ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

UDC 711.4+711.5

METHODOLOGICAL BASIS OF BIM-ANALYSIS OF DAMAGE AND ASSESSMENT OF IMPACTS, CONSEQUENCES, RESOURCES FOR RESTORATION OF BUILDINGS AND STRUCTURES

D.E. Prusov,
Doct. Tech. Sci., Prof. Dr. Habil.

D.A. Makatora,
Cand. Tech. Sci.

R.A. Kubanov,
Cand. Ped. Sci.

Kyiv National University of Construction and Architecture
Institute of Innovative Education
03037, Ukraine, Kyiv, Osvity str., 4

DOI: 10.32347/2410-2547.2024.112.302-315

The methodological basis of BIM analysis of damage and assessment of impacts, consequences, resources has been proposed for the restoration of buildings and structures based on the application of the generalized Harrington function, consisting of a number of interconnected sequential stages, aimed at determining the technical condition of the object of examination and the causes of its damage and destruction, obtaining a quantitative and qualitative assessment, choosing a comprehensive strategy for evaluating buildings and structures, and implementation of construction and technical substantiation regarding the expediency of reconstruction or impracticability of restoration.
Keywords: restoration of buildings and structures, method of system assessment, technical condition, damage analysis, assessment of impacts, consequences, resources.

Introduction

Theoretical, methodical and application-oriented aspects of assessment of impacts, consequences, resources for the restoration of buildings and structures in urban planning and territorial planning are an important component of comprehensive restoration of territories, and involve the combination of various aspects and sectors of activity in order to achieve harmonious and balanced development of territories. In particular, integrated management in urban planning and territorial planning involves the combination of such aspects as economy, ecology, social sphere, culture, transport and infrastructure. This means that when making decisions about the development of territories, it is necessary to take into account the interrelationships between various spheres of life of the population.

The theoretical aspect of the BIM analysis of damage and assessment of impacts, consequences, resources for the restoration of buildings and structures consists in the development of conceptual approaches and theoretical foundations that allow understanding the integration of various aspects of territory management. It is important to develop a methodology for assessing and analyzing interactions between different sectors, as well as to develop criteria and indicators for evaluating the effectiveness of integrated recovery management.

The methodological aspect of the BIM analysis of damage and assessment of impacts, consequences, resources for the restoration of buildings and structures involves the development of methods of integration of various sectors and aspects in the management process. It is important to develop a toolkit for accounting for various indicators and factors that affect the development of territories. It is also necessary to develop algorithmic models for decision-making and territorial planning, taking into account all aspects and sectors.

The application-oriented aspect of the development of the methodological basis of the BIM analysis of damage and assessment of impacts, consequences, resources for the restoration of buildings and structures involves the implementation of the developed methods and tools in the practice of managing urban planning and territorial planning. This means that management bodies, architectural and construction companies, public organizations and the public must take into account integrated planning and management in the development and implementation of projects. Only through joint efforts, it is

possible to ensure sustainable and balanced development of territories, improve the quality of life of the population and ensure the stability of the economy.

Therefore, the harmonious and balanced development of territories is possible only if various aspects and sectors of activity are combined on the basis of integrated management, and the development and implementation of the methodology of BIM-analysis of damage and assessment of impacts, consequences, resources for the restoration of buildings and structures will allow to achieve integrity and ensure balanced development territories, ensuring the quality of life of the population and preservation of natural resources for further sustainable development of cities and territories.

Formulation of the problem

The scale of the destroyed territories and the problems that arose during the armed conflict are extremely large, and recovery will take a lot of time and effort. Therefore, the task of comprehensive restoration of territories remains relevant for Ukraine in the long term.

Under normal conditions, the volume of construction activity increases as a result of the physical and moral aging of buildings and structures, price increases and changes in the ownership of real estate; the need for reconstruction of industrial enterprises, low-rise buildings and activation of new construction in the areas of old buildings. At the same time, a reliable assessment of the technical condition of buildings and structures stands out as an important direction of construction activity.

The identification of destroyed and damaged objects and the digitization of data on the amount and nature of destruction are now often based on the study of orthophotoplans, which are created on the basis of photo and video data taken using unmanned aerial vehicles. In addition, the number of destroyed and damaged objects is so large, and the deadlines for construction and technical expertise are so critical that the development and implementation of computerized systems and support technologies designed to minimize the participation of experts have become extremely urgent.

The methodological basis of the BIM analysis of damage and assessment of impacts, consequences, resources for the restoration of buildings and structures is the basis of a methodological foundation that provides a holistic approach to planning and development of the territory, including multifactorial aspects, such as economic, ecological, social, transport and other .

The aim of the work and research tasks

When systematically examining the existing state of destruction, the entire complex should be taken into account in the following sequence: territories, buildings and structures.

There is a need to study the components of damage assessment of buildings (structures) and to develop a systematic method of their diagnosis on the damaged object in order to achieve efficiency when making a decision regarding reconstruction or impracticality of restoration depending on the generalized coefficient of destruction. The task of the research consists in the development of a step-by-step assessment algorithm - a Method of Systematic Assessment of Damage to Buildings and Structures (hereinafter referred to as "MSADBS") using a system of indicators, the normative values and importance of which are established by certified civil engineers under the condition of substantiation, regarding the expediency of reconstruction or the impracticality of restoration. The developed methodology for assessing the damage to buildings and structures consists of a number of interrelated sequential stages aimed at obtaining a quantitative and qualitative assessment of the MSADBS, the selection of a comprehensive strategy for the assessment of buildings and structures.

The method of system assessment of the MSADBSshould be built taking into account the results of monitoring the external environment, namely taking into account the influence of factors such as: natural, market, competitive, scientific-technological, socio-demographic, political, foreign-economic, dynamism, turbulence.

To achieve the specified goal, it is proposed to develop a methodological basis for the BIM analysis of damage and assessment of the effects, consequences, resources for the restoration of buildings and structures, which can be the basis for performing construction and technical examinations, which is the determination of the technical condition of the object of examination and the causes of its damage and destruction .

Analysis and assessment of impacts, consequences, resources for restoration and methods of assessment of damage to buildings and structures

Territories, buildings and structures are destroyed during martial law. Especially in these conditions, there is a need to develop and improve damage assessment techniques to unify solutions to the

specified problem.

Certain aspects of the methodological basis, regarding the property of assessments of business entities, were reflected in the works of foreign and domestic scientists (Grynyov, 2008; Fedulova, 2005; Mandzyuk, 2011, etc.)

All calculation requirements of the norms are formed for limit states, which determine the boundary between permissible and unacceptable states of structures. According to The State Construction Standards of Ukraine limit states are divided into two groups and can be attributed to the structure as a whole, to its individual elements, connections or cross sections. The transition of the structure through the limit state corresponds to one of the types of failure. At the same time, limit states are considered permissible.

The limit states of the first group are classified as failure-disruption and may be associated with a violation of the requirements for preserving the integrity or possibility of the object's existence or with non-compliance with safety requirements for people and the environment. The second group of limit states includes states that complicate normal operation or reduce the durability of the object compared to the established service life.

The first group contains limit states, the transition through which leads to the complete inoperability of the object and for which non-limit states can be the following:

– destruction of any nature;
– loss of shape stability;
– loss of position stability;
– transition to a variable system;
– qualitative change of configuration;
– other phenomena that require the termination of operation (perforation of the wall of the container with toxic substances or excessive movement of the base during subsidence or heaving of the soil).

Off-limits for the second group of limit states are the following:

– excessive movements or turns of some points of the structure;
– unacceptable fluctuations;
– the formation and opening of cracks, their reaching the maximum permissible values of opening or length;
– loss of shape stability in the form of local deformation;
– damage from corrosion or other types of physical wear, which lead to the need to limit operation due to a reduction in the object's service life.

Limit states of this group are classified in most cases as failure-obstacle and may be associated with violation of requirements for:

– use of the object without restrictions;
– the level of comfort and amenities of the staff;
– appearance of structures;
– possibilities of development and modernization of the facility.

The technical condition of buildings and structures as a whole is a function of the efficiency of individual structural elements and the connections between them. The technical condition of objects changes during their operation, which is expressed in a change in the quantitative performance characteristics (in particular, in a decrease in reliability). Deterioration of the technical condition can occur as a result of changes in the physical properties of materials and products, the nature of connections between them, and changes in sizes and shapes.

The service life of structural elements depends on a large number of factors affecting wear. Deterioration of buildings and structures consists in the fact that individual structures and objects as a whole lose their original qualities over time (strength, stability, reliability, etc.). The characteristics of the technical condition of the object depends on the degree of its physical wear and tear, the indicator of which is decisive when making a decision regarding the further operation of the object, its technical maintenance, repair, reconstruction, restoration, demolition.

Physical wear and tear is caused by the partial or complete loss of the object's initial physical, technical and operational properties, which are provided for by the project, as a result of the action of natural-climatic, technological and man-made factors and the effects of human activities.

The technical condition of individual structures is determined by analyzing defects, damages and

the results of verification calculations.

Stage 1 "Planning". A comprehensive assessment of the MSADBS begins with the planning stage, which involves a comprehensive information analysis and goal setting. Setting goals is necessary to establish planning guidelines, the achievement of which is the result of evaluating the effectiveness of restoration of the territory, buildings and structures. When setting the goals and determining the planned indicators of the MSADBS, it is necessary to take into account the influence of external environmental factors, in particular:

– industry specifics;
– economic and technical opportunities available on the market and available for recovery;
– production capacities and technologies of specialized enterprises;
– scope of activity and competitive position;
– consumer demand characteristics.

It is advisable to consider the analysis of the external environment as a preliminary stage of goal formation, the final clarification and correction of which takes place only taking into account the results of the damage diagnosis of the affected environment as a whole.

The sources of information for the internal diagnosis of the Ministry of Internal Affairs and Communications are: the results of technical and economic analysis; professional expert assessment; simulation modeling. When conducting diagnostics of the internal environment, special attention should be paid to the following areas:

– the adequacy of the system of evaluation criteria of the MSADBS as a basis for choosing the formation of reconstruction strategies;
– the reliability and reliability of the system of key indicators of the functioning of the affected environment in innovative, financial, personnel aspects, as components of society.

The combination of the results of the assessment of the external and internal environment forms the basis for choosing a strategic or tactical decision aimed at achieving the established goals, namely the restoration of the affected environment.

Stage 2 "Diagnosis". The proposed method of diagnosis of MSADBS involves: preparatory and calculation stages of diagnosis.

The preparatory stage of the diagnosis of MSADBS is implemented by sequentially performing the following actions:

1. Selection of the diagnostic object. Separate buildings and structures serve as diagnostic objects.
2. Formation of a group of experts. This stage involves the selection of a group of experts based on quantitative and qualitative composition (architects, builders, surveyors and scientists in the field of construction), which ensures consistency of experts' opinions.
3. Justification of assessment methods and criteria. Obtaining a conclusion about the expediency of making strategic, tactical and operational decisions is based on the use of assessment methods (quantitative, qualitative, calculation, expert) and a system of criteria that correspond to the purpose of the study (determining the level of damage to a building or structure) and take into account the peculiarities of the diagnostic object (building or the building as a whole, or its component).
4. Justification of the indicator system. Diagnostics of MSADBSis carried out in the aspect of the external and internal environment according to the following groups of indicators: foundation; roof, walls and ceilings; damage to walls and ceilings; engineering communications.

The methodology of the MSADBSis based on bringing all the determined actual indicators to a single dimensionless state and obtaining a systematic assessment taking into account the influence of all factors, which ensures the use of the criterion based on the Harrington utility function [Makatora, 2016].

The requirements for the formation of a system of indicators that characterize and unify the MSADBSare the following:

– consistency and comparability at the level of individual and group indicators;
– determination of key indicators;
– the flexibility of indicators, which means the possibility of adjusting the values of the indicators depending on the level of resource use and the potential of enterprises producing construction materials;
– the possibility of obtaining a forecast regarding reconstruction.

ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

The system of criteria for evaluating the MSADBSshould meet such criteria as credibility, reliability and legality.

Determination of the importance of indicators, according to their structure, are evaluated in fractions according to the following options: the first option - the sum of the importance indicators is equal to one; the second option - each individual weighting indicator can be close to or equal to one. The coefficient of weighting of the indicators is determined depending on its priority of the MSADBS.

The calculation stage of the diagnosis of MSADBSinvolves the sequential performance of the following actions:

1. Determination of the actual single indicators that most accurately and qualitatively characterize the content of each component of the MSADBS. A set of single indicators.

2. Determination of reference unit indicators using available information support or expert method. The reference or normative value of the unit indicator characterizes the desired level of the characteristic being evaluated (the building or structure has no damage (100 percent - reference) without taking into account and/or taking into account age wear and tear (whether the building or structure needed restoration, repair, overhaul)).

3. Comparison of the actual indicators of the object of diagnosis with the standard in order to determine the degree of compliance of the actual value of the indicator with the planned level or standard. Such comparisons play an important role in the analysis of the studied phenomena, because any deviation of the relative value from 1 or 100% indicates a violation of the optimality of the process. For indicators that do not have a defined standard, the basis of comparison can be the maximum or minimum value or the average level.

4. Definition of a general indicator by a group of single indicators. The single indicators determined at the previous stage of diagnosis are grouped according to weighting criteria, taking into account the features of the MSADBS.

5. Determination of the general indicator by the object of diagnosis. It is carried out on the basis of the received data using arithmetic mean or geometric mean convolution. The larger the value of the generalizing indicator for the object of diagnosis will be closer to one, the higher the assessment of the technological level of production processes will be. A comparative analysis of MSADBSis carried out with the use of a general indicator of diagnosis.

6. Formation of a matrix of options for strategic or tactical decisions. The results of the diagnosis of the damaged environment are the basis for control, evaluation of the effectiveness and phasing of its reconstruction (Tables 1-2).

7. Justification of strategic or tactical decisions based on the results of the evaluation of the research object [Makatora, 2016] (Table 3).

Table 1

The matrix of options of the MSADBSregarding providing an assessment of the technical condition of the building and structure

The level of destruction of the building	**Variants of the technical condition**			
High	Complete destruction of the building	Partial destruction of the building	Destruction of non-bearing elements, damage to bearing elements	**C**
Average	Strong destruction	Average destruction	Weak destruction	**B**
Low	Destruction of non-bearing elements, damage to bearing elements	Destruction of non-bearing elements	Destruction of glass, suspended ceiling doors, damage to non-bearing elements	**A**
Level	Unsatisfactory	Satisfactory	High	**Group**
	0-0.49	0.51-0.79	0.80-1.00	
	3	**2**	**1**	

Stage 3 "Implementation". Use of the rest of the object to be rebuilt. The influence of external and internal factors on the effectiveness of reconstruction depends on controlled and uncontrolled factors, which requires BIM design managers to make multi-criteria mutually agreed decisions. The

organization of the reconstruction and its maintenance at the proper level takes place in accordance with the goals and takes into account the available resources of the state. A feature of the modern business environment is the systematic nature of the processes of the state's functioning, therefore, the reconstruction and intensification of auxiliary processes must be investigated in relation to such components as: resource potential, production capabilities of the territories, availability of the necessary competencies in the personnel, financial component.

Table 2

Matrix of optionsMSADBS
regarding the assessment of the technical condition of the building

The level of destruction of the building	**Variants of the technical condition**			
High	Complete destruction of the building	High level of destruction of the building	Destruction of load-bearing elements, damage to load-bearing elements, roof	**C**
Average	Strong destruction	Average destruction	Weak destruction	**B**
Low	Damage to non-bearing elements, ceilings, communications	Partial damage to the roof, supporting elements	Destruction of windows, suspended ceiling doors, facades	**A**
Level	Unsatisfactory	Satisfactory	High	**Group**
	0-0.49	0.51-0.79	0.80-1.00	
	3	**2**	**1**	

Table 3

The content of strategic and tactical decisions during provisioning
methods of systematic assessment of buildings and structures

Groups	**Characterization of strategic and tactical decisions in the provision of systematic assessment methods**
A1	In the case of surface damage to the roof - up to 10%, facades up to 10%, window glass, point damage to external communications, in the absence of damage to load-bearing structures and foundations.
A2	If there is damage to the roof up to 25%, supporting structures less than 5%, overlap less than 5%, reconstruction of communications - up to 10%
A3	Adoption of a decision, the expediency of which is ensured by the presence of a surviving roof (more than 50%), load-bearing structures less than 10%, ceilings less than 10%, reconstruction of communications - up to 25%
B1	It is advisable to make a decision on the partial replacement of the roof (more than 50%), part of the load-bearing structures (less than 25%), complete replacement of the arrangement of the facades. windows, partial replacement of communications.
B2	The decision is made if a complete replacement of the roof is necessary, and part of the load-bearing structures is less than 50%, communications, facade windows and internal partitions.
B3	Adoption of the decision is expedient in conditions of complete destruction of the roof and part of the supporting structures, with the need to replace and modernize more than 50% of communications, windows, facades and internal partitions. Under the condition of complete integrity of foundations and premises below the first level.
C1	Making a strategic decision regarding the dismantling of the building with the possibility of using the premises below the first level and - or the foundations, provided that their damage does not exceed 5%. Partial restoration and or modernization of communications is expedient.
C2	Conditions for making decisions on their implementation are a high level of destruction of buildings. With the possibility of partial use of foundations and premises below the first level. With the complete restoration of the existing communications system. With the possibility of using construction residues for secondary processing
C3	A strategic decision regarding the complete dismantling of the remains of the building (premises below the first level, foundations, load-bearing structures...) together with communications. Without the possibility of using construction waste for secondary processing.

Stage 4 "Control". The implementation of the proposed method of systematic assessment of damage

ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

to buildings and structures involves the regulation of restoration activities based on detected deviations and the development of corrective actions that implement feedback in the process of decision-making and implementation of design and production strategies.

Theoretical and methodological aspects of substantiating the need to rebuild buildings and structures in conditions of uncertainty and risk

Currently, there is no single approach to determining the destruction of buildings and structures. This is explained by the complexity of the factors that affect the assessment of destruction, taking into account external factors in conditions of uncertainty and risk.

The proposed method is based on taking into account the regularities: the destruction of various elements of buildings and structures, their possibility of reconstruction, equipping with the latest equipment. The practical significance of the obtained results lies in the provision of scientifically based recommendations on the effectiveness of restoration. It is necessary to take into account the interaction scheme of factors affecting the degree of destruction of buildings and structures (Table 4).

Therefore, obtaining dependencies that describe the relationship between controlled values (parameters) and external factors will allow determining the effectiveness of destruction; optimize the reconstruction process by finding certain systems of connections between the specified groups of factors.

Table 4

Scheme of interaction of factors acting on buildings and structures

<table>
<tr><td>Parameters of the first group of factors (x_i):
– energy saving properties;
– degree of protection from the environment;
– degree of availability of necessary communications.</td><td>Buildings and structures</td><td>Parameters of the second group of factors (y_i):
– foundation construction;
– roof construction;
– construction of walls and ceilings;
– a network of engineering communications.</td></tr>
<tr><td colspan="3">Parameters of the source group: - foundation; – walls and ceilings; – roof; – engineering communications</td></tr>
</table>

In the general case, this is a system of connections of a species

$$E_i = f(x_i, y_i) \to \max, \tag{1}$$

where E_i is the efficiency of the equipment.

A detailed examination of these relationships will make it possible to justify the feasibility of rebuilding the building and structure, based on the conditions of the working environment and parameters of destruction.

There are analyzed such factors of destruction as:

– first, it is necessary to analyze the human capital and the area of the territory that falls under the object of reconstruction;

– secondly, it is necessary to take into account city-forming components, such as the main and/or several enterprises located in the city or nearby; agricultural and/or meat processing plants: the area of their land plots, the type of crops typical for this area, the type of farms, etc.

For the correct choice of decision-making, it is necessary to take into account all the above-mentioned components, that is, to accumulate the approach, whether there will be an autonomous environment or whether additional logistics systems will be needed.

The initial data for making a decision on the evaluation of destruction, taking into account the nature of the damage of obtaining a restored building, can be technological maps, which are compiled and calculated using various methods. At the first stage of research, the results of the calculations of the evaluation of four technological maps in the destruction or damage of buildings and structures were obtained: the foundation; the roof; walls and ceilings; engineering communications that have different assessment criteria.

List of main structural elements of buildings and structures:

1) damage to the foundation (strip, monolithic, pile, solid);

2) damage to the roof (attic, non-attic, single-slope, double-slope, four-slope, tent, mansard, domed and flat), walls and ceilings (bearing structures, non-bearing structures, internal partitions; monolithic, panel and frame);

3) damage to walls and ceilings (bearing structures, non-bearing structures, internal partitions; monolithic, panel and frame);

4) damage to engineering communications (water pipelines, gas pipelines, water drainage, power grids and television and Internet communications).

The choice of a rational decision regarding the destruction or damage of buildings and structures is made taking into account the result of the assessment as a probability value. The basis of such a mathematical model is the assumption that the probabilities of occurrence of possible states of buildings and structures (external environment) (P_j) are known. The mandatory requirement is that the sum of such probabilities of the state of the main structural buildings and structures is equal to one. The functional values of element states can be such indicators as: percentage of foundation damage; the roof; walls and ceilings; engineering communications and others.

Using the generalized Harrington function as a tool for determining the level of technology development.

In order to improve the process of substantiating the methodology for assessing damage to buildings and structures, increasing the level of variability of weighting factors when choosing damage indicators, it is advisable to use a mathematical apparatus based on Harrington's generalizing function. The comparison of parameters is carried out on the basis of a quantitative and qualitative assessment of numerical values, which are reduced to a general coefficient, which characterizes the feasibility of choosing a particular building component of the territory.Using Harrington's generalized function provides a number of advantages:

– provides universality to the general approach to the assessment of damage to buildings and structures and their components;

– investigates the possibility of optimizing both the comparison methods themselves and the process of restoration of buildings and structures.

The criteria for evaluating the values of indicators of the level of development of production technology vary in five ranges from 0 to 1 (Fig. 1).

An analysis of the content of damage options is providedbelow.

High level - characterized by an almost undamaged environment, which is characterized by a high assessment of viability. Recovery can be carried out without external borrowing and with small labor costs and capital investments.

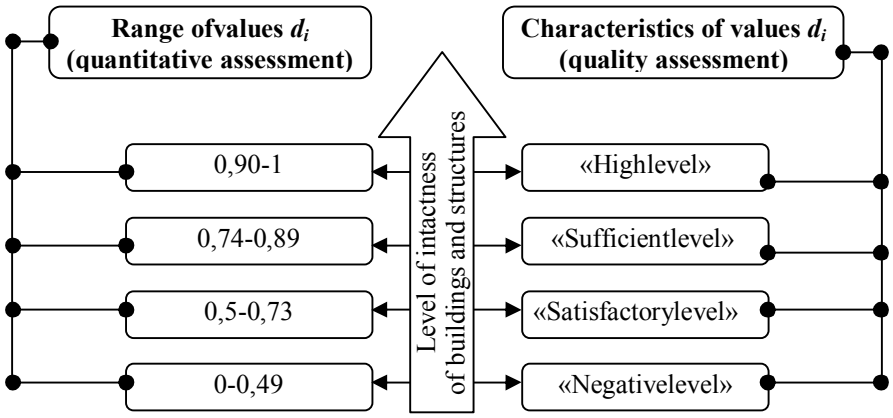

Fig. 1. Value ranges of the level of intactness of the building and structure

Sufficient level - they are characterized by an average state of damage, restoration is possible with minimal capital investments, provided that the period of reconstruction is not long. It can be carried out partly at the expense of external borrowings.

Satisfactory level - they are characterized by a rather significant state of damage, restoration is possible, but there are large capital investments with the condition of a long period of reconstruction. It is carried out at the expense of external borrowings. Achieving restoration is impossible to the previous state level and is impractical.

ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

Unsatisfactory level - characterized by severe destruction. It is impossible to achieve the previous level of efficiency, it requires significant capital investments, which are practically equal in cost to a new building, low efficiency of investment costs.

Therefore, the actual values of the ith partial indicator-indicator of the jth component of reconstruction are identified according to the ranges of values of the Harrington desirability scale. The need to take into account the impact of one or another factor on the overall assessment of the level of destruction determines the feasibility of using weighted coefficients, which are established by experts. Taking into account the weighting factors, the desirability function D is calculated according to the formula:

$$D = \sum_{i=1}^{n} \alpha_i \sqrt{\prod_{i=1}^{n} d_i^{\alpha_i}}, \quad (2)$$

where the weight limit α is $0 \le \alpha_i \le 1$.

The method of systematic determination of the level of damage to buildings and structures has consideredusing the example of four groups of damage factors (A_1, A_2, A_3 and A_4) for nine variants of objects.

Making a management decision regarding the expediency of rebuilding the territory, building or structure from the reference (planned, expected and practically achievable) value of the object's parameter. Planned indicators of restoration are probabilistic values, which has been assumed (for the purpose of simplifying intermediate calculations) to be represented by partial integral indicators-indicators characterizing the level of damage d_1, d_2, d_3 and d_4 where:

d_1 – the foundation conforms to the technical documentation (the ratio of the actual balance of the foundation to the reference (nominal));

d_2 – the roof conforms to the technical documentation (the ratio of the actual roof balance to the reference (nominal));

d_3 – structures comply with the technical documentation (the ratio of the actual balance of the structures to the reference (nominal));

d_4 – walls and ceilings comply with the technical documentation (the ratio of the actual balance of the wall and ceilings to the reference (nominal)).

Table5

Initial characteristics for determining the integral indicator of the level of technology development based on the Harrington function

Variants of damaged buildings and/or structures		Response functions of partial integral indicators-indicators of the development of the production technology component			
		d_1	d_2	d_3	d_4
A_1	Object1	0,94	0,85	1,00	1,00
A_2	Object2	0,85	0,62	0,95	0,96
A_3	Object3	1,00	1,00	0,88	0,92
A_4	Object4	0,84	0,96	0,52	0,84
Weighting coefficients α_i		0,9	0,95	0,5	0,3

Each variant of the damaged object (building or structure) (A_i) corresponds to the value of the integral indicator of the level of damage (D_i), determined using the Harington function.Taking into account the weighting coefficients (see table D.1 of the Standard of the Organization of Ukraine of Housing and Communal Services, 2009), it could be determined the desirability function D, which characterizes the level of development of production technology (for these examples, the authors' reasoning is taken):

Object (A_1):

$$D(A_1) = \sqrt[2,65]{0,94^{0,9} \cdot 0,85^{0,95} \cdot 1,0^{0,5} \cdot 1,0^{0,3}} = \sqrt[2,65]{0,81} = 0,924;$$

Object (A_2):

$$D(A_2) = \sqrt[2,65]{0,85^{0,9} \cdot 0,62^{0,95} \cdot 0,95^{0,5} \cdot 0,96^{0,3}} = \sqrt[2,65]{0,528} = 0,786;$$

Object (A_3):

$$D(A_3) = \sqrt[2,65]{1,0^{0,9} \cdot 1,00^{0,95} \cdot 0,88^{0,5} \cdot 0,92^{0,3}} = \sqrt[2,65]{0,914} = 0,967;$$

Object (A_4):

$$D(A_4) = \sqrt[2,65]{0,84^{0,9} \cdot 0,96^{0,95} \cdot 0,52^{0,5} \cdot 0,84^{0,3}} = \sqrt[2,65]{0,563} = 0,805.$$

According to the results of calculations:

- "high level" corresponds to two variants of damaged objects, namely: A_1 and A_3, which are characterized by surface damage to the roof - up to 10%, facades up to 10%, window glass, point damage to external communications, in the absence of damage to supporting structures and foundations . These objects are an almost intact environment, which is characterized by a high assessment of vitality. Restoration can be carried out without external borrowing and with small labor costs and capital investments, and reconstruction should be a priority;

– the "sufficient level" corresponds to two other variants of damaged objects A_2 and A_4, the use of which will ensure an average duration of the life cycle.

Thus, the analysis of the function of the desirability of partial integral indicators-damage indicators allows to assess the possibilities and determine the ways of further actions regarding the reconstruction of the territory, buildings, structures, etc.

The obtained results of the study made it possible to formulate the following conclusions:

1. The result of using the proposed method of systematic assessment of damage to buildings and structures is: 1) determining the degree of damage and making a decision on reconstruction; 2) attraction of capital for necessary reconstruction depending on the destruction; 3) ensuring the high efficiency of damage assessment.

2. The expediency of conducting diagnostics of the components of the systematic assessment of damage to buildings and structures in the following directions: object of diagnosis, form of diagnosis, tools and time interval of diagnosis, which helps to objectively determine future financing and implementation of decision-making regarding reconstruction, is justified. A graphic interpretation of the MSADBStechnique is presented. A matrix for the selection of management decisions, strategic and tactical decisions in the provision of methods of systematic evaluation of buildings and structures is proposed.

3. In order to assess the criteria for damage to buildings and/or structures, the use of a mathematical apparatus based on the generalized Harrington desirability function is proposed. In order to ensure the high-quality application of the methodology based on Harrington's generalized desirability function in determining the level of damage and further justifying management decisions regarding reconstruction, it is necessary to: 1) classify all objects under analysis by scope of application; 2) justify the number and quantitative values of partial indicators (the number of which is unlimited); 3) substantiate the weighting coefficients of the "significance" of each partial indicator-indicator of the component technology; 4) develop a methodology for making changes to the classification of analysis objects, a set of comparison parameters, and their weighting factors.

General conclusions and recommendations

The State Construction Standards of Ukraine provide categories of responsibility for structures and elements depending on the consequences that may be caused by their failure.

The technical condition of structures is determined by analyzing defects, damages and the results of verification calculations. Assessment of the technical condition of the object as a whole requires the application of a different system of rules, which are determined by the degree of reduction in the load-bearing capacity of structures, taking into account the influence of various environmental factors in each individual case.

The rules for assessing the technical condition of the facility as a whole are determined by the totality of detected damages or categories of the technical condition of structural elements, the type of structures, the type of their connections, and the categories of responsibility of structures or elements depending on the consequences of their failure. At the same time, the recommendations regarding the further operation of the construction objects provide for forecasting the nature of development and the degree of danger of the detected signs of degradation for any predetermined period of time.

Forecasting the likely consequences of detected deviations, as well as making decisions regarding the further operation of the object, also require the application of an appropriate system of rules, the selection of which in each individual case is one of the problems. The degree of this problem depends

on the level and nature of the uncertainty inherent in the environment in which the facility is operated (Petrochenko et al., 2023).

The procedure for performing construction and technical examinations, which are associated with negative changes in the technical condition of the construction object as a result of the possible influence of various environmental factors, provides for the following sequence of studies:

– studying of documents;

– carrying out inspections of damaged objects;

– comparing of detected damages with the technical condition certificate;

– in the absence of a certificate of technical condition, the expert analyzes and classifies the detected damage to separate a group of defects that are related to the accumulated physical wear and tear of the building during the period of operation;

– separationing of a group of defects and damages that are caused by external factors of influence and are of a non-operational nature;

– studying of design documentation for repair and construction works related to the restoration or improvement of operational indicators of the object of examination or carried out nearby.

The procedure for carrying out an expert analysis to establish the reasons for the deterioration of the technical condition of the premises, next to which repair and construction work was carried out, involves an examination of the foundation of the house (structure), the structural elements of which became the object of the examination, since the subsidence of the foundation is often the cause of damage to the load-bearing structures. At the same time, the possible reasons for the subsidence of the foundation of the house (structure) can be various factors of both internal and external nature.

General damages to buildings (structures) during their operation, in most cases, appear as a result of local or total changes in hydrogeological and engineering-geological conditions on the construction site or other natural phenomena (earthquakes, floods, storms, etc.). Also, the general condition of buildings and structures is affected by fires, dynamic components of loads, new buildings erected on the built-up area alongside the existing ones, shortcomings in design and construction, and other technological factors.

The specified factors can significantly affect the stress-strained state of the foundations, which can cause the occurrence of additional uneven deformations of both the foundations themselves and the foundations (Prusov, 2020). Uneven settlement of foundations, in turn, causes additional deformations of buildings and structures as a whole. At the same time, the indicators of operational suitability are significantly reduced in individual structural elements of buildings and structures.

Depending on the causes, the deformations of the foundations are distinguished, which are caused by the deformation of the soil from the loads transmitted to the foundations by the house, as well as deformations that are not related to the load from the house.

The most dangerous are uneven deformations of the foundations of buildings and structures. The reasons for the significant deterioration of the technical condition of the facility as a whole may be deformations of its base during new construction due to failure to maintain the required distance between the existing construction facility and the new building; massiveness and multi-storey building; non-compliance with construction technology; lack of measures to ensure the preservation of existing facilities; a large difference in the depth of laying the foundations of the existing object and the new building(Prusov, 2022).

The result of comparing the examination data and case materials submitted for investigation with the requirements of current regulatory documents is the expert's conclusion about a possible connection between the occurrence of damage:

– construction activities that are carried out near the house (structure);

– carrying out repair and construction works in the premises of buildings and structures;

– negative changes of the object of examination during operation;

– natural or man-made influence factors affecting the change in the properties of construction materials of the object of examination;

– natural or man-made influence factors affecting the physical and mechanical properties of the soil of the object of examination.

Territories, buildings and structures are destroyed during martial law. Especially in these conditions, there is a need to develop and improve damage assessment techniques to unify solutions to the

specified problem. In particular, in the systematic examination of the existing state of destruction, the entire complex should be taken into account in the following sequence: territories, buildings and structures.

The result of using the proposed method of systematic assessment of damage to buildings and structures is: 1) determining the degree of damage and making a decision on reconstruction; 2) attraction of capital for necessary reconstruction depending on the destruction; 3) ensuring the high efficiency of damage assessment.

The expediency of conducting diagnostics of the components of the systematic assessment of damage to buildings and structures in the following directions: object of diagnosis, form of diagnosis, tools and time interval of diagnosis, which helps to objectively determine future financing and implementation of decision-making regarding reconstruction, is justified. A graphic interpretation of the MSADBStechnique is presented. A matrix for the selection of management decisions, strategic and tactical decisions in the provision of methods of systematic assessment of buildings and structures is proposed.

In order to assess the criteria for damage to buildings and/or structures, the use of a mathematical apparatus based on the generalized Harrington desirability function is proposed. In order to ensure the high-quality application of the methodology based on Harrington's generalized desirability function in determining the level of damage and further justifying management decisions regarding reconstruction, it is necessary to: 1) classify all objects under analysis by scope of application; 2) justify the number and quantitative values of partial indicators (the number of which is unlimited); 3) justify the weighting coefficients of the "significance" of each partial indicator-indicator of the component technology; 4) develop a methodology for making changes to the classification of analysis objects, a set of comparison parameters, and their weighting factors.

Developing and improving damage assessment techniques is necessary in order to have a more complete understanding of the extent of damage and to determine restoration priorities.

The assessment of damage to territories should include an analysis of ecological consequences and the ability to restore the natural resource potential. It is important to consider the impact of hostilities on land cover, water resources, wildlife and other ecosystems.

When assessing damage to building infrastructure, the condition of structures, systems and utility equipment should be taken into account. This will help identify risks to residents and bring recovery to the fore.

Damage assessment of structures includes analysis of their structure, functionality and safety. It is also necessary to take into account the possibility of spreading danger to other buildings and citizens.

A unified damage assessment methodology will allow efficient use of resources for recovery and ensure transparency in decision-making. In addition, it will create an opportunity to compare damage in different territories, develop best practices and speed up post-war recovery.

Assessing damage during martial law is a confusing and complex process, but it is critical to the country's continued recovery and development. The given technique will help to make this process more organized and efficient, and its implementation in information modeling can provide a technical opportunity to move from the traditional process of information management to the creation of expert models to optimize key project indicators based on reliable, consistent data, contributing to the creation of the necessary conditions for further transition to the principles of managing the assessment of impacts, consequences, resources for restoration, and the subsequent life cycle of construction objects.

REFERENCES

1. Hrynyov A.V., Dedilova T.V. 2008. Management of innovative development of industrial enterprises in a global environment: a monograph. *Kharkiv National Automobile and Road University*, 148 c.(ukr)
2. Fedulova L.I. etc. 2005. Innovative development of the economy: model, management system, state policy. *NAS of Ukraine, Institute of Economic Forecasting*. K.: Osnova, 550 p.(ukr)
3. Mandyuk O.M. 2011. The essence and peculiarities of the organizational and economic mechanism of transformation of property relations. *Bulletin of the National University of Water Management and Nature Management*. No. 2, pp. 139–144.(ukr)
4. Makatora D.A., Lisun Y.V. 2016. The Harrington function as a tool for determining the level of technology development. *Bulletin of the Kyiv National University of Technology and Design*. No. 6 (105), pp. 80–85.(ukr)
5. Zharkov Yu., Tsiciliano O., Makatora D. 2004. Optimizing the work criteria of conformity assessment bodies using the Harrington method. *Standardization, certification, quality*. No. 4, pp. 36–38.(ukr)

6. Hrabovetskyi B.E. 2010. Methods of expert evaluations: theory, methodology, directions of use: *Monograph*. Vinnytsia: VNTU, 171 p.(ukr)
7. Prusov D.E., 2020. Scientific substantiation of engineering preparation measures due to the influence of construction in the dense building conditions. *Strength of Materials and Theory of Structures*, Vol.104. - P.229-241. [DOI: 10.32347/2410-2547.2020.104.229-241]
8. Prusov D.E. 2022. Assessment of interaction the new construction object at full load and the surrounding building in the dense urban development conditions. Strength of Materials and Theory of Structures, Vol.109, 455-466. [DOI: 10.32347/2410-2547.2022.109.455-466]
9. Petrochenko O.V., Prusov D.E., Kuzmin R.I., and others. 2023. Aspects of integrated management in urban planning and territorial planning as an integral part of comprehensive restoration of territories. *The educational and methodological manual*. K.: IINO KNUBA, 572 p.(ukr)
10. The State Construction Standardof UkraineDBN-B.1.2-5:2007. Scientific and technical support of construction objects. Appendix A.(ukr)
11. The State Construction Standardof UkraineDBN-B.1.2-14:2018.The system for ensuring the reliability and safety of construction objects. General principles of ensuring the reliability and structural safety of buildings and structures.(ukr)
12. The State Construction Standardof UkraineDBN-B.2.2-12:2019. Planning and development of territories.(ukr)
13. The State Construction Standardof UkraineDBN-V.1.2.-2:2006.System for ensuring the reliability and safety of construction objects. Loads and influences. Design standards.(in Ukr.)
14. The State Construction Standardof UkraineDBN-A.2.2-3-2014.Composition and content of project documentation for construction. (ukr)
15. The State Construction Standardof UkraineDBN-V.3.1-1-2002.Repair and strengthening of load-bearing and enclosing building structures and foundations of industrial buildings and structures. (ukr)
16. The State Construction Standardof UkraineDBN-V.1.1-46:2017.Engineering protection of territories, buildings and structures against landslides and collapses. Substantive provisions. (ukr)
17. The State Construction Standardof UkraineDBN-A.2.1-1-2014.Search, design and territorial activity. Engineering searches for construction.(ukr)
18. The National Standard of Ukraine DSTUB.V.1.2-18:2016. Guidelines for the inspection of buildings and structures to determine and assess their technical condition.(ukr)
19. The National Standard of Ukraine DSTU B.V.2.1-2-96. Foundations and foundations of buildings and structures. Soils. Classification.(ukr)
20. Standard of the Organization of Ukraineof Housing and Communal Services75.11–35077234.0015:2009.Residential buildings. Rules for determining the physical wear and tear of residential buildings.(ukr)

Стаття надійшла 03.04.2024

Прусов Д.Е., Макатьора Д.А., Кубанов Р.А.

МЕТОДОЛОГІЧНИЙ БАЗИС BIM-АНАЛІЗУ ПОШКОДЖЕНЬ ТА ОЦІНКИ ВПЛИВІВ, НАСЛІДКІВ, РЕСУРСІВ ДЛЯ ВІДНОВЛЕННЯ БУДІВЕЛЬ І СПОРУД

Методологічний базис BIM-аналізу пошкодження та оцінки впливів, наслідків, ресурсів для відновлення будівель і споруд є базисом методологічного підґрунтя, що забезпечує цілісний підхід до планування та розвитку території, включаючи в себе багатофакторні аспекти. Постає необхідність у дослідженні складових оцінки пошкодження будівель (споруд) та розробці системної методики їх діагностики на пошкодженому об'єкті з метою досягнення ефективності при прийнятті рішення щодо відбудови або не доцільності відновлення в залежності від узагальненого коефіцієнту руйнування. Завдання дослідження полягає у розробці поетапного алгоритму оцінювання – методика системної оцінки пошкодження будівель і споруд на основі застосовування узагальненої функції Харінгтона як інструменту визначення рівня розвитку технологій, з використанням системи показників, нормативні значення та вагомість яких встановлюються сертифікованими інженерами-будівельниками при умові обґрунтування, щодо доцільності відбудови або недоцільності відновлення. Розроблена методика оцінки пошкодження будівель і споруд складається з ряду взаємопов'язаних послідовних етапів, спрямованих на отримання кількісної та якісної оцінки, вибору комплексної стратегії оцінювання будівель та споруд.

Для досягнення зазначеної мети, пропонується розроблення методологічного базису BIM-аналізу пошкодження та оцінки впливів, наслідків, ресурсів для відновлення будівель і споруд, що може бути основою для виконання будівельно-технічних експертиз є визначення технічного стану об'єкта експертизи та причин його пошкоджень і руйнувань, у чотири етапи: планування, діагностика, реалізація, контроль. Наведена методика допоможе зробити цей процес більш організованим і ефективним, а її впровадження в інформаційне моделювання може надати технічну можливість для переходу до створення експертних моделей задля оптимізації ключових показників проекту на основі надійних, узгоджених даних, сприяючи створенню необхідних умов для подальшого переходу до принципів управління оцінкою впливів, наслідків, ресурсів для відновлення, та подальшого життєвого циклу об'єктів будівництва.

Ключовіслова: відновлення будівель і споруд, методика системної оцінки, технічний стан, аналіз пошкоджень, оцінка впливів, наслідків, ресурсів.

Prusov D.E., Makatora D.A., Kubanov R.A.

METHODOLOGICAL BASIS OF BIM-ANALYSIS OF DAMAGE AND ASSESSMENT OF IMPACTS, CONSEQUENCES, RESOURCES FOR RESTORATION OF BUILDINGS AND STRUCTURES

The methodological basis of the BIM-analysis of damage and assessment of impacts, consequences, resources for the restoration of buildings and structures is the basis of the methodological foundation that provides a holistic approach to the planning and development of the territory, including multifactorial aspects. There is a need to study the components of damage assessment of buildings (structures) and to develop a systematic method of their diagnosis on a damaged object in order to

achieve efficiency in making a decision on reconstruction or the impracticality of restoration depending on the generalized coefficient of destruction. The task of the research consists in the development of a step-by-step assessment algorithm - a method of systematic assessment of damage to buildings and structures based on the application of the generalized Harrington function as a tool for determining the level of technology development, using a system of indicators, the normative values and weight of which are established by certified civil engineers under the condition of substantiation, regarding feasibility reconstruction or impracticality of restoration. The developed methodology for assessing damage to buildings and structures consists of a number of interconnected sequential stages aimed at obtaining a quantitative and qualitative assessment, choosing a comprehensive strategy for assessing buildings and structures.

To achieve the specified goal, it is proposed to develop a methodological basis for the BIM analysis of damage and assessment of the effects, consequences, resources for the restoration of buildings and structures, which can be the basis for performing construction and technical examinations, which is the determination of the technical condition of the object of examination and the causes of its damage and destruction , in four stages: planning, diagnosis, implementation, control. The given technique will help to make this process more organized and efficient, and its implementation in information modeling can provide a technical opportunity to move from the traditional process of information management to the creation of expert models to optimize key project indicators based on reliable, consistent data, contributing to the creation of the necessary conditions for further transition to the principles of managing the assessment of impacts, consequences, resources for restoration, and the subsequent life cycle of construction objects.

Keywords: restoration of buildings and structures, method of system assessment, technical condition, damage analysis, assessment of impacts, consequences, resources.

УДК 69.059
Прусов Д.Е., Макатьора Д.А., Кубанов Р.А. **Методологічний базис BIM-аналізупошкоджень та оцінкивпливів, наслідків, ресурсів для відновленнябудівель і споруд**/ Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2024. – Вип. 112. – С. 302-315.
Запропонований методологічний базис BIM-аналізу пошкодження та оцінки впливів, наслідків, ресурсів для відновлення будівель і споруд на основі застосовування узагальненої функції Харінгтона, що складається з ряду взаємопов'язаних послідовних етапів, спрямованих на визначення технічного стану об'єкта експертизи та причин його пошкоджень і руйнувань, отримання кількісної та якісної оцінки, вибору комплексної стратегії оцінювання будівель і споруд, та виконання будівельно-технічного обґрунтування щодо доцільності відбудови або недоцільності відновлення.
Табл. 5. Іл. 1. Бібліогр. 20 назв.

UDC69.059
Prusov D.E., Makatora D.A., Kubanov R.A. **Methodological basis of BIM-analysis of damage and assessment of impacts, consequences, resources for restoration of buildings and structures**/ Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2024. – Issue 112. – P. 302-315.
The methodological basis of BIM analysis of damage and assessment of impacts, consequences, resources has been proposed for the restoration of buildings and structures based on the application of the generalized Harrington function, consisting of a number of interconnected sequential stages, aimed at determining the technical condition of the object of examination and the causes of its damage and destruction, obtaining a quantitative and qualitative assessment, choosing a comprehensive strategy for evaluating buildings and structures, and implementation of construction and technical substantiation regarding the expediency of reconstruction or impracticability of restoration.
Tabl. 5. Fig. 1. Ref. 20.

Автор (науковий ступінь, вчене звання, посада): доктор технічних наук, професор, завідувач кафедри БІТ Інституту інноваційної освіти КНУБА, Прусов Дмитро Едуардович
Адреса робоча: 03037, Україна, м. Київ, вул. Освіти, 4. Інститут інноваційної освіти Київського національного університету будівництва і архітектури, ПРУСОВУ Д.Е.
Тел.:+38 (044) 597-19-86
E-mail: prusov.de@knuba.edu.ua
ORCID ID: http://orcid.org/0000-0002-1720-2798

Автор (науковий ступінь, вчене звання, посада): кандидат технічних наук, заступник директора з науково-педагогічної роботи, міжнародних зв'язків та дистанційного навчання Інституту інноваційної освіти Київського національного університету будівництва і архітектури. Макатьора Дмитро Анатолійович
Адреса робоча: 03037, Україна, м. Київ, вул. Освіти, 4. Інститут інноваційної освіти Київського національного університету будівництва і архітектури, МАКАТЬОРІ Д.А.
Тел.:+38 (044) 245-48-56
E-mail: makatora_d@ukr.net
ORCID ID: https://orcid.org/0000-0002-1909-900X

Автор (науковий ступінь, вчене звання, посада): кандидат педагогічних наук, доцент, доцент кафедри економіки, менеджменту та управління територіями Інституту інноваційної освіти КНУБА. Кубанов Руслан Анатолійович
Адреса робоча: 03037, Україна, м. Київ, вул. Освіти, 4. Інститут інноваційної освіти Київського національного університету будівництва і архітектури, КУБАНОВУ Р.А.
Тел.:+38 (044) 244-96-63
E-mail: kubanov12@gmail.com
ORCID ID: https://orcid.org/0000-0002-0121-4858