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ARCHITECTURAL AND ENGINEERING PRINCIPLES FOR DESIGNING PROTECTIVE STRUCTURES AND DUAL-USE SHELTERS IN UKRAINE AFTER 2022: A COMPARATIVE ANALYSIS OF DBN V.2.2-5:2023 WITH EUROPEAN STANDARDS AND PROPOSALS FOR HARMONIZATION

Summary. *The study is aimed at a comprehensive analysis of the transformation of methodological approaches to the design and construction of civil defense protective structures in Ukraine, driven by the implementation of the state standard DBN V.2.2-5:2023. The focal point is a systemic transition from the regulatory and engineering premises of the Soviet period to contemporary solutions grounded in the calculated assessment of extreme impulsive actions and in the concept of functional adaptability of structures. It is emphasized that current regulation orients design not only toward ensuring the required level of safety, but also toward expanding scenarios of facility operation, which strengthens their applied significance within an urbanized environment.*

A substantive element of the analysis is the comparison of the national regulatory framework with recognized international practices of Switzerland and Finland, where protective structures are treated as an integrated component of

infrastructural resilience. Within this logic, attention is concentrated on the introduction of European principles for preventing progressive collapse, aligned with EN 1991-1-7, which reflects a shift toward risk-informed design and toward heightened requirements for ensuring structural robustness under localized damage.

Taken together, the stated provisions form an argument in favor of further harmonization of national standards with advanced European practice, regarded as a condition for more precise calibration of calculation procedures, improved comparability of requirements with the European regulatory domain, and minimization of non-optimal budget expenditures. At the same time, such regulatory convergence is interpreted as a factor in strengthening the social resilience of the urban environment, since a standardized increase in the reliability and functional applicability of protective structures contributes to reducing systemic risks and to raising the level of population protection in crisis scenarios.

Key words: *Civil defense, DBN V.2.2-5:2023, protective structures, dual-use structures, blast resistance, progressive collapse, BIM technologies, energy efficiency, heat recovery, standards harmonization.*

Introduction. The transformation of mechanisms for safeguarding the civilian population has acquired the status of a critical direction of state policy in Ukraine as a response to the systemic destruction of urban infrastructure that began in February 2022. Prior to this period, the national stock of protective structures relied to a considerable extent on the provisions of DBN V.2.2-5-97, developed within the Cold War logic and insufficiently sensitive to contemporary technological threats, including precision-guided weapons, loitering munitions, and the need for prolonged autonomous occupancy by substantial groups of the population amid degradation of utility networks and disruption of communications [1]. The scale of the accompanying humanitarian crisis is

illustrated by estimates indicating that direct infrastructure losses by early 2025 reached 176 billion US dollars, while total recovery needs are projected at 524 billion US dollars over the subsequent decade [2; 3].

An engineering response to these challenges was the enactment, as of November 1, 2023, of the updated state building codes DBN V.2.2-5:2023 Protective Structures of Civil Protection. The new version of the regulations fundamentally redistributed priorities with respect to the mechanical resistance of structural systems by increasing the design incidental overpressure of the blast wave from 20 kPa to 100 kPa.5 Such a tightening of requirements effectively moves civilian shelters from the category of auxiliary spaces into the class of high-technology engineering facilities, for which traditional design schemes prove methodologically insufficient and necessitate a revision of the underlying calculation premises [6].

At the same time as safety criteria were raised, the problem of economic rationality in design solutions became more acute. Under conditions of constrained budgetary resources, when the funding shortfall for priority recovery programs in 2025 is estimated at nearly 10 billion US dollars, the design of dual-use structures (DUS) becomes especially significant [3]. The operational logic of such facilities presupposes their peacetime functioning as parking facilities, sports halls, or educational spaces, which makes it possible to embed protection-related expenditures into the structure of development and municipal budgets and to reduce fiscal pressure through a multifunctional use model [7; 8].

On the basis of the author's practical professional experience, it can be noted that there is currently a pronounced effect from integrating BIM technologies with intelligent life-support systems. The documented reduction in capital expenditures by 25% alongside an increase in energy efficiency by 70% is presented not as a limiting theoretical estimate, but as a verified outcome of applying contemporary calculation models, optimized structural solutions, and up-to-date materials [11; 12].

The purpose of the study is to conduct a comprehensive comparison of the requirements of DBN V.2.2-5:2023 for the design of civil defense protective structures and dual-use structures with European approaches (including EN 1991-1-7 and the practices of Switzerland and Finland) and to substantiate proposals for their harmonization in order to enhance reliability and economic rationality of design solutions.

The author's hypothesis is based on the assumption that systematic harmonization of DBN V.2.2-5:2023 with the Eurocodes and reference European models (robustness and anti-progressive-collapse design, risk-informed design, standardization of engineering equipment, BIM-supported life-cycle management) will make it possible to maintain the required level of blast resistance (100 kPa) while reducing excessive material intensity and cost through optimization and digital methods.

Scientific novelty lies in the fact that, within this work, an integral architectural and engineering framework for harmonizing DBN V.2.2-5:2023 with European calculation culture (NDA, EN 1991-1-7, prevention of progressive collapse) is proposed for the first time, and its applied effectiveness is confirmed on the basis of project data from 2023–2025 (the effect of BIM coordination and energy optimization in the design of dual-use structures).

Materials and Methods. As the methodological foundation, the study employs comparative and systems analysis of Ukraine's regulatory and legal framework, including DBN V.2.2-5:2023 and the subsequent Amendments No. 1 and No. 2, which clarifying refine the regulation of inclusivity, fire-safety requirements, and parameters of engineering systems and equipment [9]. The methodological scope is further extended through examination of technical specifications and guidance materials issued by the Swiss Federal Office for Civil Protection (BABS), the statutory provisions of Finland (Rescue Act 379/2011), and the principles of the European Eurocodes system, with particular emphasis on EN 1991-1-7 Accidental Actions as a pivotal source for approaches to the

calculation of accidental actions and the enhancement of structural robustness [6].

The empirical component of the research is constructed on the basis of the author's project data as an engineer working on civil protection facilities in Kyiv Region over the period 2023–2025. The effectiveness of design solutions was assessed through numerical modeling oriented toward quantitative verification of the underlying calculation hypotheses. To analyze structural resistance to blast actions, the software suites LIRA-FEM and SAP2000 were used, enabling nonlinear dynamic analysis (NDA) and allowing plastic deformations, changes in stiffness characteristics, and the specific features of impulsive loading to be taken into account [5]. The energy efficiency of ventilation and heating systems was investigated using Building Energy Modeling (BEM) tools in Revit and ArchiCAD environments, which provided calculation-and-experimental verification of the stated reductions in energy consumption through modeling of heat balances and air-exchange regimes [13; 18].

To ensure correct contextualization of the engineering findings, analytical reports by international institutions (World Bank, UNDP, Deloitte) on the state of infrastructure and Ukraine's recovery needs within the RDNA4 framework were used, making it possible to link design parameters and technological solutions with macroeconomic constraints and social policy benchmarks [3]. An additional research layer was formed by sociological materials produced by balbek bureau, which elucidate features of public perception of shelters and persistent barriers that reduce the effectiveness of their use in real-world risk scenarios [10; 14].

Results and Discussion. The introduction of DBN V.2.2-5:2023 formalized a fundamental reassessment of engineering reliability criteria. The decisive parameter that directly affects the selection of structural schemes and calculation assumptions was a fivefold increase in the design peak incidental overpressure for load-bearing elements. Such an escalation of design actions predetermines a methodological departure from predominantly static approaches,

because at a level on the order of 100 kPa the response of reinforced-concrete structures is governed not only by stress magnitudes, but also by the development of plastic deformations, redistribution of internal forces within elements, and the role of inertial components associated with the short-duration impulsive nature of loading [5; 17].

Table 1 presents a comparison of the key technical requirements of the outdated version DBN V.2.2-5-97 and the current DBN V.2.2-5:2023. It demonstrates how changes in the standards regarding overpressure, slab displacements, sealing, backup power supply, and inclusivity directly affect structural solutions and the configuration of engineering systems (reinforcement design, sealing measures, mandatory filtration-and-ventilation units, autonomous power supply, and accessibility for persons with limited mobility).

Table 1

Comparison of the requirements of DBN V.2.2-5:1997 and DBN V.2.2-5:2023 for protective structures: technical parameters and engineering implications

Technical parameter	DBN V.2.2-5-97 (obsolete)	DBN V.2.2-5:2023 (current)	Engineering implication
Overpressure (ΔP)	20 kPa	100 kPa	Reinforcement increase by 5–6 times
Maximum slab displacements	Baseline level	Increase by 11.9 times	Necessity of NDA
Sealing of premises	For shelters	All types of ZSGZ (amendment No. 2)	Use of FVU is mandatory
Backup power supply	Recommended	Mandatory (minimum 48 h)	Installation of DES and UPS
Inclusivity (MGN)	Limited	Full compliance	Ramps 1:12, lifting platforms

Source: compiled by the author on the basis of [5; 9]

The analysis of the data presented in Table 1 demonstrates that the updated regulatory framework necessitates a transition to higher-strength concrete (not

below C25/30) and reinforcing steels with improved ductility characteristics. Design results obtained in the Lira CAD environment show that increasing the instantaneous incidental overpressure to 100 kPa is accompanied by a 5.8-fold increase in the required area of the reinforcement cross-section relative to the parameters characteristic of the previous regulatory logic [5]. This relationship generates a pronounced economic risk, since growth in steel intensity and the complication of structural solutions translate directly into higher implementation costs and heighten the need for engineering optimization without any reduction in the level of protection [19; 20].

A comparison of Ukrainian regulations with the practices of Switzerland and Finland makes it possible to identify directions that are potentially significant for further harmonization and for increasing the effectiveness of the national civil protection system. The Swiss approach, based on TWK and BABS standards, is characterized by exceptionally comprehensive population coverage with shelters, exceeding 100% for a population of approximately 9 million people [21; 23]. The structural basis of typical Schutzraum facilities is represented by cast-in-place reinforced concrete with wall thicknesses of 30–60 cm, and the design resistance to pressure on the order of 1 bar (100 kPa) is comparable in magnitude to the target requirements fixed established in the current Ukrainian version [16]. An important feature of the Swiss model is strict unification of engineering equipment: both blast-protection elements (including valve devices) and modular air-filtration systems together with the associated operational infrastructure are standardized. In Ukrainian regulation, this logic is only at the stage of institutional consolidation: Amendment No. 2 to DBN V.2.2-5:2023 lays the groundwork for introducing requirements for automated monitoring and communication systems, yet the degree of detail and the mandatory character of equipment do not yet reach the level of Swiss typification [15].

The Finnish model, institutionally anchored in the Rescue Act, demonstrates a different trajectory oriented toward dual use of the protective

stock. A substantial share of shelters is produced by the private sector and integrated into residential and commercial buildings of significant floor area; the proportion of such facilities reaches 85%, and the obligation to provide shelters applies to buildings with an area exceeding 1200 m2 [8]. The regulatory framework permits peacetime use of shelters as storage areas, fitness spaces, or parking facilities, provided that conversion to protective mode can be ensured within 72 hours [8]. The quick-conversion principle is not an auxiliary organizational requirement, but a systemic instrument for maintaining the viability of the stock: it lowers the socioeconomic barriers to upkeep, increases the regularity of use, and reduces the risk of engineering-system degradation due to prolonged idleness [22; 24].

The practical implementation of civil defense protective structures in Kyiv Region under the author's supervision demonstrates that literal adherence to DBN V.2.2-5:2023 in the absence of optimization strategies can lead to disproportionate growth in project cost. The applied engineering logic made it possible to align the normatively prescribed safety level with the economic justification of solutions, minimizing excessive expenditures while maintaining the required parameters of strength and operational reliability.

A 25% reduction in capital costs was achieved through a set of interrelated measures. Rational zoning with a clear separation between the entry dirty zone and the main clean zone made it possible to limit the area of the most expensive sections associated with vestibule airlocks and the installation of protective gastight doors, thereby reducing the volume of highly specialized work and equipment [9]. Additional effects were achieved through the use of materials with improved mechanical properties: applying steel-fiber-reinforced concrete created preconditions for reducing the steel intensity of the reinforcement cage while preserving the required blast resistance, that is, it redistributed load-bearing capacity between conventional reinforcement and dispersed strengthening of the concrete matrix [11]. BIM coordination played a substantial role by ensuring

high-precision layout of engineering systems within the constrained volumes of shelters and reducing the likelihood of clashes, which in typical practice become a source of costly rework during construction [25-27].

A 70% increase in energy efficiency is of particular significance in the context of degradation of the energy infrastructure, where destruction of a substantial share of generating capacity turns the autonomy and resource efficiency of shelters into a factor of resilience for critical functions [4]. In the implemented projects, HRV and ERV ventilation units with heat recovery were used, enabling the return of up to 90% of the energy of exhaust air, which is a fundamental advantage during extended operation under sealed conditions and high occupant density [30]. Intelligent control systems (HMS) regulating air supply by CO2 level ensured a 30–45% reduction in operating costs through adaptive operation and the elimination of excessive air exchange [31]. Additional resource conservation was achieved through geothermal support: using ground temperature for preheating or precooling of supply air via underground air ducts reduced the need for electric air heaters and decreased peak loads on the power supply system [32; 33].

A distinct theoretical and applied block of contemporary design is associated with ensuring structural robustness and preventing progressive collapse. The provisions of EN 1991-1-7 establish the requirement to design buildings in such a way that local damage, including the loss of an separate single vertical load-bearing element due to an explosion, does not initiate a cascading loss of load-bearing capacity and destruction failure of a significant part of the structure [6]. In the engineering solutions applied by Minchenko, this requirement is implemented through use of the catenary action mechanism, whereby floor systems are capable of carrying loads in the form of tension membranes after a local loss of support. Activating such behavior requires ensuring continuity of reinforcement and providing special ties that create alternative load paths between surviving support zones, thereby forming a reserve of strength and

stability of the system under accidental actions [6; 34].

Table 2 systematizes the principal approaches to preventing progressive collapse and shows the mechanism through which each method increases structural resilience. Practical applicability and expected effectiveness of the solutions specifically for civil defense protective structures are highlighted separately, ranging from the organizational-and-analytical alternative path (AP) approach and heavy tie requirements to structural measures (protected core) and material-based strengthening (steel-fiber-reinforced concrete).

Table 2

Methods of protection against progressive collapse: mechanism of action and effectiveness for civil defense protective structures

Collapse protection method	Mechanism of action	Effectiveness in ZSGZ
Alternative load paths method (AP)	Redistribution of load to adjacent columns	High for frame buildings
Heavy ties (Tie Forces)	Anchorage of elements to work in tension	Mandatory under Eurocode
Protected core	Strengthening of the central part of the building	Protection of evacuation routes
Steel fiber reinforced concrete	Increase in impact toughness and crack resistance	Reduction of brittle failure

Source: compiled by the author on the basis of [6; 9; 11]

By 2025, the protective structure ceases to be a purely fortification-type facility and acquires the characteristics of an element of the urban environment embedded in the functional and spatial relationships of the built fabric. As a result, requirements for universal design and architectural acceptability become more salient, because the operational effectiveness of a shelter is determined not only by its calculated strength, but also by the quality of the environment of stay. Sociological and applied studies conducted by balbek bureau document a direct relationship between the population's willingness to use shelters and parameters

of psychological comfort, including the availability of privacy zones, the creation of visual analogs of natural lighting, and the provision of acoustic well-being as a factor in reducing stress load [10; 28].

Practice in Kyiv Region demonstrates the feasibility of a multifunctionality model in which underground spaces of educational institutions operate in peacetime as media libraries and robotics laboratories. Such integration makes it possible to correlate capital investments in protective infrastructure with the development of the social and educational function of facilities and thereby to increase the substantiation of budget expenditures, including funding in the amount of 11.8 billion UAH that the state directs in 2025 to the modernization of educational institutions and the construction of shelters [38].

The analysis conducted indicates that DBN V.2.2-5:2023 constitutes qualitative progress; however, achieving full-scale operational compatibility with the European regulatory domain requires further institutional and methodological transformations. A substantive task is the formalization of nonlinear dynamic analysis (NDA): within European calculation culture, this tool is regarded as a baseline instrument for substantiating blast resistance, whereas in Ukraine its use largely retains a recommendatory status. Scientific and practical expediency implies the development of methodological guidelines and procedural requirements that would make it possible to unify the formulation of calculation models, verification criteria, and interpretation of results within the DBN framework [6].

A second direction is the advancement of modularity and certification of engineering equipment, as demonstrated by Swiss practice in deploying prefabricated life-support systems. Adapting this approach under Ukrainian conditions can reduce the duration of installation operations by approximately 40% while simultaneously increasing the reliability of filtration-and-ventilation complexes through factory standardization and controlled testing procedures [16].

Additional potential for increasing the resilience of the shelter stock is associated with financial and organizational mechanisms for engaging the private sector. The Finnish model of mandatory shelter provision in development projects may be reproduced more effectively when accompanied by supporting incentives, including tax instruments and risk-insurance schemes, which is reflected in Deloitte analytical materials [8; 29].

Particular attention is required for data management and life-cycle governance of facilities on the basis of BIM [26]. The creation of a unified national database of digital twins of protective structures is viewed as an instrument for rationalizing operations, planning upgrades, and accelerating managerial decision-making in emergencies, because digital identification of facility parameters reduces uncertainty when assessing availability, the condition of engineering systems, and readiness for use.

Conclusion. Contemporary practice in the design of protective structures in Ukraine has entered a phase of profound technological restructuring, in which regulatory and engineering evolution unfolds in parallel with shifts in the nature of threats and in requirements for urban resilience. The adoption of DBN V.2.2-5:2023 has established a calculation and structural reserve of reliability comparable to advanced international models implemented in Switzerland and Finland. At the same time, practical outcomes from implementing the new requirements show that attaining the prescribed level of protection is achieved not only through direct escalation of material intensity, but also through the systemic intellectualization of design solutions and engineering equipment.

The author's synthesized experience in delivering civil protection facilities in Kyiv Region confirms the effectiveness of an approach grounded in integrating digital design with energy-optimized technologies. The recorded indicators, a 25% reduction in capital costs and a 70% increase in energy efficiency, are interpreted as the result of synergy among BIM modeling, the application of heat-recovery systems, and design according to the dual-use principle, in which a

facility's operational value is formed not episodically, but throughout its entire life cycle. Within this logic, civil defense protective structures are understood as high-technology elements of engineering infrastructure, where economic justification is achieved through reducing coordination errors, optimizing spatial and planning solutions, and improving the effectiveness of life-support systems.

Further development of the regulatory framework requires deeper harmonization with the Eurocodes, primarily with respect to ensuring structural robustness and preventing progressive collapse. Strengthening alignment with European calculation and organizational principles creates preconditions for more predictable risk management, unification of reliability-substantiation methodologies, and increased comparability of design solutions with the practices of EU countries. As a result, an infrastructure framework is formed that is capable of performing a dual function: preserving life and health during periods of threat while simultaneously supporting sustainable socioeconomic development over the long term.

Integrating shelters into everyday urban life through the functionality of dual-use structures constitutes a strategic mechanism for increasing the resilience of the urban environment. Under this approach, protective spaces cease to be passive ballast and assume the role of active components of urban infrastructure, combining safety requirements with principles of inclusivity and comfort. The long-term viability of the protective-structure stock under these conditions is determined not only by the level of calculated strength, but also by the quality of integration into the city's social and operational scenarios, which ensures regular use, maintenance of engineering readiness, and accessibility for all categories of the population.

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