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TECHNOLOGY OF EDUCATIONAL INSTITUTIONS' RECONSTRUCTION AFTER DESTRUCTION CAUSED BY ARMED CONFLICT ON THE TERRITORY OF UKRAINE RIGIDITY

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Abstract. The article is of a review nature and is devoted to the analysis of modern trends in technologies for the restoration of secondary education institutions after destruction as a result of the armed conflict in Ukraine. It substantiates the urgent need to develop a new, forward-looking model for restoring educational infrastructure, grounded in the principles of energy efficiency, technological innovation, resilience, and elevated safety standards. In the context of post-war recovery, education is recognized as a critical pillar for societal stability and sustainable development, making the reconstruction of schools a strategic priority for the country.

The study includes a thorough analysis of the existing regulatory and legal framework that governs reconstruction efforts. Key stages of the construction and design cycle are outlined, such as structural assessment of damaged buildings, development of project and technical documentation, coordination of civil protection strategies, and implementation of construction and installation activities. Special focus is placed on the engineering and architectural aspects of building safe and resilient educational spaces capable of withstanding future threats.

Furthermore, the article explores the integration of protective infrastructure, such as reinforced shelters, early warning systems, and optimized evacuation paths, into school design. Beyond physical protection, the study emphasizes the psychological and emotional well-being of students and educators. This includes the adoption of human-centered architectural approaches, inclusive spatial planning, and flexible, adaptive design that meets the diverse needs of school communities.

A comprehensive reconstruction model is proposed, incorporating innovative building technologies, resource-efficient and sustainable materials, and a strategic methodology tailored to post-conflict conditions. This integrated approach aims to create durable, functionally advanced, and socially safe educational environments that respond to both current challenges and future demands.

Keywords: reconstruction, educational facilities, rebuilding, educational environment safety, energy efficiency, innovative technologies, civil protection shelters, infrastructure resilience.

Introduction. The armed conflict on the territory of Ukraine, which began in 2014 and escalated into a full-scale war in February 2022, has caused significant destruction to civilian infrastructure, particularly general secondary education institutions (Fig. 1). The restoration of

educational infrastructure has become one of the top priorities for the state, local communities, and international partners.

The process of rebuilding general secondary education facilities requires a comprehensive approach that combines modern technologies, innovative materials, and advanced design methods while taking into account new safety requirements. The reconstruction of damaged schools, kindergartens, colleges, and universities must not only restore their physical structures but also ensure the creation of a safe, comfortable, and modern educational environment that meets the needs of a post-conflict society.

Fig. 1. Damaged educational facility

Analysis of Recent Research and Publications. The process of restoring damaged general secondary education institutions is regulated by a number of legal acts, standards, and methodological guidelines. The foundational documents in this field include the Law of Ukraine *"On Regulation of Urban Development Activities"*, the State Building Codes (DBN), and specialized methodological recommendations developed by the Ministry for Communities and Territories Development of Ukraine and other relevant authorities.

In 2022–2023, special methodological guidelines were developed and approved for drafting design assignments for the reconstruction of damaged school buildings, which define the key requirements for the educational infrastructure restoration process [1, p. 5]. These guidelines cover issues such as technical condition assessments, design documentation development, scope of work

determination, and cost estimation for reconstruction.

An important aspect of regulatory support is the design standards approved by the National Council for the Recovery of Ukraine, which establish baseline parameters for rebuilding general secondary education institutions, taking into account modern safety, energy efficiency, and functionality requirements [2, p. 12]. These standards mandate the inclusion of civil protection shelters, early warning systems, backup power sources, and water supply systems in reconstruction projects.

Purpose and Objectives. The purpose of this study is to develop a comprehensive, scientifically grounded approach to the restoration of general secondary education institutions damaged or destroyed due to armed aggression against Ukraine, in compliance with regulatory requirements, safety standards, and innovative approaches to educational space organization. This approach involves integrating modern construction technologies, energy efficiency principles, safety measures, and psychological comfort for participants in the educational process.

To achieve this goal, the following research objectives were defined:

– to investigate modern approaches to restoring educational infrastructure, considering the complexity and multifaceted nature of this process;

– to examine the effectiveness of contemporary diagnostic methods in comprehensive technical assessments of damaged buildings;

– to assess the feasibility of implementing innovative materials and technologies for structural reinforcement and civil protection shelters;

– to identify prospective directions for further research aimed at enhancing the resilience, energy autonomy, and comfort of educational institutions.

Materials and Research Methodology.To achieve the research objectives, a comprehensive interdisciplinary approach was employed, integrating methods of technical expertise, architectural design, analysis of regulatory and legal acts, systems modeling, and socio-psychological analysis.

The material basis of the study included:

– actual data on the condition of damaged or destroyed general secondary education institutions;

– regulatory and legal acts governing design, reconstruction, and civil protection;

– results of public reports, engineering assessments, and expert conclusions obtained in collaboration with design organizations.

The research methodology comprised the following key stages:

– analysis of modern approaches to reconstruction, conducted through content analysis of scientific sources, technical documentation, and international experience in the restoration of educational infrastructure;

– assessment of the condition of damaged objects, performed using methods of visual, instrumental, and thermal imaging inspection of structures.

Main Findings and Results. *Technological Aspects of Damage Assessment and Inspection.*

The first stage in the restoration of general secondary education institutions is a comprehensive assessment of the buildings' technical condition and the extent of damage. According to the methodological guidelines developed by the Department of Economy and Investments of the Kyiv City State Administration, inspections should include: visual and instrumental diagnostics of structures, evaluation of utility networks and systems, analysis of foundation soils [3, p. 8].

Modern technologies used for high-quality inspections include:

– laser 3D scanning of buildings, which creates a precise digital model of the structure, capturing all deformations and damages. This technology ensures high measurement accuracy (up to 2 mm) and helps detect hidden defects;

– thermographic surveys using thermal imaging cameras are employed to detect hidden structural defects, heat losses, moisture anomalies, and other issues not visible during visual inspections;

– ultrasonic testing is used to assess the strength of concrete structures, identifying cracks, voids, and other material integrity issues;

– ground-penetrating Radar (GPR) is applied to analyze the condition of foundation soils,

detect underground utilities, cavities, and areas prone to flooding.

Based on the results of a comprehensive survey, a detailed report is compiled, containing information on the technical condition of structures, the nature and extent of damage, and recommendations for restoration methods. This report serves as the basis for developing design documentation and determining the scope of necessary work [4, p. 14].

Design of Restoration for Educational Institutions. The design phase of restoring damaged general secondary education institutions is a critical stage that defines all subsequent work. According to methodological guidelines developed by the Department of Urban Planning and Architecture, the design process must be based on principles of safety, energy efficiency, inclusivity, and functionality [4, p. 20].

A key aspect of design is the development of a detailed design brief, which should include:

– technical parameters of the restoration object (total area, number of floors, structural scheme, etc.);
– characteristics and parameters of elements subject to restoration;
– safety requirements (including civil protection shelters);
– energy efficiency parameters;
– requirements for engineering equipment and systems;
– requirements for the organization of educational spaces;
– features of inclusivity and accessibility.

In the design process for restoring general secondary education institutions, Building Information Modeling (BIM) technologies are widely used. This technology enables the creation of a detailed digital model of the object, incorporating information about all structural elements, engineering systems, and materials. BIM modeling ensures efficient coordination between different project sections, enables simulations and analyses (energy, acoustic, insolation, etc.), and optimizes project costs and timelines [5, p. 32].

Innovative Materials and Restoration Technologies. Modern approaches to restoring general secondary education institutions involve the use of innovative materials and technologies that ensure high quality, reliability, and speed of work. According to methodological guidelines developed by the Confederation of Builders of Ukraine, preference should be given to materials and technologies with high durability, environmental friendliness, and energy efficiency [5, p. 78].

Among the innovative materials used in restoration are:

– composite reinforcement based on basalt or fiberglass, offering high strength, corrosion resistance, and low thermal conductivity;
– self-healing concretes containing special additives that activate upon the appearance of cracks, "healing" them and ensuring long-term operation without repairs;
– next-generation thermal insulation materials, such as aerogels, vacuum panels, nanocellulose, perlite, vermiculite, and gypsum mixtures, which have extremely low thermal conductivity [6-12];
– photocatalytic coatings capable of purifying air from harmful substances and pollutants under sunlight exposure.

Among the innovative construction technologies applied in restoration are:

– 3D printing of building structures, enabling the rapid creation of complex geometric shapes with minimal waste;
– modular construction technologies, involving the production of individual modules in factories followed by on-site assembly, significantly reducing construction timelines;
– dry construction technologies using lightweight steel thin-walled structures (lSSTS), which provide high installation speed, lightweight structures, and flexibility for various architectural solutions [3, p. 92].

The restoration and strengthening of damaged structures are among the most critical aspects of restoring general secondary education institutions. Depending on the nature and extent of damage, various technologies are applied:

– for the restoration of reinforced concrete structures, composite materials based on carbon

or fiberglass fabrics are widely used, significantly increasing the load-bearing capacity of elements without substantially increasing their dimensions. These materials offer high strength, corrosion resistance, and durability [3, p. 25];

– for strengthening brick walls, reinforcement technologies using basalt fiber or stainless steel meshes followed by the application of high-strength mortars are employed. This technology significantly enhances the strength and seismic resistance of structures;

– for foundation restoration, injection technologies involving the filling of cracks and voids with special solutions, as well as the installation of additional reinforcement elements (e.g., bored piles, benches), are effective.

Special attention is given to the use of modern concretes with enhanced strength, frost resistance, and water impermeability. Specifically, self-compacting concretes, fiber-reinforced concretes, and concretes with nanoparticles are used to ensure the high quality of restored structures [2, 6-10].

Creation of Protective Structures and Safety Elements. One of the key aspects of restoring general secondary education institutions during an armed conflict is the establishment of civil protection shelters and the implementation of comprehensive safety systems. According to approved design standards, every educational institution must be equipped with a shelter compliant with the requirements of DBN V.2.2-5:2022 "Civil Protection Structures" [1, p. 30].

Technological solutions for creating shelters include:

– reinforcing existing basement premises by strengthening load-bearing structures, installing protective sealed doors and window systems, and equipping ventilation systems with filters and autonomous power sources;

– constructing separate protective structures using monolithic reinforced concrete with enhanced strength characteristics or prefabricated reinforced concrete structures designed for special purposes;

– equipping shelters with engineering systems, including air filtration systems, autonomous power sources, water reserves, and sewage systems.

In addition to shelters, critical safety elements include early warning and monitoring systems that enable timely responses to threats and organized evacuations. These systems incorporate acoustic alarms, light indicators, automated door-locking systems, and other components [5, p. 56].

Energy-Efficient Technologies in Restoration. The restoration of damaged general secondary education institutions provides a unique opportunity to implement modern energy-efficient technologies, significantly reducing energy consumption and enhancing building sustainability. According to the requirements outlined in methodological guidelines, restoration projects must ensure an energy efficiency class of at least "B" [4, p. 38].

Key energy-efficient technologies applied during restoration include:

– comprehensive thermal modernization of building envelopes using modern insulation materials (mineral wool, graphite-enhanced polystyrene, PIR and PUR panels) to achieve high thermal resistance;

– installation of energy-efficient windows and doors with triple glazing and low-emissivity coatings to minimize heat loss;

– implementation of heat recovery ventilation systems that retain up to 80% of thermal energy;

– use of various types of heat pumps (air-to-water, ground-to-water) for heating and cooling, significantly reducing the consumption of conventional energy resources;

– integration of solar collectors and photovoltaic panels to provide hot water and generate electricity;

– implementation of automated building management systems (BMS) to optimize energy consumption based on building usage patterns [6, p. 63].

Organization of Educational Space During Restoration. The restoration of general secondary education institutions offers not only the opportunity to restore the physical parameters of buildings but also to implement modern approaches to organizing educational spaces. According to methodological guidelines developed by the Ministry of Communities and Territories Development, restoration projects should provide for flexible, adaptable spaces that align with modern

pedagogical practices [5, p. 105, 13].

Key principles for organizing educational spaces include:

– creating multifunctional rooms that can be adapted based on educational tasks and students' needs;

– designing open learning spaces (open space) to foster collaboration and project-based work;

– zoning spaces to include areas for individual work, group activities, rest, and creativity;

– integrating digital technologies into physical spaces, creating "smart classrooms" with interactive surfaces and virtual or augmented reality systems.

Special attention is given to creating an inclusive environment that ensures accessibility and comfort for all participants in the educational process, regardless of their physical abilities [4, p. 118, 14, 15].

Conclusions. The restoration of general secondary education institutions after destruction caused by armed conflict is a complex and multifaceted process requiring a comprehensive approach. An analysis of modern approaches to restoring educational infrastructure highlights the need to combine innovative technologies, modern materials, and advanced design methods to ensure the safety, energy efficiency, and functionality of restored facilities.

Key technological solutions for effective restoration include comprehensive surveys using modern diagnostic methods, the application of Building Information Modeling (BIM) during the design phase, the use of innovative materials and technologies for strengthening and restoring structures, the creation of civil protection shelters, and the implementation of energy-efficient solutions.

Particular attention should be paid to approaches for organizing educational spaces, which involve creating flexible, adaptable environments that align with modern pedagogical practices and support the development of innovative educational forms.

Future research in this area should focus on developing new technological solutions to enhance the resilience of general secondary education institutions to potential threats, ensure their energy autonomy, and create a comfortable environment for all participants in the educational process.

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ТЕХНОЛОГІЯ ВІДНОВЛЕННЯ ЗАКЛАДІВ ОСВІТИ ПІСЛЯ РУЙНУВАНЬ ВНАСЛІДОК ЗБРОЙНОГО КОНФЛІКТУ НА ТЕРИТОРІЇ УКРАЇНИ

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Анотація. Стаття має оглядовий характер і присвячена аналізу сучасних тенденцій у технологіях відновлення закладів загальної середньої освіти після руйнувань внаслідок

збройного конфлікту на території України. Обґрунтовано актуальність формування нової моделі відновлення освітньої інфраструктури, що базується на принципах енергоефективності, технологічної інноваційності, адаптивності до нових загроз і підвищених вимог до безпеки. У контексті післявоєнного відновлення країни освіта виступає ключовою сферою, що забезпечує сталість розвитку, тому питання створення безпечного, функціонального та комфортного освітнього середовища набуває пріоритетного значення.

Здійснено системний аналіз чинної нормативно-правової бази, що регламентує процеси відновлення, з виокремленням ключових етапів проєктно-будівельного циклу, таких як: обстеження технічного стану об'єкта, розробка проєктної та технічної документації, узгодження рішень у сфері цивільного захисту, виконання будівельно-монтажних робіт і контроль якості виконання. Особлива увага приділена адаптації архітектурних та інженерних рішень до умов підвищеної загрози. Розглянуто інтеграцію елементів укріпленого захисту: облаштування укриттів, впровадження систем раннього оповіщення, організація безпечних маршрутів евакуації, а також використання «розумних» технологій моніторингу ризиків.

Крім забезпечення фізичної безпеки, окреслено роль архітектурної гуманізації, інклюзивного та адаптивного дизайну для створення психологічно комфортного середовища, сприятливого для навчання й соціалізації дітей різного віку. Запропоновано комплексну модель відновлення освітніх установ, яка синтезує сучасні будівельні технології, ресурсозберігаючі матеріали та системний стратегічний підхід до відновлення. Така модель орієнтована на створення довготривало стійких, соціально безпечних і функціонально ефективних навчальних середовищ нового покоління, що відповідають викликам сучасності та майбутнього розвитку.

Ключові слова: реконструкція, заклади освіти, відновлення, безпека освітнього середовища, енергоефективність, інноваційні технології, укриття цивільного захисту, стійкість інфраструктури.

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