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Theoretical and methodological provisions regarding the development and implementation of an integral method for assessing the level of information support of the multipurpose real estate cadastre at the regional level

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Abstract

The paper considers the development and implementation of a method for integral assessment of the application level of the multipurpose real estate cadastre at the regional level. Factors affecting the formation and application of the multipurpose real estate cadastre are singled out. The technology for the formation of information-analytical and spatial support of the results of an integrated assessment deserves attention. In addition, the European experience of forming and applying the multipurpose cadastre, determining the factors affecting its creation, and constructing a theoretical and methodological platform for the real estate identification is systematized.

In modern conditions, the creation of a quantitative basis for the formation and application of the multipurpose real estate cadastre is realized applying the method of integral assessment for making reasonable management decisions at the regional level and developing recommendations for increasing the efficiency of the real estate use.

Based on the formed quantitative basis based in turn on the results of an integral assessment, it is proposed to carry out mathematical modelling and determine the points of growth of the efficiency of the use of the real estate at the regional level using a multipurpose cadastre. The impact of spatial, urban planning, investment and environmental factors on the formation and application of the multipurpose real estate cadastre is determined.

Keywords: multipurpose cadastre; real estate cadastre; land management; land use; spatial, urban planning, investment, environmental factors; scientifically based recommendations; information support; regional development.

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Introduction

The formation of theoretical and methodological provisions regarding the development and implementation of an integral method for assessing the level of information support of the multipurpose real estate cadastre at the regional level is based on relevant scientific developments [1–15].

As a result of the study, the stages of development and implementation of the integral method for assessing the level of information support of the multipurpose real estate cadastre at the regional level are proposed: formation of information and analytical provisions of the integrated assessment of the level of information provision of the multipurpose real estate cadastre at the regional level; selection of the integrated assessment indicators; formation of a multilevel system of factors of the integral assessment; directions for determining local indicators; construction of generalized assessment models; determination of generalizing indicators; construction of an integral assessment model; determination of weighting coefficients; estimation of the integral indicator; interpretation of the obtained results.

The construction of a multilevel system of indicators requires compliance with the following properties: emergentity, which makes for the possibility of the emergence of new properties of the system, which are in turn not inherent in individual components, that is, the properties of the constructed system will not represent a simple set of properties of the components; integrity, thanks to which each component of the system makes a certain contribution to the implementation of the system tasks; structurality, which determines the selection and ordering of

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elements and connections between them; functionality, which serves to define the functions of interaction of the system with the external environment; stability, which makes for the possibility to counteract external factors; reliability, which makes for the possibility to maintain the integrity of the system when removing or adding individual elements; adaptability, which makes for the possibility to change the structure to improve it in case of changes in external factors.

Main part

To solve the stated problem, it is necessary to construct an abstract generalizing model, which includes conceptual models. When synthesizing a complex system for assessing the level of information provision of a multipurpose real estate cadastre, an aggregation procedure is implemented, which involves combining elements into groups accounting for the hierarchy of the indicator system to analyse their impact on the integral features of the system. According to the nature of development, a system that has the ability to develop and responds to a limited set of external factors was chosen. The method of system analysis involves implementation of three general principles: unity (when the system is considered as a whole and as a collection of individual elements); connectivity (when any element of the system is considered in terms of its connection with other elements and the external environment); development (when the possibility of internal changes in system elements and their exclusion or addition by others, as well as the possibility of changes in the nature or degree of interaction of the system elements with the external environment, are considered).

The modular principle of system construction is applied where all indicators of the integrated assessment of the level of information provision of the multipurpose real estate cadastre at the regional level are combined into four modules: spatial indicators (I_{bc1}), urban planning indicators (I_{bc2}), environmental indicators (I_{bc3}) and investment indicators (I_{bc4}).

Of course, the “weight” of each indicator in the module (block) cannot be equal. That is why a hierarchy of indicators was introduced in the middle of each block and their ranking, accounting for the assumption that several indicators can occupy the same positions in the hierarchical “tree”.

The set of indicators of each of the modules of the general structure of the system of indicators of the integrated assessment of the level of information provision are characterized by the assessment method (quantitative, qualitative) and the assessment measure (relative), which is expressed in the names of indicators: “level”, “rate of change”, “index”, “factor of change”, “specific weight”, etc.

The set of indicators was chosen based on the possibility of obtaining objective information from open sources, supplementing with new data. Therefore, the selection of an input set of indicators satisfies the properties of adaptability and the principle of the development of a smart system. To form an integral assessment of the level of information provision of the multipurpose real estate cadastre at the regional level, it is necessary that all indicators of the system are comparable, which can be achieved by normalizing each indicator. It is proposed to carry out normaliza-tion within each of the four groups of indicators and determine the weighting coefficients in accordance with the hierarchy in the whole structure.

The first group is spatial indicators (I_{bc1}), which consists of three hierarchically equivalent indicators. The levels of the real estate use, spatial provision and provision of the state control should receive a quantitative assessment and the introduction of normative values and expected directions of change. The level of the real estate use is proposed to be assessed in accordance with the type of real estate (land, housing, non-residential premises), functional purpose (land areas intended for development, nature protection complexes, residential premises, industrial premises, etc.), operational readiness (ready objects, those that require completion of construction, those in need of capital repair or reconstruction), degree of reproducibility: non-reproducible (mineral deposits), reproducible (buildings, structures), specialization: specialized, which is usually closed to the real estate market (for example, objects of the military-industrial complex or cultural objects) and non-specialized, which are open for direct investment, and purposes of ownership (residence, business, consumption of resources, investments for development).

The matrix of correspondence of the real estate types to the given classification is presented in Table 1.

The level of use of each type of the real estate at the regional level is proposed to be estimated by relative indicators:

– share of the real estate used for functional purposes:

$$fp_{ij} = \frac{S_{ij}^{r}}{S_{ij}^{U}}\left(i = \overline{1,n},\ldots \overline{j = 1,m}\right), \quad (1)$$

where S_{ij}^{r} and S_{ij}^{U} are the total area of the j-th type of the real estate for the i-th functional purpose in the selected region (r) and country (U);

– degree of readiness for operation:

$$ro_{ij} = \frac{S_{ij}^{o}}{\sum_{j=1}^{m} S_{ij}^{o}},\left(i = \overline{1,n},\ldots \overline{j = 1,m}\right), \quad (2)$$

where S_{ij}^{o} is the area of objects of the j-th type of the real estate according to the i-th degree of readiness for operation in the region;

– according to the degree of reproducibility:

$$dr_{ij} = \frac{S_{ij}^{r}}{S_{j}^{p}}\left(i = \overline{1,n},\ldots \overline{j = 1,m}\right), \quad (3)$$

Table 1

Correspondence matrix of the real estate types according to the classification of objects, accounting for the main features

Classification			Property type		
			Land	Dwelling	Non-residential buildings
Functional purpose	land plots for building	fp_1	+	+	+
	nature protection complexes	fp_2	+		+
	residential premises	fp_3	+	+	
	production premises	fp_4	+		+
Readiness for operation	ready-made objects	ro_1	+	+	+
	objects that need to be completed	ro_2	-	+	+
	objects in need of capital repair or reconstruction	ro_3	-	+	+
Degree of reproducibility	Unreproducible	dr_1	+		
	Reproducible	dr_2	-	+	+
Specialization	Specialized	sp_1	+	-	+
	Unspecialized	sp_2	+	+	+
Purposes of possession	Residence	pp_1		+	
	Business	pp_2	+	+	+
	consumption of resources	pp_3	+	-	-
	investment for development	pp_4	+	+	+

where S_{ij}^r is the area of objects of the j-th type of the real estate according to the i-th degree of reproducibility,

S_j^p is the area of objects of the j-th type of the real estate according to the perspective development plan in the region;

– share of the real estate by specialization:

$$sp_{ij} = \frac{S_{ij}^s}{\sum_{j=1}^m S_{ij}^s}, \left(i = \overline{1,n}, \ldots \overline{j = 1,m}\right), \quad (4)$$

where S_{ij}^s is area of objects of the j-th type of the real estate according to the i-th specialization in the region;

– share of the real estate for ownership purposes:

$$pp_{ij} = \frac{S_{ij}^t}{\sum_{j=1}^m S_{ij}^t}, \left(i = \overline{1,n}, \ldots \overline{j = 1,m}\right), \quad (5)$$

where S_{ij}^t is the area of objects of the j-th type of real estate for the i-th purpose of ownership in the region.

Determination of local indicators is carried out according to absolute and qualitative methods using the toolkit of expert assessments (Table 2).

The level of influence of some local indicators on the general level of information provision of the multipurpose real estate cadastre of the regions is assessed by specialists based on the method of expert analysis. The formation of expert groups is one of

Table 2

Determination of local indicators

Indicator	Methods		Indicator	Methods	
	Absolute	Qualitative		Absolute	Qualitative
i_{bcp11}	-	+	i_{bc34}	-	+
i_{bcp12}	-	+	i_{bc35}	-	+
i_{bcp13}	-	+	i_{bc36}	+	-
i_{bc21}	-	+	i_{bc37}	+	-
i_{bc22}	-	+	i_{bc38}	+	-
i_{bc23}	-	+	i_{bc39}	+	-
i_{bc24}	-	+	i_{bc310}	+	-
i_{bc25}	-	+	i_{bc311}	+	-
i_{bc26}	+	-	i_{bc312}	+	-
i_{bc27}	+	-	i_{bc41}	+	-
i_{bc28}	+	-	i_{bc42}	+	-
i_{bc29}	+	-	i_{bc43}	+	-
i_{bc210}	+	-	i_{bc44}	-	+
i_{bc211}	-	+	i_{bc45}	-	+
i_{bc31}	-	+	i_{bc46}	-	+
i_{bc32}	-	+	i_{bc47}	-	+
i_{bc33}	-	+			

the important stages of the expert analysis since their professional experience, combined with modern mathematical methods of information processing, allows determining general development trends and parameters of individual technical and social systems. That is why, when conducting an expert analysis, it is necessary to formulate clear requirements for the quantitative and qualitative composition of expert groups. The most important modules of the general scheme of expert evaluation will be considered separately.

As for the qualitative composition of the expert group, the main requirement is professional competence, which is determined based on the analysis of the significance of the results of its activities, the level of awareness of the world achievements in science and technology on the subject under consideration, understanding of problems and prospects for their development. The paper proposes a method for determining the level of an expert's competence – self-assessment (or assessment by a decision-maker) based on the reference table of an expert's self-assessment. According to the given problem, the selection of experts was carried out according to the following criteria: higher education in specialization 193 "Geodesy and land management" (bc_{11}); a scientific degree in the relevant field (bc_{12}); experience of participation in expert groups (bc_{13}); participation in the development of projects for the field of geodesy, land management, cadastre formation and complex spatial plans (bc_{14}); experience of practical activities in the presented field (bc_{15}); experience of interaction with stakeholders operating in the field of geodesy, land management, cadastre formation and complex spatial plans for the development of territories (bc_{16}); experience of participation in the formation of geospatial and cadastral information, development of land management documentation and comprehensive plans for the development of territories (bc_{17}).

It was determined that for the selection of experts and the formation of an expert group, relevant factors are used, the values of which vary from 0 to 10. The decision on the selection of experts is made depending on the average value of the factors for each expert. The spatial index has a great influence on the accuracy of expert assessments. Thus, the more precisely the spatial indicator is determined, the more accurate the result of the expert assessment will be. The spatial indicator has such an influence because it is the basis for building a multipurpose real estate cadastre system, and the accuracy of spatial factors is directly influenced by the quality of the cartographic base, on which the cadastral system is based.

If the average value of indicators for the relevant expert is in the range from 0 to 5, then a decision is made to refuse his participation in the expert group, and if the average value is in the range from 6 to 10, then the expert is included in the expert group. Formation of information according to relevant experts was carried out based on their questionnaire. The results of determining the average values for the selection of experts according to the specified criteria are presented in the Table 3.

The accuracy of expert assessment is affected by quantitative indicators of expert groups since a decrease in the number of experts leads to a decrease in the accuracy of assessments while an increase leads to complications in the organization of examinations, an increase in the terms of its conduct and processing of results. The formation of expert groups from 10 to 150 people is proposed. When conducting a specific survey, a group is formed that would satisfy the following conditions based on quantitative indicators:

$$N_{min} \le N \le N_{max}, \quad (6)$$

where N_{min} and N_{max} are minimum and maximum number of experts in the group.

Proposed models for estimating the maximum and minimum number of experts:

$$N_{max} \le \frac{3}{2} \cdot \frac{\sum_{i=1}^{n} K_i}{K_{max}}, \quad (7)$$

where K_i is the competence of the i-th expert in a group of n experts, K_{max} is the maximum value of competence in the group;

$$N_{min} = \frac{1}{2} \cdot \left(\frac{3}{\varepsilon} + 5 \right), \quad (8)$$

where ε is a predetermined value of the average polling error.

The accuracy of the measurement of the presented estimates is determined by the concordance criterion, the value of which varies between 0 and 1. If this criterion approaches 1, the higher the accuracy of the estimates and the consistency of the experts' opinions are. To confirm the reliability of the values of the concordance criterion, Pearson's χ^2 is determined. The obtained values of the concordance criterion (0.75) indicate a high level of consistency of the experts' opinions and measurement accuracy.

To ensure objectivity and increase the effectiveness of expert evaluation, it is advisable to invite experts whose opinions systematically differ from the average ones across the group, which will allow for correcting biases and making systemic corrections.

Based on models (6) – (8), a group of 22 experts was formed, the competence coefficient of each of which is above average ($K \geqslant 0.75$). Each expert is assigned a corresponding serial number. The decision regarding the inclusion of experts in expert groups to determine local indicators of the level of information support of the multipurpose real estate cadastre at the regional level is made according to the functioning algorithm of the expert group selection module. Directions for determining local indicators

Table 3

The results of determining the average values regarding the selection of experts according to the specified criteria, resp. unit

Expert number	bc_{11}	bc_{12}	bc_{13}	bc_{14}	bc_{15}	bc_{16}	bc_{17}	Average value
E_{bc1}	0	0	2	6	9	8	8	4.714
E_{bc2}	5	10	5	9	9	8	7	7.571
E_{bc3}	0	0	8	8	7	8	8	5.571
E_{bc4}	0	0	8	8	8	7	6	5.286
E_{bc5}	0	0	9	9	8	7	6	5.571
E_{bc6}	0	0	3	8	7	8	8	4.857
E_{bc7}	5	0	4	9	8	9	9	6.286
E_{bc8}	5	10	8	9	8	9	9	8.286
E_{bc9}	0	0	7	7	5	8	8	5.0
E_{bc10}	5	0	8	6	9	7	6	5.857
E_{bc11}	5	0	5	7	9	7	5	5.429
E_{bc12}	5	10	8	9	4	8	9	7.571
E_{bc13}	0	0	7	6	4	7	6	4.286
E_{bc14}	0	0	8	6	3	7	6	4.286
E_{bc15}	0	0	6	4	3	9	9	4.429
E_{bc16}	0	0	6	5	4	8	8	4.429
E_{bc17}	5	10	7	9	9	8	8	8.0
E_{bc18}	5	10	6	6	9	9	7	7.429
E_{bc19}	0	0	7	6	4	7	7	4.429
E_{bc20}	5	0	8	7	5	9	8	6.0
E_{bc21}	0	0	8	6	4	8	8	4.857
E_{bc22}	0	0	8	7	3	8	7	4.714
E_{bc23}	0	0	4	4	3	7	6	3.429
E_{bc24}	0	0	6	6	3	8	8	4.429
E_{bc25}	5	0	7	7	8	9	9	6.429
E_{bc26}	5	10	9	9	9	9	9	8.571
E_{bc27}	0	0	7	5	5	6	5	4.0
E_{bc28}	5	0	7	6	5	8	8	5.571
E_{bc29}	0	0	5	7	4	6	6	4.0
E_{bc30}	0	0	4	8	4	6	5	3.857
E_{bc31}	5	10	6	9	5	8	8	7.286
E_{bc32}	5	0	6	7	4	9	9	5.714
E_{bc33}	0	0	5	5	5	7	7	4.143
E_{bc34}	0	0	6	5	4	6	6	3.857
E_{bc35}	5	10	7	8	8	8	8	7.714
E_{bc36}	5	0	4	6	9	9	9	6.0
E_{bc37}	0	0	5	5	4	6	6	3.714
E_{bc38}	5	0	5	6	8	9	9	6.0
E_{bc39}	0	0	5	6	5	6	5	3.857
E_{bc40}	0	0	6	5	5	7	7	4.286
E_{bc41}	5	10	4	9	8	9	9	7.714
E_{bc42}	5	0	5	7	9	8	8	6.0
E_{bc43}	0	0	6	6	5	5	4	3.714

for assessing the level of information provision of the multipurpose real estate cadastre at the regional level are characterized by absolute and relative factors.

The construction of generalized evaluation models is carried out based on the relevant indicators of the multi-level system and local factors using the geometric mean formula:

$$I_{bc_i} = \sqrt[N]{\prod_{j=1}^{N} i_{bc_{ij}}}, \qquad (9)$$

where $i = 1$ are spatial indicators (I_{bc1}), $i = 2$ are urban indicators (I_{bc2}), $i = 3$ are environmental indicators (I_{bc3}), $i = 4$ are investment indicators (I_{bc4}).

An integrated model for assessing the level of information support was constructed:

$$I_{bc} = \sqrt{I_{bc_1} \cdot k_{vbc_1} + I_{bc_2} \cdot k_{vbc_2} + I_{bc_3} \cdot k_{vbc_3} + I_{bc_4} \cdot k_{vbc_4}}, \quad (10)$$

where $k_{vbc_1}, k_{vbc_2}, k_{vbc_3}, k_{vbc4}$ are weighting coefficients, which are determined by the scale of T. Saati.

The determined quantitative parameters characterize the level of mutual influence of generalizing indicators relative to the integral factor of assessing the level of information support of the multipurpose real estate cadastre at the regional level, the value of which varies from 0.11 to 9.

Construction of a matrix of mutual influence of generalizing indicators relative to the integral factor of assessing the level of information support of the multipurpose real estate cadastre at the regional level (A_{Ibci}):

$$A_{I_{bci}} = \begin{bmatrix} 1 & \frac{I_{bc_1}}{I_{bc_2}} & \frac{I_{bc_1}}{I_{bc_3}} & \frac{I_{bc_1}}{I_{bc_4}} \\ \frac{I_{bc_2}}{I_{bc_1}} & 1 & \frac{I_{bc_2}}{I_{bc_3}} & \frac{I_{bc_2}}{I_{bc_4}} \\ \frac{I_{bc_3}}{I_{bc_1}} & \frac{I_{bc_3}}{I_{bc_2}} & 1 & \frac{I_{bc_3}}{I_{bc_4}} \\ \frac{I_{bc_4}}{I_{bc_1}} & \frac{I_{bc_4}}{I_{bc_2}} & \frac{I_{bc_4}}{I_{bc_3}} & 1 \end{bmatrix}. \quad (11)$$

Determination of the components of the eigenvector for generalizing indicators:

$$K_{I_{bc_i}} = \frac{I_{bc_i}}{\sqrt[4]{\prod_{j=1}^{4} I_{bc_j}}}, \quad (12)$$

where $i = 1$ – spatial, $i = 2$ – urban planners, $i = 3$ – environmental, $i = 4$ – investment;

determination of weighting coefficients for generalizing indicators:

$$k_{vbc_i} = \frac{K_{I_{bc_i}}}{\sum_{i=1}^{4} K_{I_{bc_i}}}, \quad (13)$$

where $i = 1$ – spatial, $i = 2$ – urban planners, $i = 3$ – environmental, $i = 4$ – investment.

An approach to the determination of weighting coefficients based on the method of analysis of hierarchies is proposed. The degree of reliability of the simulation model of the level of information provision of the multipurpose real estate cadastre of the regions is completely determined by a well-founded selection of correction factors. It is proposed to choose the correction factors of the modified method for analyses of hierarchies. The most significant advantage of this method is that it allows the decision maker (DM) to interactively find the "right" solution, rather than presenting conclusions based on the own experience to find the option that best addresses the nature of the problem. This method is not based on a large amount of information received from experts, it is dynamic, and that is, with the change of the given advantages, the criterion indicators also change. The classic statement of the problem consists in choosing a set of alternatives (options) $V = \{V_1, V_2, ..., V_n\}$, which are estimated according to defined criteria $K_{vbc} = \{K_{vbc1}, K_{vbc2}, ..., K_{vbcm}\}$.

At the first stage of the method of analyses of hierarchies, ranking of the criteria should be carried out. Conducting an expert assessment of the level of information provision of the multipurpose real estate cadastre of the regions allowed ranking in groups of spatial, urban planning, environmental and investment indicators. To obtain reliable results, it is necessary to build a scale that will distinguish the feelings of experts according to the quality of reasoning with the numerical indicators of the selected scale. The scale is determined based on pairwise comparisons, estimating the intensity from 1 to 9. In intermediate cases, even numbers are used. Pairwise comparisons are made under the assumption that preferences are deterministic rather than probabilistic, so the given preferences are assumed constant and independent of factors not included in the formulation of the problem. Construction and analysis of hierarchy matrices was carried out according to the following algorithm:

1. Conducting pairwise comparisons of criteria for the level of information provision of the multipurpose real estate cadastre of regions in groups of spatial, urban planning, environmental and investment indicators. The system of pairwise comparisons can be represented in the form of a square inversely symmetric matrix, the elements of which satisfy the condition:

$$a_{ij} = \frac{1}{a_{ji}}, \; a_{ii} = 1; \; i, j = \overline{1, n}. \quad (14)$$

Constructed matrices of pairwise comparisons in groups of spatial, urban planning, environmental and investment indicators of the level of information support of the multipurpose real estate cadastre of the regions are presented in Tables 4–7.

Table 4

Matrix of pairwise comparisons of spatial indicators, resp. unit

a_{ij}	i_{bcp11}	i_{bcp12}	i_{bcp13}
i_{bcp11}	1	0.50	5
i_{bcp12}	2	1	6
i_{bcp13}	0.2	0.17	1
$\sum_{i=1}^{n} a_{ij}$	3.2	1.67	12.0

Table 5

Matrix of pairwise comparisons of urban planning indicators, resp. unit

a_{ij}	i_{bcp21}	i_{bcp22}	i_{bcp23}	i_{bcp24}	i_{bcp25}	i_{bcp26}	i_{bcp27}	i_{bcp28}	i_{bcp29}	i_{bcp210}	i_{bcp211}
i_{bcp21}	1	0.25	3	0.20	2	3.00	2.00	1	2	1	3.00
i_{bcp22}	4	1	5	0.2	6	4	4	3	2	3	2
i_{bcp23}	0.33	0.2	1	0.14	1	2	2	0.5	0.33	1	2
i_{bcp24}	5	5	7	1	7	6	7	5	5	7	6
i_{bcp25}	0.5	0.17	1	0.14	1	2.00	1	1.00	0.33	0.5	1.00
i_{bcp26}	0.33	0.25	0.5	0.17	0.5	1	2	2	1	0.5	0.33
i_{bcp27}	0.5	0.25	0.5	0.14	1	0.5	1	1	1.00	0.5	2
i_{bcp28}	1	0.33	2	0.2	1	0.5	1	1	2	1	1
i_{bcp29}	0.5	0.5	3	0.2	3	1	1	0.5	1	3	0.5
i_{bcp210}	1	0.33	1	0.14	2	2.00	2	1.00	0.33	1	2.00
i_{bcp211}	0.33	0.5	0.5	0.17	1	3	0.50	1	2	0.5	1
$\sum_{i=1}^{n} a_{ij}$	14.5	8.78	24.50	2.7	25.5	25.0	23.5	17.0	17.0	19.0	20.83

Table 6

Matrix of pairwise comparisons of environmental indicators, resp. unit

a_{ij}	i_{bcp31}	i_{bcp32}	i_{bcp33}	i_{bcp34}	i_{bcp35}	i_{bcp36}	i_{bcp37}	i_{bcp38}	i_{bcp39}	i_{bcp310}	i_{bcp311}	i_{bcp312}
i_{bcp31}	1	0.17	0.14	3	2	1	1	0.2	0.25	1	0.5	0.33
i_{bcp32}	6	1	1	4	4	7	5	3	3	5	5	4
i_{bcp33}	7	1	1	5	5	4	5	3	4	3	3	4
i_{bcp34}	0.33	0.25	0.2	1	1	2	2	0.25	0.2	3	1	2
i_{bcp35}	1	0.25	0.2	1	1	1	2	1	1	2	2	2
i_{bcp36}	1	0.14	0.25	0.5	1	1	0.25	0.2	0.14	1	2	1
i_{bcp37}	1	0.2	0.2	0.5	0.5	4	1	0.25	0.2	2	1	0.25
i_{bcp38}	5	0.33	0.33	4	1	5	4	1	1	5	3	3
i_{bcp39}	4	0.33	0.25	5	1	7	5	1	1	3	5	0.5
i_{bcp310}	1	0.2	0.33	0.33	0.5	1	0.5	0.2	0.33	1	1	0.5
i_{bcp311}	2	0.2	0.33	1	0.5	0.5	1	0.33	0.2	1	1	1
i_{bcp312}	3	0.25	0.25	0.5	0.5	1	4	0.25	2	2	1	1
$\sum_{i=1}^{n} a_{ij}$	32.33	4.33	4.49	25.83	18.0	34.5	30.75	10.68	13.33	29.0	25.5	19.58

Table 7

Matrix of pairwise comparisons of investment indicators, resp. unit

a_{ij}	i_{bcp41}	i_{bcp42}	i_{bcp43}	i_{bcp44}	i_{bcp45}	i_{bcp46}	i_{bcp47}
i_{bcp41}	1	2	2	0.33	1	0.2	0.2
i_{bcp42}	0.5	1	0.5	0.5	1	0.17	0.25
i_{bcp43}	0.5	2	1	2	0.5	0.25	0.2
i_{bcp44}	3	2	0.5	1	1	0.2	0.17
i_{bcp45}	1	1	2	1	1	5	0.2
i_{bcp46}	5	6	4	5	0.2	1	0.33
i_{bcp47}	5	4	5	6	5	3	1
$\sum_{i=1}^{n} a_{ij}$	16.0	18.0	15.0	15.83	9.7	9.82	2.35

Table 8

Vector columns of weighting coefficients of all groups of indicators, resp. unit

Groups of indicators of the level of information provision of the multipurpose real estate cadastre of the regions			
Spatial	Urban planning	Ecological	Investment
$\begin{pmatrix}0.343\\0.575\\0.082\end{pmatrix}$	$\begin{pmatrix}0.086\\0.162\\0.049\\0.330\\0.042\\0.045\\0.043\\0.058\\0.069\\0.061\\0.054\end{pmatrix}$	$\begin{pmatrix}0.042\\0.205\\0.202\\0.051\\0.062\\0.035\\0.040\\0.117\\0.114\\0.032\\0.039\end{pmatrix}$	$\begin{pmatrix}0.077\\0.054\\0.071\\0.084\\0.145\\0.213\\0.356\end{pmatrix}$

Table 9

Variants of the values of the weighting coefficients of the indicators of the level of information provision of the multipurpose real estate cadastre of the regions presented by experts, resp. unit

Indicator	Weighting coefficients		
	Variant 1 (V_1)	Variant 2 (V_2)	Variant 3 (V_3)
Spatial indicators			
i_{bcp11}	0.4	0.4	0.2
i_{bcp12}	0.4	0.5	0.7
i_{bcp13}	0.2	0.1	0.1
Urban indicators			
i_{bc21}	0.1	0.2	0.1
i_{bc22}	0.2	0.2	0.1
i_{bc23}	0.05	0.05	0.05
i_{bc24}	0.3	0.2	0.2
i_{bc25}	0.05	0.05	0.05
i_{bc26}	0.05	0.05	0.05
i_{bc27}	0.05	0.05	0.1
i_{bc28}	0.05	0.05	0.1
i_{bc29}	0.05	0.05	0.1
i_{bc210}	0.05	0.05	0.1
i_{bc211}	0.05	0.05	0.05
Environmental indicators			
i_{bc31}	0.05	0.05	0.05
i_{bc32}	0.15	0.2	0.15
i_{bc33}	0.2	0.2	0.1
i_{bc34}	0.05	0.05	0.1
i_{bc35}	0.05	0.05	0.1
i_{bc36}	0.05	0.05	0.05
i_{bc37}	0.05	0.05	0.05
i_{bc38}	0.2	0.1	0.1
i_{bc39}	0.1	0.1	0.1
i_{bc310}	0.03	0.05	0.05
i_{bc311}	0.02	0.05	0.05
i_{bc312}	0.05	0.05	0.1
Investment indicators			
i_{bc41}	0.1	0.05	0.1
i_{bc42}	0.1	0.15	0.15
i_{bc43}	0.1	0.1	0.1
i_{bc44}	0.1	0.1	0.2
i_{bc45}	0.1	0.1	0.1
i_{bc46}	0.2	0.25	0.15
i_{bc47}	0.3	0.25	0.2

2. Normalization of each element of the matrix of pairwise comparisons is made according to the formula:

$$A_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}. \quad (15)$$

3. Determination of the "weight" of the criterion is made according to the research objective:

$$\overline{A_{ij}} = \frac{1}{n}\sum_{j=1}^{n} A_{ij}. \quad (16)$$

Based on the calculated "weight", vector-columns of the weighting coefficients of the indicators of each group are arranged, determining their compliance with individual criteria.

Calculated column vectors (MK_n) of the weighting coefficients of all groups of indicators are presented in the Table 8.

4. Selection of a set of options for each criterion of all groups of indicators by a group of experts (Table 9).

5. Construction of matrices of pairwise comparisons according to the selected options for each criterion of all groups of indicators; normalization and determination of "weight" according to the research objective (12) – (14).

6. Formation of matrices of alternatives (MA_n) for each group of indicators. The results of the numerical experiment are presented in the Tables 10–13.

Table 10

Matrix of alternatives (comparison of options according to criteria) of spatial indicators, resp. unit

Indexes	i_{bcp11}	i_{bcp12}	i_{bcp13}
V_1	0.63	0.44	0.65
V_2	0.11	0.39	0.12
V_3	0.26	0.17	0.23

Table 11

Matrix of alternatives (comparison of options by criteria) of urban planning indicators, resp. unit

Indexes	i_{bcp21}	i_{bcp22}	i_{bcp23}	i_{bcp24}	i_{bcp25}	i_{bcp26}	i_{bcp27}	i_{bcp28}	i_{bcp29}	i_{bcp210}	i_{bcp211}
V_1	0.50	0.66	0.35	0.22	0.56	0.49	0.24	0.64	0.41	0.55	0.38
V_2	0.12	0.24	0.50	0.47	0.31	0.25	0.62	0.21	0.33	0.28	0.5
V_3	0.38	0.10	0.15	0.31	0.13	0.26	0.14	0.15	0.26	0.17	0.12

Table 12

Matrix of alternatives (comparison of options according to criteria) of environmental indicators, resp. unit

Indexes	i_{bcp31}	i_{bcp32}	i_{bcp33}	i_{bcp34}	i_{bcp35}	i_{bcp36}	i_{bcp37}	i_{bcp38}	i_{bcp39}	i_{bcp310}	i_{bcp311}	i_{bcp312}
V_1	0.53	0.16	0.33	0.16	0.50	0.52	0.23	0.46	0.39	0.39	0.35	0.20
V_2	0.33	0.62	0.39	0.66	0.35	0.35	0.65	0.39	0.42	0.44	0.5	0.49
V_3	0.14	0.22	0.28	0.19	0.15	0.14	0.12	0.15	0.19	0.17	0.15	0.31

Table 13

Matrix of alternatives (comparison of options by criteria) of comparisons of investment indicators, resp. unit

Indexes	i_{bcp41}	i_{bcp42}	i_{bcp43}	i_{bcp44}	i_{bcp45}	i_{bcp46}	i_{bcp47}
V_1	0.51	0.66	0.35	0.45	0.61	0.57	0.54
V_2	0.16	0.22	0.38	0.4	0.3	0.26	0.3
V_3	0.33	0.12	0.27	0.15	0.09	0.17	0.16

Table 14

Estimated values of the final priorities of the values of the weighting coefficients of the indicators, etc. unit

Variants	Groups of indicators of the level of information provision of the multipurpose real estate cadastre of the regions			
	Spatial	Urban planning	Environmental	Investment
V_1	0.343	**0.415**	0.325	**0.540**
V_2	**0.575**	0.359	**0.471**	0.290
V_3	0.082	0.225	0.206	0.170

Table 15

The value of the random consistency indicator for each group of indicators, resp. unit

Indexes	N	I_r
Spatial	3	0.58
Urban planning	11	1.49
Ecological	12	1.5
Investment	7	1.32

7. The calculation of the final values of the priorities to determine the "weight" of the alternatives for achieving the goal set in the study is carried out according to the formula:

$$P_n = MA_n \cdot MK_n, n = \overline{1;4}. \quad (17)$$

8. The calculated final priorities of the variants of the weighting coefficients of the indicators presented by the experts are presented in the Table 14.

According to the results of the numerical experiment, the priority variants of the values of the weighting coefficients of all groups of indicators of the level of information support of the multipurpose real estate cadastre of the regions were identified: for spatial – the second option (V_2) – 57.5%; for urban planning – the first option (V_1) – 41.5%; for ecological – the second option (V_2) – 47.1%; for investment – the first option (V_1) – 54.0%.

The reliability of the obtained collective determination of the priority variants of the values of the weighting coefficients of all groups of indicators is estimated based on the generalized consistency ratio. The evaluation algorithm is based on the calculation of matrix elements normalized by the geometric mean of pairwise comparisons of indicators:

– normalization by the geometric mean of the elements of the matrices of pairwise comparisons is carried out according to the formula:

$$G_k = \sqrt[n]{\prod_{j=1}^{n} a_{kj}}; \quad (18)$$

– the components of the normalized geometric mean vector of priorities are calculated according to the formula:

$$VG_k = \frac{G_k}{\sum_{k=1}^{n} G_k}; \quad (19)$$

– the eigenvalue of the matrices of pairwise comparisons is found by the formula:

$$\lambda_{max} = \sum_{k=1}^{n}\left(\sum_{i=1}^{n} a_{ik} \cdot G_k\right); \quad (20)$$

– based on the known eigenvalues of the matrices of pairwise comparisons of each group of indicators, the consistency index is calculated as:

$$I_c = \frac{\lambda_{max} - 1}{n - 1}; \quad (21)$$

– the consistency ratio is determined by the formula:

$$K_{vbk_i} = \frac{I_c}{I_r}, \quad (22)$$

where I_r is an indicator of random consistency, which depends on the size of the matrix of pairwise comparisons only. The values of I_r for each group of indicators of the level of information provision of the multipurpose real estate cadastre of the regions are presented in Table 15.

Conclusion

The found solution regarding the selection of priorities for the distribution of weighting coefficients is considered consistent if the value of the consistency ratio satisfies the condition $K_{vbk_i} \leq 0.15$. The conducted numerical experiment allows us to assert that the decision regarding the selection of options for the values of the weighting coefficients of all groups of indicators can be considered reliable because the corresponding values of the consistency ratio in each group correspond to the normative ones: for spatial $K_{vbk_1} = 0.135$; for urban planners $K_{vbk_2} = 0.097$; for ecological ones $K_{vbk_3} = 0.088$; for investment $K_{vbk_4} = 0.123$.

Thus, the priority variants of the values of the weighting coefficients of the indicators can be applied when constructing a simulation model, and the presented algorithm for their selection allows obtaining a consistent result on groups of indicators of different sizes and when analysing any number of variants presented by experts. The assessment of the integral indicator of the level of information support of the multipurpose real estate cadastre at the regional level is carried out based on the corresponding integral model.

The interpretation of the obtained results forms a quantitative basis and a theoretical basis for substantiating directions to create and implement information support of the multipurpose cadastre. Based on the obtained results, mathematical modelling of changes in the integral indicator, its forecasting and the formation of reasonable decisions regarding the increase in the efficiency of land relations are carried out using modern information support of the multipurpose cadastre at the regional level. Thus, as a result of the study, an integral method for assessing the level of information support of the multipurpose real estate cadastre at the regional level was developed. The application of this method allows creating a quantitative basis for decision-making regarding the increase in the efficiency of the formation and use of the multipurpose real estate cadastre at the regional level [16–22]. In addition, the results of the implementation of the integral method create a basis for the construction of an algorithm for the implementation of the multipurpose real estate cadastre at the regional level.

Теоретико-методичні положення щодо розробки та реалізації інтегрального методу оцінки рівня інформаційного забезпечення багатоцільового кадастру нерухомості на регіональному рівні

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Анотація

У статті розглянуті питання розробки та реалізації методу інтегральної оцінки рівня застосування багатоцільового кадастру нерухомості на регіональному рівні. Виокремлені чинники, що впливають на формування та використання багатоцільового кадастру нерухомості. Заслуговує на увагу технологія формування інформаційно-аналітичного та просторового забезпечення результатів інтегральної оцінки. Крім того, систематизовано європейський досвід формування та використання багатоцільового кадастру, визначення чинників, що впливають на його створення, побудови теоретико-методичної платформи визначення нерухомості.

У сучасних умовах створення кількісної основи формування та використання багатоцільового кадастру нерухомості здійснюється шляхом застосування методу інтегральної оцінки для прийняття обґрунтованих управлінських рішень на регіональному рівні та розробки рекомендацій зростання ефективності використання нерухомості.

На основі сформованої кількісної основи за результатами інтегральної оцінки запропоновано здійснити математичне моделювання та визначити точки зростання ефективності використання нерухомості на регіональному рівні шляхом застосування багатоцільового кадастру. Визначено вплив просторових, містобудівних, інвестиційних та екологічних чинників на формування та використання багатоцільового кадастру нерухомості.

Ключові слова: багатоцільовий кадастр; кадастр нерухомості; землеустрій; використання земель; просторові, містобудівні, інвестиційні, екологічні чинники; науково обґрунтовані рекомендації; інформаційне забезпечення.

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