \in [0.4, 0.7]$ medium priority
- $S\left(A_j\right) \in [0.7, 1.0]$ high priority

The solutions can optionally be supplemented with statistical analysis:
Statistical analysis:

a) Correlation analysis

To examine the impact of individual criteria on the final result, Pearson correlation coefficients can be used Eq. (3.5):

$$P\left(K_i, S\right) = \frac{\operatorname{Cov}\left(K_i \cdot S\right)}{\sigma K_i \cdot \sigma S} \tag{3.5}$$

Where:

– $\operatorname{Cov}\left(K_i \cdot S\right)$ are the covariances between $K_{\text{and}} \cdot S$,
– $\sigma K_i \cdot \sigma S$ is the product of the standard deviation

b) Sensitivity analysis

The sensitivity of the results to changes in weights can be calculated as a derivative of the aggregation function Eq. (3.6):

$$\frac{\partial S(A_j)}{\partial w_i} = K_i^{\text{norm}}(A_j) \tag{3.6}$$

This allows for an assessment of how changing the weights affects the final quantification result.

c) Distribution of final values

For spatial analysis, the distribution of $S(A_j)$ values in the analyzed region can also be calculated Eq. (3.7):

$$f(S) = \frac{\text{number of areas } S(A_j)}{\text{total number of areas}} \tag{3.7}$$

3.4. Layered Ownership in a Hybrid Model

In addition to the possibility of point-based and area-based implementation, a hybrid model approach should also be explored, combining point-based and area-based solutions. Point-based implementations could be implemented as pilot projects in key locations addressing existing challenges, or as investment catalysts. Area-based implementations would encompass complexes of plots/properties, and even districts or neighborhoods, which, as regions with complex spatial structures, require precise management.

In the author's opinion, the district should be adopted as the basic unit of area for the city of Krakow, and based on this, the validity of area implications should be defined within a relatively small area. While adopting the plot as the reference unit would be quite precise and would best meet the needs of investors, it would also require intensified workload in collecting additional data and processing it. Furthermore, it would not allow for the capture of the overall spatial structure, such as infrastructure networks. Choosing the district as the reference unit facilitates implementation planning in a broader context and significantly reduces the number of units to be analyzed and managed compared to plots. Furthermore, it will be useful in spatial analyses by taking into account the overall structure.

The implementation process could begin through selective selection and be expanded to include additional areas, ultimately encompassing the entire entity. An undoubted advantage of the solution is the optimization of costs and associated risks. An additional advantage is the ability to test and refine proposed solutions before a larger-scale implementation. This applies not only to legislative solutions but also to technical solutions. Recommendations for site selection should take into account high space intensity (city centers with significant traffic flow), high-rise facilities, both underground and above-ground, with diverse functions, and the expansion of registration to include new key areas and infrastructure facilities.

Given the analysis of the research area of Krakow, a hybrid approach was chosen. This approach assumes that the areas with the potential to be incorporated into a multidimensional cadastre will primarily include the city's historic center (downtown).

The following criteria were adopted in the proposed analytical model:

building density (K1); height of buildings (K2); density of underground infrastructure (K3); land use (K4).

The features included as input parameters of the model were adjusted by calculating in the given cases:

a) building density, counting the average distances from the building centroids,
b) average height of storeys per precinct
c) infrastructure density calculated as the ratio of the total length of the network to the area of the entire area
d) method of use, weighing as follows.

The final result will therefore include the performed spatial analysis calculated as the sum of the weighted coefficients together with the performed standardization (Tab. 1).

Table 1. Weighting of land use types, source: own study

Terrain type	Implementation potential	Justification
Roads/overpasses/railway tracks	1.0	Vertical collisions, bridges and tunnels, slender objects – a classic case of layer conflict
Areas of a service and industrial nature	0.8	Basements, parking lots and often irregularly shaped superstructures
Multi-family residential areas	0.6	Multi-story development with potential for conflict
Other built-up areas	0.5	Places with vertical investment opportunities
Recreation, landscaped greenery	0.3	Low vertical collision
Arable land/allotment gardens	0.1	Minimum requirements for registering a strata property
Historic architectures objects	0	The elimination of the type of objects is justified due to their inclussion on the UNESCO list

The final result will therefore include the performed spatial analysis calculated as the sum of the weighted coefficients together with the performed standardization.

The proposal to introduce layered ownership is closely related to the Land Administration Domain Model (LADM), which is a hierarchical, international standard that can stimulate application development and accelerate the implementation of land management systems that support sustainable development goals. The Land Administration Domain Model [43] contains basic information components relating to entities, objects, administrative units, as well as taking into account the geometry, topology, and attributes of objects.

In this context, we cannot forget about the specificity of the Polish conceptual model of land and building records data, which, as a UML application schema of the records data, should be the basis for creating a new schema

In accordance with the previously explained assumptions, the new conceptual cadastral data model should be expanded to include the ability to record time, including the beginning and end of an object's existence, as well as the ability to demonstrate the volume of a spatial artifact. The model has also been enriched with a spatial registration unit encompassing, in addition to geometry and topology, volume. This model construction method is a proposed step towards creating a cadastre system that is not only multidimensional but also multi-purpose.

4. Discussion of the results

Referring to the results of the spatial and database analyses, it should be noted that the presented results indicate the validity of introducing layered ownership solutions in 14 districts. Implementation capabilities are at an average level in 19 of the 34 districts studied. Only one district indicates a low validity of introducing layered ownership solutions (Fig. 7).

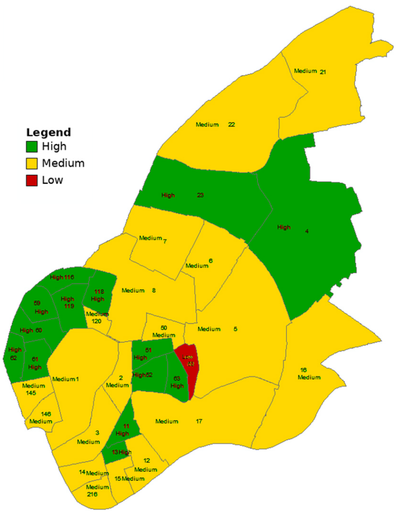

Fig. 7. District-level priority map for implementing multidimensional cadastral alternatives (high-medium-low) with available language scale and legend; source: own study

A detailed analysis verifying the quality of the conducted research in an empirical context indicates the validity of the presented results. The area with low implementation validity is largely comprised of the botanical garden located on Lubicz Street. This area demonstrates significantly lower potential than those in the surrounding area. Areas encompassing the city center, containing structures of particular architectural value, reduced the feasibility of potential implementation due to limited investment potential. However, due to the complex relationships between the structures and their accumulation, areas (1, 2, and 3) demonstrated medium implementation potential. Areas 4 and 23 also demonstrated high implementation potential, where major investment projects related to the construction of new tram and city rail lines are currently underway (as of October 2025), confirming the results of the conducted research.

Although the conceptual framework and the proposed quantification workflow are transferable, the empirical results reported here are limited to a single case study (the City Centre cadastral unit in Kraków). Therefore, the spatial pattern of ‘high/medium/low’ districts should be interpreted as a local prioritization. Replication in other Polish cities and in areas with different morphological and legal contexts is required to test the robustness of the criteria set and weights, and to calibrate decision thresholds.

From a legal perspective, the main barrier to implementing stratified property in Poland remains the rigidity of the superficies solo cedit principle and the limited catalogue of rights that can be separated from land. A scalable introduction of layered ownership would require at least: defining 3D spatial units as objects of rights and registration; ensuring interoperability between the cadastre (EGiB) and land and mortgage registers (KW) so that rights can be secured (including mortgages) in a legally enforceable manner; and establishing rules for delimiting and maintaining ‘legal spaces’ for underground and above-ground infrastructure, including public-law restrictions and temporally conditioned limitations. These prerequisites frame the technical options discussed in this manuscript.

5. Summary and conclusions

The considerations presented in this manuscript encompass the possibility of adapting the currently functioning cadastral system to growing social needs. The research analyzes implementation options, along with a proposal indicating the milestones necessary for full-fledged data integration and the creation of a cadastral system that goes beyond its currently known functions. In addition to the milestones, the proposal highlights the possibility of point-based, area-based, and hybrid implementations. The analyses present the advantages and disadvantages of the proposed legal, dogmatic, and functional solutions for the real estate cadastre institution in the context of its utilitarian nature, which explicitly stems from socio- economic needs.

The manuscript contains a proposal for milestones aimed at replacing the two-dimensional cadastre with solutions enabling the unambiguous identification of distinct cadastral objects in space and time (multiple dimensions). This proposal is defined as a significant achievement of the publication not only due to its modernist attempts to concretize the scope of layered property rights in a vertical approach, but above all due to its application-oriented nature. The existing application model allows not only for efficient implementation but also for active modification if necessary. The proposed solutions are therefore evolutionary in nature, consisting of the successive supplementation of data sets with information ensuring the unambiguous identification and visualization of the space above and below the ground. The idea of creating a model that distinguishes spatial parcels, buildings, premises, and utility networks, constituting an object of ownership separate from the land, supplemented with time and space data (volume) and capable of integration with other standards, aligns with the concept of creating a cadastre of the future - SMART Cadastre. This system should be understood as transcending current knowledge, relational and synergistic. Due to the information it contains, it will have the potential to be used for other purposes, even those currently unknown and difficult to define. This may indicate added value beyond the register's nature. The area model can be selectively supplemented point by point, thus gaining a hybrid character. When analyzing the results of previous research, it should be noted that the number of features determining the study result is not a closed set, which means the topic has implications for continued research. An area in which research could certainly continue is artificial intelligence, whose elements were used as a KNIME workflow analysis for comprehensive spatial data flow with statistical and classification analysis. These activities can certainly be continued in the field of advanced neural network prediction tools.

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Kwantyfikacja przestrzeni na rzecz akomodacji własności warstwowej

Słowa kluczowe: ewidencja gruntów i budynków, kataster 3D, własność, działka przestrzenna, kataster SMART, CityGML

Streszczenie:

Transformacja systemów katastralnych z paradygmatu płaskiej projekcji do wielowymiarowej rejestracji nie jest kwestią wyłącznie technologiczną, ale przede wszystkim epistemiczną - dotyczy konceptualizacji własności jako bytu rozciągającego się w przestrzeni i czasie. Niniejszy artykuł stanowi próbę odpowiedzi na pytanie, w jaki sposób system oparty na rzymskiej zasadzie „surficies solo cedit" można dostosować do rzeczywistości, w której relacje własnościowe nie nakładają się hierarchicznie, lecz przenikają się wertykalnie. Autor dowodzi, że problem dotyczy nie tylko rejestracji mostów, tuneli czy infrastruktury podziemnej, ale także redefinicji samej jednostki przestrzeni prawnej. Proponowany algorytm kwantyfikacji powierzchni nie służy zatem wyłącznie doboru obszarów pilotażowych, lecz stanowi narzędzie diagnozy „strukturalnej odporności" przestrzeni na obowiązujący model katastralny. Wyniki analiz przeprowadzonych w obrębie centrum Krakowa pokazują, że granica między tym, co prawnie możliwe, a tym, co przestrzennie konieczne, ulega przesunięciu. W artykule postuluje się, że wdrożenie katastru warstwowego należy rozumieć nie jako reformę rejestru, lecz jako zmianę ontologii własności - z powierzchniowej na objętościową, z trwałej na czasoprzestrzenną, z jednocelowej na relacyjną.

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