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Technologies & Innovations

Urbanistic

Oleksiy V. Myronyuk [a][1], *Oleksiy O. Sikorsky* [b][2]

Wetting Anomalies on Kaolin Particles Highlighting Limits of the Thin-Layer Washburn Technique [1]

Abstract:

The determination of surface free energy and wetting characteristics of powdered minerals remains a methodological challenge due to the inability to apply conventional contact-angle techniques to porous and highly absorbent materials. Kaolin is widely used as a model aluminosilicate system, yet its complex surface chemistry raises questions concerning the applicability of classical approaches such as the Washburn equation. The present study investigates the wetting behaviour of thin kaolin layers using water and cyclohexane, with the aim of evaluating deviations from Washburn-type capillary rise dynamics. A thin-layer wicking method was employed, combining controlled sample preparation, high-resolution video tracking, and statistical analysis of capillary kinetics. The work builds on established research by Chibowski, Newby, Danchenko, Rybka and others, who have highlighted both the utility and the limitations of the Washburn method for powders. The results show that the initial wetting front is strongly non-uniform and influenced by adsorption-driven and inertial effects, while subsequent stages reflect a transition to capillary-controlled motion accompanied by the formation of a diffuse partially saturated region. Despite this heterogeneity, repeated measurements demonstrated high reproducibility, yielding a consistent average capillary rise rate of approximately 4460 µm²/s for water. However, a pronounced divergence from theoretical predictions was observed: cyclohexane permeated the kaolin layer significantly faster than water, contradicting Washburn-based expectations derived from assumed contact angles. These findings indicate that the classical Washburn model does not adequately describe wetting in kaolin layers and suggest that additional factors — such as ionic interactions, partial pore saturation, or dissolved-gas effects — may govern the observed anomalies. The study thus defines clear limitations of the thin-layer Washburn technique and outlines directions for refining wetting analysis in complex mineral powders.

Keywords: mural, public art, street art, urban environment.

Introduction

It is well established that surface free energy represents the effective potential governing how dispersed solids interact with liquids, gases, or foreign bodies, serving as a quantitative measure of interfacial reactivity (*Danchenko et al., 2018*). Although numerous techniques for flat surfaces—such as the sessile drop, Wilhelmy plate, or du Noüy ring methods—are based on contact angle measurements (*Kwak et al., 2018*; *De Farias et al., 2025*), they cannot be applied to powders (*Alghunaim et al., 2015*). Thus, reliable determination of surface free energy for particulate materials remains a significant challenge (*Kirdponpattara et al., 2013*).

For powders undergoing mechanical treatment, surface reactions, oxidation, or hydrophobization, such measurements become particularly important. However, adapting flat-surface methods—e.g., sessile-drop analysis on compressed powder beds—is usually infeasible, as droplets are immediately absorbed by the porous structure, preventing equilibrium contact angle formation.

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[a] Doctor of Engineering Sciences, Associate Professor, Department Head, Chemical Technology of Composite Materials Department, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.
[b] Candidate of Engineering Sciences (Ph.D.), Senior Lecturer, Chemical Technology of Composite Materials Department, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.

Since the 1950s, the Washburn method has been widely used to address this issue. A porous body formed from powder—either on a thin plate or within a narrow capillary—is successively wetted with a nonpolar liquid such as diiodomethane or hexane and with water (*Chibowski & Holysz, 1992*). The Washburn equation relates the squared penetration height to time, allowing estimation of contact angles when corrected for liquid viscosity and surface tension (*Myronyuk et al., 2020*).

For materials such as quartz or silica, contact angles obtained by the Washburn technique match those measured on equivalent flat surfaces, supporting its validity for simple systems. However, other studies show deviations for silicate-based materials, indicating that the method does not universally apply to more complex chemistries or morphologies.

In particular, preliminary results by the authors revealed similar limitations for dispersed kaolin. The present work was therefore designed to demonstrate systematic deviations from the classical Washburn prediction when kaolin is wetted by the commonly used probe liquids, water and cyclohexane.

The present investigation focuses on the wetting behaviour of kaolin in a thin-layer configuration using water and cyclohexane.

The object of study is the wetting behaviour of kaolin powder layers—specifically, how liquids penetrate and interact with kaolin surfaces under capillary conditions modelled by the Washburn equation.

The principal subject of analysis is the deviation of the experimentally observed wetting dynamics from those predicted by the Washburn equation.

The study aims to critically evaluate the applicability and limitations of the classical Washburn equation for describing capillary rise and wetting kinetics in kaolin-based systems. The study seeks to identify and explain the observed deviations between theoretical predictions and experimental measurements obtained via thin-layer wicking experiments.

According to the purpose, following tasks are set:

− fabricate and characterise thin kaolin layers suitable for reproducible wicking experiments with both polar (water) and non-polar (cyclohexane) liquids.

− measure and statistically analyse capillary rise kinetics using a calibrated video-based system to ensure methodological precision;

− compare experimentally determined wetting rates with those predicted by the classical Washburn model;

− identify potential physicochemical factors (ionic interactions, partial pore saturation, evaporation effects, gas retention) that may cause observed deviations;

− determine the methodological boundaries of the Washburn approach when applied to complex aluminosilicate materials such as kaolin.

To this end, thin-layer kaolin plates were fabricated to enable repeated measurements in different media. A calibrated video-based procedure was developed to track capillary infiltration, and statistical datasets were obtained for water and hexane.

The results consistently show departures from Washburn behavior, confirming that the method is significantly limited for this aluminosilicate powder.

Materials and Methods

In the study to create the thin layer of powders the approach was used. The kaolin powder was obtained from a local supplier (KC-1 of Ukraine kaolin company), dried in oven for 5 h at 105°C and cooled. The slurry for coating was formed by taking 5 g of dry kaoline and 95 g of water, mixing powder with water with slow speed stirrer, disparaged with laboratory high-speed blender for 3 min and poured into the microscopic laboratory glasses. The poured slurry was left to dry overnight and the obtained uniform layer was additionally dried for 6 h at 105°C, then the layer was vertically segmented to obtain straight lines from the kaoline powder on the glass by remove of the layers' fraction with blade. The setup of wetting speed measurement includes the microscope UCMOS 1300 digital camera, optical tube and the probe liquid inside the transparent cuvette. Depending on the measurement either water of the cyclohexane was used. At the start of measurement, the microscopic glass mounted in the holder was immersed into the liquid. The wicking layer started to move upwards and from this moment the recording was started and kept at 20 fps rate for 20 sec for each sample. The video files then were analysed with Toup View software, that was calibrated to identify precisely an object scale and the frame duration. The measurement was kept from the line of wetting to the highest point of the wetting front in several points of the sample. The real ratio of h^2/m was calculated basing on the average of 4–6 experimental results using the ANOVA analysis tool built in Origin software.

Literature Review

The determination of surface free energy and wettability parameters for powdered materials remains a significant methodological challenge in surface science. Traditional contact-angle measurement techniques, such as the sessile drop, Wilhelmy plate, or du Noüy ring methods, are applicable to smooth, impermeable surfaces but cannot be reliably used for porous or particulate media, where immediate absorption prevents equilibrium contact formation (*Kwak et al., 2018*; *De Farias et al., 2025*). Consequently, researchers have developed alternative approaches capable of describing the interaction between liquids and heterogeneous solids, among which the Washburn capillary rise method has gained particular prominence. By relating the square of penetration height to time under controlled conditions, this technique offers an indirect yet practical way to estimate surface free energy and contact angles in powders (*Alghunaim et al., 2015*).

The Washburn equation assumes uniform cylindrical capillaries, constant fluid properties, and ideal wetting behaviour governed solely by capillary forces. Early studies demonstrated its validity for homogeneous materials such as quartz and silica, where the experimentally obtained contact angles closely matched theoretical predictions (*Chibowski & Holysz, 1992*). However, later investigations revealed that deviations from the ideal model become significant for systems with irregular pore structures, mixed wettability, or complex surface chemistries. In such cases, the linear relation between squared penetration height and time begins to fail, indicating that other processes—adsorption, partial saturation, or evaporation—affect the infiltration dynamics.

A growing body of work has therefore focused on quantifying and interpreting these discrepancies. Kirdponpattara, Phisalaphong, and Newby (*2013*) demonstrated that the Washburn method systematically overestimates contact angles for fibrous and granular materials

due to dynamic effects at the wetting front. Similarly, Danchenko et al. (*2018*) designed an automated system for measuring surface energy in epoxy composites and reported that results obtained through classical Washburn analysis must be corrected for material-specific characteristics. Myronyuk, Baklan, and Nudchenko (*2020*) further showed that the Owens–Wendt theory, when combined with experimental data, allows a more accurate evaluation of surface energy for dispersed aluminium oxide, illustrating the need for hybrid models that bridge theoretical and empirical approaches.

Experimental observations of capillary rise often reveal phenomena that contradict the assumptions underlying the Washburn model. Tullis and Wright (*2007*) observed three-dimensional instabilities in wetting fronts propagating through granular media, while Benner and Petsev (*2017*) demonstrated that evaporation can create diffuse, partially saturated regions that alter the apparent rise rate. Mampallil et al. (*2018*) described how inertial effects, adsorption, and surface heterogeneity contribute to transient deviations from classical capillary behaviour, producing complex patterns of liquid advance similar to those detected in kaolin layers. These studies collectively suggest that the dynamics of wetting are governed not only by capillary pressure and viscosity but also by physicochemical factors intrinsic to the solid matrix.

Kaolin serves as a particularly illustrative model for studying such effects. As a layered aluminosilicate mineral, it exhibits high surface heterogeneity, hydrophilicity, and pronounced ionic activity. The surface hydroxyl groups of kaolin participate in hydrogen bonding and electrostatic interactions with both polar and non-polar liquids, significantly affecting interfacial energy and adsorption capacity. Kwaśniewska et al. (*2020*) demonstrated that kaolin additives can substantially modify the mechanical and structural properties of polymer matrices, underscoring its strong interfacial reactivity. When subjected to capillary infiltration, these same properties yield complex wetting patterns that diverge from classical Washburn predictions.

The literature therefore converges on a consistent conclusion: while the Washburn equation remains an essential analytical tool, its straightforward application to complex mineral powders such as kaolin is limited. The assumptions of uniform capillary geometry and constant contact angle do not adequately represent systems with variable pore sizes, surface heterogeneity, or competing adsorption phenomena. The discrepancies reported in recent studies cannot be dismissed as experimental artefacts; rather, they point to fundamental physicochemical processes—ionic interactions, gas retention, partial pore saturation, and surface restructuring—that must be incorporated into revised models. Accordingly, the refinement of the Washburn approach through integrated experimental and theoretical methods represents a promising direction for advancing the characterisation of wetting and surface energy in heterogeneous mineral systems.

Results

At the onset of wetting of a kaolin particle layer, the infiltrating liquid fills the interparticle pores, leading to a change in the optical transparency of the layer. This transparency variation enables visual tracking of the height to which the wetting front rises and the rate at which it propagates.

In Figure 1 (*Appendix*), it can be observed that the wetting front begins to advance from the top downward. This motion is distinctly non-uniform, as it was previously pointed out in

the work of Tullis and Wright (*2007*). Along the entire length of the wetting front shown in Figure 1a, two pronounced protrusions appear on the left and right sides, whereas the central region forms a depression. This pattern corresponds to the initial stage of wetting, during which the process is governed primarily by adsorption phenomena. The front is inertial, as its shape is also influenced by the velocity at which the substrate enters the wetting liquid. As a result, the non-uniformity of the wetting front is highly evident at this stage and cannot be compensated rapidly.

However, after a certain period of time, the wetting rate begins to decrease. This slowdown is partly attributable to gravitational forces and partly to the progressive homogenisation of the wetting process (*Mampallil et al., 2018*). At this stage, inertial effects no longer dominate; instead, capillary forces govern the motion of the liquid front. As illustrated in Figure 1D, the wetting front becomes more uniform over time. Additionally, the boundary of this front becomes increasingly diffuse.

This diffuse boundary is a noteworthy phenomenon. It arises because liquid evaporation occurs directly from the advancing front. As a result, there exists a transitional region in which the pores are not fully saturated with liquid, yet they contain a measurable amount of adsorbed moisture deposited during evaporation (*Benner et al., 2017*). This effect is more distinctly visible in Figure 1C.

Figure 1 clearly demonstrates that the wetting rate varies considerably across different regions of the sample. Therefore, when comparing the wetting kinetics of different liquids, it is reasonable to measure the rise velocity at a single, well-defined point on the specimen. This observation also raises questions regarding the overall reproducibility of such measurements.

To evaluate and illustrate this reproducibility, we performed nine independent measurements of the capillary rise kinetics of water in different locations of the same kaolin layer. The resulting kinetic curves are presented in Figure 2 (*Appendix*).

The results presented in Figure 2 are rather unexpected. They show that the slope of the main kinetic dependence—not at the initial moment of wetting, but within the interval from approximately 5 to 20 seconds, and in some cases even longer—remains effectively constant. This behaviour is particularly evident when the data are plotted in the coordinates $h^2 = f(t)$. Under these conditions, the capillary rise of water proceeds at a constant rate.

From these measurements, an average capillary rise velocity of approximately 4460 µm²/s can be derived for water. This value is consistently reproduced across a broad range of measurement points within the same sample.

Thus, the method demonstrates sufficiently high reproducibility, provided that an appropriate level of statistical processing is applied and an adequate number of repeated measurements are performed. We then proceed to examine whether the experimentally obtained average imbibition rates for the polar liquid (water) and the nonpolar liquid (hexane) correspond to the values predicted by the Washburn equation.

To estimate the expected velocities using the Washburn model, we assumed a water–kaolin contact angle of approximately 45°C (*Kwaśniewska et al., 2020*). Based on this assumption, the theoretical wetting curves were calculated, and these predicted dependencies are presented in Figure 3a (*Appendix*).

In Figure 3a (*Appendix*), it is clearly seen that the predicted wetting rate of kaolin by water should exceed that of cyclohexane. This expectation is reasonable, given that a polar solid is anticipated to exhibit stronger affinity toward a polar liquid. However, the experimental results shown in Figure 3b (*Appendix*) reveal the opposite trend: cyclohexane wets the kaolin layer considerably faster than water.

One could suggest that the discrepancy arises from the initial assumptions—namely, that the kaolin–water contact angle is approximately 45°C, whereas the hypothetical contact angle for hexane might be as low as ~3° or even less. It is also possible that kaolin is more hydrophilic than assumed, which would shift the expected water curve upward. Yet, the more hydrophilic the kaolin surface is, the higher the predicted water wetting curve should lie. Consequently, even for a strongly hydrophilic kaolin surface, the trend observed experimentally in Figure 3b cannot be reconciled with the prediction of the Washburn equation.

Discussion

The experimental results obtained in this study deviate markedly from the behavior predicted by the Washburn equation. Moreover, the measurements were performed with sufficient statistical rigor, including a substantial number of repetitions, to ensure the reliability of the observed trends. Consequently, the discrepancy between the experimentally measured values and those forecasted by the Washburn model cannot be attributed to statistical uncertainty, as it lies well beyond the limits of experimental error.

The results of this study leave unresolved the question of whether the Washburn equation can be reliably applied to predict the wetting behavior of materials with complex surface architectures, such as kaolin, including the estimation of their specific surface energy and contact angle. Additionally, the underlying origin of the pronounced discrepancy between the theoretical predictions and the experimental observations remains unclear and warrants further investigation.

Only by addressing these two key questions can the actual limits of applicability of the Washburn equation to different mineral systems be determined. At the same time, the very factors responsible for the deviation from the theoretical model represent a valuable subject of study in their own right. These deviations provide important insights into the physicochemical nature of such materials when examined through the Washburn method and the technique of thin-layer capillary rise.

For example, if the source of such deviations is the ionic character of the material—i.e., its ability to retain water through specific association mechanisms—then this very property could be probed and quantified using the thin-layer capillary rise method.

Conclusion

The present study systematically investigated the wetting behaviour of thin kaolin layers using water and cyclohexane as probe liquids, with particular attention to the applicability and limitations of the classical Washburn equation for such mineral systems. The experimental analysis demonstrated that the initial stage of wetting is strongly non-uniform and dominated by adsorption and inertial effects, as manifested by irregular propagation of the wetting front. As the process progresses, capillary forces become the prevailing driving mechanism, resulting

in gradual homogenization of the wetting profile and the appearance of a diffuse transition zone attributed to liquid evaporation and partial pore saturation.

Repeated measurements of the capillary rise kinetics revealed that, despite the local non-uniformities of the wetting front, the method exhibits high reproducibility when adequate statistical treatment is applied. The experimentally observed linearity of the $h^2 = f(t)$ dependence within defined time intervals enabled estimation of an average capillary rise velocity of approximately 4460 µm²/s for water. This value was consistently reproduced across multiple locations on the same kaolin layer, confirming that the thin-layer method can reliably provide kinetic parameters.

However, a major outcome of this work is the discovery of a pronounced discrepancy between the experimentally determined wetting rates and those predicted by the Washburn equation. According to the theoretical model, water—due to higher polarity and expected stronger affinity to kaolin—should exhibit faster infiltration than cyclohexane. In contrast, the experiments revealed the opposite behavior: cyclohexane permeated the kaolin layer significantly more rapidly. Attempts to reconcile this discrepancy through variations in assumed contact angles or increased kaolin hydrophilicity remained insufficient, demonstrating that the classical Washburn framework does not capture the actual dynamics for this material.

These findings raise two fundamental issues: (1) whether the Washburn equation is appropriate for estimating surface energy and contact angles of minerals with complex physicochemical characteristics such as epokaolin, and (2) what specific material properties or interfacial phenomena give rise to the observed deviations. Potential contributing factors include ionic interactions, water retention via specific adsorption, pore blocking by dissolved gases, or changes in surface hydrophobicity following exposure to organic liquids. Each of these mechanisms represents a promising direction for further research and may itself be quantifiable through refined thin-layer capillary rise measurements.

Overall, the study highlights that while thin-layer wicking experiments offer high reproducibility and valuable kinetic insights, the Washburn equation should be applied to kaolin and similar minerals with considerable caution. The deviations observed are not random artifacts but systematic effects intrinsic to the material's interfacial behavior. Understanding these deviations provides a pathway to expanding the method's diagnostic capabilities and refining theoretical models for predicting wetting in complex porous mineral systems.

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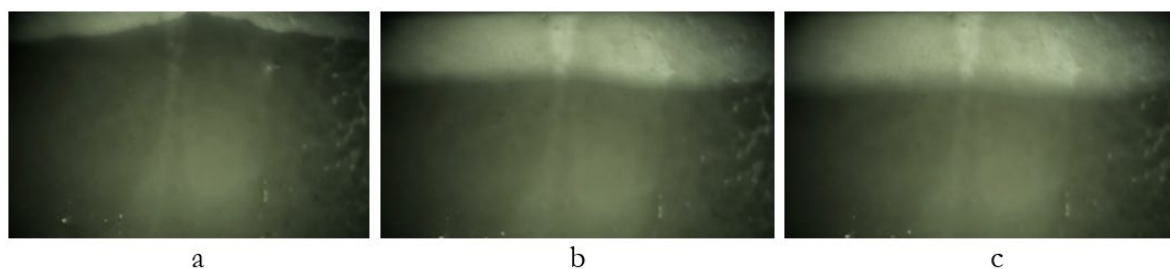
Appendix

Figure 1. Tracking images of kaolin layer wetting with cyclohexane: (a) initial stage, (b) slow down to uniform speed; (c) diffuse wetting
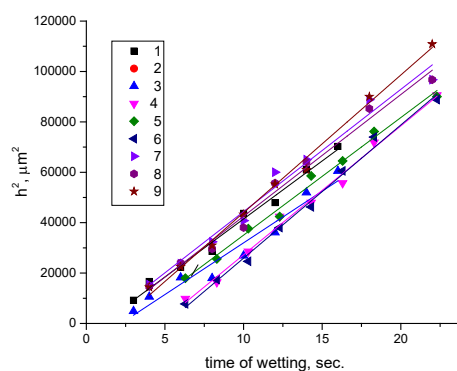

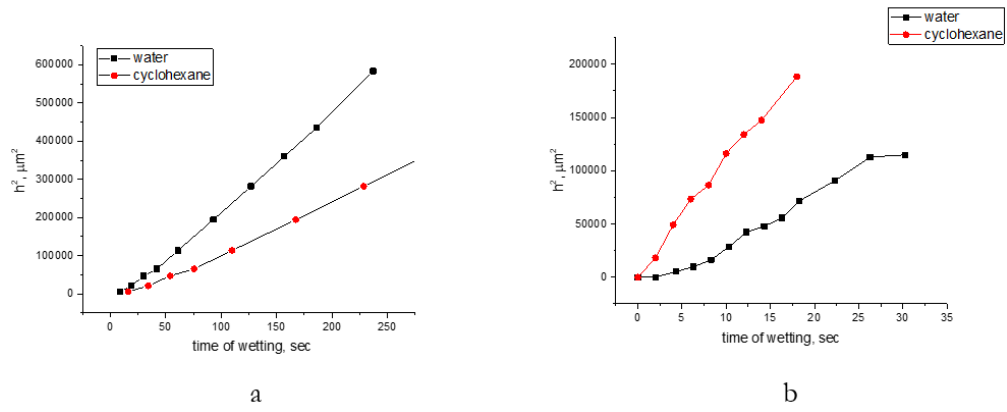Figure 2. Wetting kinetics of kaolin layer (water as a probe liquid)

Figure 3. Wetting kinetics of water/hexane: (a) predicted with Washburn equation for kaolin surface, (b) obtained experimentally

Kateryna Yu. Redko [a][3]

Empowering Women through Social Entrepreneurship: Comparative Insights from Ukraine and the Middle East [2]

Abstract:

This article investigates the development of women-led social entrepreneurship in Ukraine and the Middle East, focusing on how institutional frameworks, socio-cultural contexts and economic conditions shape female participation and effectiveness in this domain. The object of the study is social enterprises founded and led by women; the study aims to identify the enabling and constraining factors that influence their performance across contrasting contexts. The study uses a comparative institutional and gender-based analytical framework, integrating qualitative case analysis, content review of policy and academic documents, and a semi-systematic literature review covering the period 2014–2025. Principal theoretical contributions derive from institutional theory, gender and development theory and social innovation theory. The findings reveal that hybrid mechanisms — combining formal support and informal networks — digital tools and circular economy strategies, as well as cross-border mentorship, critically affect growth, social impact and sustainability of women's social enterprises. In Ukraine, stronger formal institutional support and higher digital adoption correlate with greater growth and impact; in Middle Eastern contexts, women compensate through informal networks and community ties but face significant structural barriers. The results are intended to inform policymakers, practitioners and scholars designing gender-inclusive, context-sensitive interventions to advance social innovation and enterprise ecosystems.

Keywords: women social entrepreneurship, gender equality, Ukraine, Middle East, institutional support, digital tools, social impact, female entrepreneurs.

Introduction

In recent decades, women's social entrepreneurship has emerged as a transformative force in driving inclusive and sustainable economic development. Across both Ukraine and the Middle East, female-led enterprises increasingly address social inequalities, unemployment, and community resilience. However, their evolution reflects distinct institutional, cultural, and economic realities. Ukraine, transitioning toward European integration and digitalization, provides an environment where formal mechanisms and international support programs play an essential role. Conversely, Middle Eastern countries—such as Iran, Jordan, Lebanon, and Egypt—operate within more constrained socio-political and institutional frameworks, where informal networks and community engagement often substitute for state support. This divergence underscores the need for a comparative, cross-regional analysis of how women navigate institutional barriers and innovate for social impact.

Thus, understanding the structural and cultural differences between Ukraine and Middle Eastern economies enables policymakers to design more context-sensitive strategies for women's empowerment through entrepreneurship.

The object of this study is the system of women-led social enterprises operating within transitional and restrictive institutional contexts. The purpose is to identify the core institutional,

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[a] Candidate of Economic Sciences (Ph.D.), Associate Professor, Senior Researcher, G. M. Dobrov Institute for Scientific and Technological Potential and Science History Studies. Kyiv, Ukraine.

socio-cultural, and economic determinants shaping women's participation, sustainability, and impact in social entrepreneurship. Specific objectives include:

1) analyze the institutional frameworks and policy support systems in Ukraine and selected Middle Eastern countries;
2) assess digital and technological adoption by female social entrepreneurs;
3) evaluate the role of informal networks, mentorship, and cross-border collaboration;
4) propose a conceptual model for enhancing women's social entrepreneurship ecosystems across regions.

Thus, the study's design enables a multidimensional understanding of how gender, governance, and innovation intersect in emerging economies.

Methodologically, the research applies to a comparative institutional and gender-based analytical framework. A mixed qualitative approach integrates comparative case studies, content analysis of policy and academic documents, and a semi-systematic literature review covering the period 2014–2025. Primary and secondary data were sourced from official databases (World Bank, UN Women, ILO), academic journals, and policy reports. The study combines macro-level indicators—such as women's labor participation and access to finance—with micro-level analyses of entrepreneurial motivation, leadership styles, and innovation behavior.

Thus, by triangulating theory and evidence across institutional, gender, and innovation dimensions, this research offers a comprehensive framework for analyzing women's entrepreneurship in transitional economies.

The findings of this study are intended for scholars, policymakers, and development practitioners working on gender-inclusive economic policies and social innovation strategies. For Ukraine, the insights can inform post-war recovery and EU-aligned policy design, while for Middle Eastern countries, they offer guidance on leveraging informal mechanisms and digital tools to overcome regulatory and cultural barriers.

Thus, the practical and theoretical outcomes of this paper aim to strengthen regional collaboration, promote sustainable development, and empower women through the expansion of social entrepreneurship ecosystems.

Methods

This study adopts a comparative institutional and gender-based analytical design to examine the dynamics of women-led social entrepreneurship in Ukraine and selected Middle Eastern countries (Iran, Jordan, Lebanon, and Egypt). The primary aim is to identify the institutional, socio-cultural, and economic determinants influencing women's participation, sustainability, and impact in the social enterprise sector. The object of the study is the ecosystem of women-founded social enterprises functioning within transitional, post-crisis, or restrictive institutional environments.

The research design combines qualitative comparative analysis and document-based content analysis. The choice of a comparative approach allows for identifying both convergences and divergences in institutional frameworks and gendered entrepreneurship patterns between post-socialist and Middle Eastern economies. Ukraine, representing a post-industrial transformation model under EU-aligned reforms and wartime recovery, is compared

with Middle Eastern countries that reflect hybrid economic structures, religious norms, and emerging digital ecosystems.

Thus, this methodological choice provides a multidimensional perspective, uncovering how gender, institutions, and innovation interact under diverse economic and cultural regimes.

Data was collected from secondary and documentary sources to ensure comprehensiveness and credibility. The study integrates information from: Official international databases—*World Bank Gender Data Portal, UN Women, OECD MENA Policy Reports*, and *ILO Statistics*; National and regional reports—*Ministry of Digital Transformation of Ukraine* (*2023*), *Iran Statistical Center* (*2023*), *Egypt CAPMAS* (*2024*); Scholarly and peer-reviewed publications from 2014–2025, emphasizing institutional, gender, and innovation studies; Grey literature and policy documents from development agencies (We-Fi, EU4Business, USAID, Diia.Business).

Selection criteria for data sources included relevance, recency, academic credibility, and regional balance. Countries were chosen based on:
1) availability of data on female entrepreneurship,
2) distinct institutional structures,
3) relevance to the study's comparative framework.

Thus, the study ensures representativeness by combining data from reform-oriented (Ukraine) and institutionally constrained (Middle Eastern) economies.

The study is grounded in three interlinked theoretical lenses:
1. Institutional Theory (*North, 1990*; *Scott, 2014*)—explaining how formal and informal institutional arrangements shape opportunities for women entrepreneurs.
2. Gender and Development Theory (*Kabeer, 1999*)—addressing empowerment mechanisms and social capital formation.
3. Social Innovation Theory (*Mulgan, 2019*)—framing women's enterprises as adaptive responses to social and economic disruptions.

These frameworks guide the interpretation of variables across four analytical dimensions:
- *Institutional environment*: policies, regulations, and financial support systems;
- *Socio-cultural factors*: gender norms, social legitimacy, and community engagement;
- *Digital transformation*: access to technology, digital literacy, and online markets;
- *Social impact and sustainability*: employment generation, innovation, and social inclusion outcomes.

Thus, the integration of theoretical perspectives allows for a holistic understanding of women's entrepreneurial ecosystems, linking structure, agency, and innovation.

A semi-systematic literature review (*Snyder, 2019*) was applied to synthesize academic and policy findings. Thematic coding identified recurring variables and patterns in institutional barriers, policy frameworks, and innovation behavior. Comparative matrix analysis was used to juxtapose Ukrainian and Middle Eastern contexts across the four analytical dimensions. To enhance analytical rigor, triangulation was employed—cross-verifying data from academic publications, policy reports, and international databases.

Additionally, the study draws on descriptive statistical indicators such as female labor force participation, social enterprise density, and digital adoption rates to provide contextual quantification. Where possible, country-level indicators (e.g., % of women entrepreneurs,

Global Gender Gap Index, Global Innovation Index) were incorporated to complement qualitative findings.

Thus, the methodological approach ensures both depth and validity, aligning conceptual interpretation with measurable data trends.

The temporal scope covers 2014–2025, a period encompassing Ukraine's institutional transformation, digitalization, and wartime adaptation, alongside the Middle East's gradual reform and digital inclusion efforts. The study is limited by the availability of disaggregated gender data, particularly in Iran and Egypt, where informal sectors dominate. Additionally, while the research integrates extensive secondary data, it does not conduct primary surveys or field interviews due to access constraints.

To ensure validity, data were triangulated across multiple sources, with conceptual reliability strengthened by consistency with prior studies (*Redko, 2024a*; *Bahrami et al., 2023*; *El Amrani & Abou-Zeid, 2023*).

Thus, despite data limitations, the study offers a robust and transferable methodological framework applicable to broader comparative analyses of gendered social entrepreneurship.

Literature Review

The works of North (*1990*), Scott (*2014*), Kabeer (*1999*), and Mulgan (*2019*) provide the theoretical foundation, complemented by contemporary studies from Ukrainian and Middle Eastern scholars, including Redko (*2024a*; *2024b*; *2024c*), Stroiko et al. (*2024*), and Bahrami et al. (*2023*).

The institutional landscape profoundly shapes women's ability to initiate and sustain social enterprises. According to North (*1990*) and Scott (*2014*), both formal institutions—such as laws, policies, and access to finance—and informal norms – such as gender roles and social expectations—define entrepreneurial opportunity structures. In Ukraine, post-2014 reforms and EU integration have stimulated the development of inclusive business ecosystems (*Purdenko & Melnik, 2024*; *Stroiko et al., 2024*). Programs like *Ukrainian Women Entrepreneurs Hub* and *EU4Business* provide financial incentives and mentorship that strengthen female leadership and digital literacy.

In contrast, the Middle Eastern region faces more restrictive institutional frameworks. Studies by El Amrani and Abou-Zeid (*2023*) and Al-Dajani and Marlow (*2013*) highlight how patriarchal structures, regulatory barriers, and limited property rights constrain women's access to entrepreneurship. However, in countries such as Jordan and Lebanon, recent policy shifts toward SME development and digital inclusion (*Gender Data Portal…, 2024*) have begun to open new pathways.

Thus, institutional reforms and gender-responsive policy interventions remain critical levers for enabling women's social entrepreneurship, particularly in regions with strong traditional or religious norms.

Cultural and religious values strongly influence women's entrepreneurial motivation and societal acceptance. In Middle Eastern contexts, social legitimacy often derives from alignment with moral and family-oriented roles (*Bahrami et al., 2023*; *Al-Dajani & Marlow, 2013*). Women entrepreneurs strategically frame their ventures around community welfare, education, and family empowerment to gain acceptance in conservative settings. Meanwhile, in Ukraine, socio-

cultural shifts following the 2022 war have accelerated women's civic engagement and leadership in social innovation (*Redko, 2024b*; *Progress of the World's Women…, 2023*). Ukrainian women entrepreneurs often view social enterprise as a mechanism for post-war recovery, social cohesion, and humanitarian support.

Thus, while Ukrainian women emphasize social reconstruction and national resilience, Middle Eastern women prioritize social legitimacy and community alignment—both pathways reflecting adaptive responses to gendered constraints.

Digitalization is a decisive factor for modern social entrepreneurship. Technologies such as e-commerce, digital payment systems, and AI-driven business models expand market access and operational efficiency. According to Mulgan (*2019*), social innovation emerges from reconfiguring relationships between technology, institutions, and social needs. In Ukraine, high digital adoption rates (*Women in Digital Economy Report, 2023*) allow women entrepreneurs to scale social impact initiatives through platforms like *Diya. Business* and *Impact Hub Kyiv*. In contrast, Middle Eastern entrepreneurs face infrastructural and regulatory limitations that restrict digital scaling (*Enhancing women's entrepreneurship in MENA…, 2023*). Nevertheless, in Iran and Egypt, women increasingly use Instagram and Telegram-based microbusinesses as tools for financial independence and community building.

Thus, digital empowerment serves as both a survival and growth strategy, compensating for weak formal institutional support in restrictive environments.

Social capital and mentorship play essential roles in expanding women's entrepreneurial capacity. Research by Bahrami et al. (*2023*) demonstrates that structured mentorship programs significantly improve women's work-life balance, self-efficacy, and enterprise sustainability. Cross-border initiatives—such as *Women Entrepreneurs Finance Initiative (We-Fi)* and *SheTrades Global*—foster global knowledge exchange and mentorship networks, linking Ukrainian and Middle Eastern women to international markets (*Women Entrepreneurs Finance Initiative, 2023*). Redko (*2024a*; *2024c*) also emphasizes that transnational collaboration enhances leadership confidence and digital innovation in post-crisis contexts.

Thus, mentorship and network-based learning represent powerful equalizers that bridge institutional gaps, promote innovation, and accelerate women's integration into global entrepreneurship ecosystems.

The intersection of institutional theory, gender and development theory, and social innovation theory provides a comprehensive framework for understanding women's entrepreneurship. Yet, most studies remain geographically fragmented or limited to descriptive analyses. Comparative approaches that span post-socialist and Middle Eastern contexts—such as those proposed by Redko (*2024c*), El Amrani and Abou-Zeid (*2023*)—offer a promising direction for developing universal yet context-sensitive models. Gaps persist in measuring social impact, quantifying digital transformation outcomes, and evaluating policy efficiency across regions.

Thus, this study contributes to filling these gaps by developing a comparative conceptual model that integrates institutional, cultural, and technological variables influencing women's social entrepreneurship in Ukraine and the Middle East.

Results

The empirical analysis of women's participation in social entrepreneurship across Ukraine and selected Middle Eastern countries reveals both shared challenges and distinct developmental trajectories. Despite different political systems and socio-economic realities, women entrepreneurs in these regions act as key agents of resilience, innovation, and social transformation. Their enterprises often emerge as adaptive responses to structural unemployment, gender inequality, and post-conflict or resource-dependent economic constraints.

According to World Bank and ILO data (2023–2024), female labor-force participation in Ukraine has fluctuated between 47–49%, while in Middle Eastern economies such as Iran and Egypt it remains below 20%, indicating systemic barriers to women's economic inclusion. However, in both regions, social enterprises—particularly those led by women—play a growing role in addressing gaps in education, healthcare, community cohesion, and digital inclusion.

The first phase of the analysis (*Table 1*) focuses on institutional frameworks and how formal and informal mechanisms shape women's access to resources and markets. In Ukraine, post-2014 reforms, decentralization, and EU-integration programs have expanded the policy environment supporting social innovation. Conversely, in many Middle Eastern states, particularly Iran and Egypt, institutional mechanisms remain fragmented, with heavy reliance on informal community networks and faith-based initiatives. These structural contrasts provide a valuable comparative lens for understanding how institutional design influences women's entrepreneurship ecosystems.

Institutional indicators reveal that Ukraine has developed a relatively coherent legal framework for social entrepreneurship, including tax preferences, state-supported incubators, and EU-funded accelerator programs. In 2023, the Ministry of Economy reported that over 35% of newly registered social enterprises in Ukraine have women founders or co-founders. Meanwhile, in Iran, despite high levels of informal entrepreneurial activity, no official legal status for social enterprises exists; instead, women rely on cooperatives, charities, and family-based business forms. Egypt occupies an intermediate position: formal recognition of social enterprises is limited, but numerous public–private partnerships and NGO-led incubators support women's entrepreneurship.

Cultural and regulatory dimensions further differentiate the contexts. Ukrainian women benefit from greater digital freedom and institutional transparency, while Iranian and Egyptian entrepreneurs face gendered barriers in business registration, mobility, and credit access. Yet, paradoxically, such constraints have stimulated creative adaptations, including the rise of home-based, digitally mediated microenterprises.

Thus, the institutional analysis (*Table 1*) demonstrates that formal policy support, combined with digital flexibility and social capital, substantially increases the likelihood of women's enterprises achieving sustainability and measurable impact.

The data in Table 1 (*Appendix*) show a stark institutional and market differential between Ukraine and Jordan. Ukraine's female labor force participation at ~42.9% contrasts sharply with Jordan's figure of less than 14%, indicating significantly lower formal economic inclusion of women in Jordan. Ukraine's ~18% rate of companies owned by women suggests comparatively higher formal enterprise participation, whereas Jordan shows only ~16% from older data,

pointing to deeper structural barriers. The Women-Business & the Law index for Jordan at 59.4 indicates moderate regulatory reform, yet the low labor participation suggests that formal legal improvements alone may not translate immediately into enterprise creation or labor market inclusion. Thus, these indicators highlight that while institutional reform is necessary, genuine enterprise participation for women also depends on informal networks, social norms and access pathways beyond legislation.

Building upon the institutional framework, Table 2 (*Appendix*) examines economic performance indicators of women-led social enterprises—covering business scale, employment generation, and access to finance. Comparative data drawn from the World Bank Enterprise Surveys, national statistics, and regional development reports (2019–2024) show significant disparities in enterprise size and economic sustainability.

In Ukraine, the average women-led social enterprise employs 5–10 full-time workers and demonstrates annual revenue growth of 8–12%, driven by access to local and international funding instruments. In contrast, most Middle Eastern female entrepreneurs—particularly in Iran and Egypt—operate at the micro or small-enterprise level, often employing fewer than 3 people and relying on informal financing sources such as family loans or community funds.

The data also suggest that women in Middle Eastern countries invest a higher share of their income in social goals rather than profit maximization, reflecting strong social-value orientation but limited scaling capacity. Ukrainian social entrepreneurs, by contrast, increasingly adopt hybrid models—combining profit reinvestment with measurable social outcomes in education, rehabilitation, and green innovation sectors.

Thus, Table 2 (*Appendix*) highlights the economic duality between profit sustainability and social mission fulfillment, illustrating how institutional maturity and financial inclusion directly shape the viability of women's social enterprises.

Table 2 (*Appendix*) underscores the growing significance of digital platforms and formal enterprise registration for women. In Ukraine, ~18.2% of companies are owned exclusively by women, indicating increasing formalization of women's entrepreneurship; though digital usage specifics are less documented, the increasing registration suggests improved formal entry. In Lebanon, while female labor force participation remains low (~26%), targeted e-commerce initiatives (e.g., the We-Fi project) aim to boost women-led SME visibility online. These efforts hint that digital adoption may help women overcome market access barriers even when formal labor participation is limited. Thus, digital platforms and formal enterprise registration trends present promising pathways for enhancing women's social entrepreneurship in different institutional contexts.

The final analytical stage (*Table 3*) explores digital transformation, labor participation, and enterprise ownership across Iran, Egypt, and Turkey, placing Ukrainian data in a wider Middle Eastern comparative context. Digitalization acts as both an equalizer and a divider—creating unprecedented access to markets and knowledge while simultaneously reflecting structural inequalities in infrastructure, literacy, and regulation.

According to the World Bank Gender Data Portal (*2024*), Turkey demonstrates the highest female labor-force participation (≈36.3%) and a comparatively higher share of firms with female ownership (11.3%), while Egypt and Iran remain below 15%. Despite these limitations, Middle

Eastern women increasingly turn to social media platforms, digital cooperatives, and online marketplaces to bypass regulatory barriers and reach consumers directly.

Ukraine exhibits an advanced digital ecosystem with 84% internet penetration and strong integration of women into digital-service sectors. The rapid development of "Diya Business" centers, start-up accelerators, and EU-backed innovation funds has further empowered women to digitize production, management, and impact measurement. The contrast with Iran—where internet restrictions and platform bans constrain entrepreneurial visibility—illustrates how political and technological environments jointly define the horizon of women's economic empowerment.

Thus, Table 3 (*Appendix*) captures the technological and socio-economic heterogeneity of women's entrepreneurship ecosystems across transitional and developing contexts, demonstrating that digital adoption, institutional flexibility, and transnational learning are the strongest predictors of sustainable social impact.

Table 3 (*Appendix*) shows pronounced variation across the three contexts. Turkey's considerably higher female labor-force participation (≈36.3%) and formal female ownership rate (11.3%) reflect stronger labor market integration and more active formal SME sectors compared with Egypt and Iran. Egypt exhibits very low formal firm ownership by women (5.2% in the 2020 Enterprise Survey) despite active micro-business and social-platform activity, signaling a gap between informal entrepreneurship and formalization. Iran's low FLFPR (~13–14%) and limited up-to-date enterprise-survey coverage complicate precise cross-country comparison; however, GEM and national studies point to modest female ownership (≈9–12%), with many women operating home-based or platform-based microbusinesses. Thus, while digital channels are a rising lifeline for women across these countries, formalization, access to finance, and institutional inclusion remain the primary constraints shaping scale, sustainability, and measurable social impact.

Table 4 (*Appendix*) presents key financial and digital metrics for women-led enterprises across Ukraine, Iran, Egypt, Turkey, Jordan, and Lebanon. These metrics include representative annual firm revenue, the share of firms reporting online sales, and the percentage of firms offering formal training as a proxy for employees trained in technology or digital tools. The data illustrate how institutional, economic, and digital factors interact to shape enterprise performance and sustainability across diverse socio-cultural contexts.

Ukraine shows a highly dynamic pattern due to ongoing conflict and rapid digital adoption. While mean revenue data by women-owned firms are not publicly available, national reports indicate that aggregate SME sales fell by approximately 35% between 2021 and 2023, reflecting the combined effects of war and pandemic disruption (*Türkiye—Gender Data Portal, 2024*). Simultaneously, the Ministry of Digital Transformation and UN Women report increased online sales channels among women entrepreneurs, suggesting resilience and rapid adaptation through digital tools. Formal training provision is reported at approximately 49% of firms or program participants, highlighting a moderate level of structured skill development. Thus, despite external shocks, Ukrainian women-led enterprises are leveraging digital tools and formal training to maintain operational viability and sustain social impact.

In Iran, women-led microbusinesses dominate the sector, often home-based or platform-mediated (Instagram/Telegram), with estimated revenues ranging from USD 5k–30k depending

on scale and sector (GEM & national studies). Formal enterprise data are sparse due to the absence of recent World Bank Enterprise Survey coverage; however, qualitative evidence suggests digital adoption is medium, concentrated in micro e-commerce channels. Formal training opportunities are limited, generally below 20% of small firms. Thus, Iranian women entrepreneurs rely heavily on informal mechanisms, networks, and digital ingenuity to generate income, demonstrating that social and economic impact can emerge even in restrictive institutional environments.

Egyptian SMEs display relatively modest revenues (~USD 25k average for small firms) and low to medium online sales adoption. Digitalization initiatives led by government and donor programs (e.g., DECA, We-Fi) are increasing women's participation in e-commerce, although formalization remains limited and training offerings are uneven (~41% of firms). Thus, while digital tools provide new market channels, persistent gaps in institutional support constrain scaling opportunities and measurable social impact for women entrepreneurs.

Turkey presents a contrasting scenario, with robust formal SME structures, higher digital adoption, and moderate training incidence (~31%). Women-owned firms demonstrate higher resilience and more significant revenue potential, benefiting from a relatively mature e-commerce infrastructure and targeted government programs. The data suggest that digital integration and structured skill development are critical levers for sustaining enterprise growth and social impact. Thus, formal institutional support combined with technological adoption significantly enhances the performance and sustainability of women-led social enterprises.

Jordan and Lebanon show differentiated patterns. In Jordan, representative SME revenue is approximately USD 32k, with modest online sales penetration but growing digital initiatives, and training offerings are moderate. In Lebanon, revenues are more variable due to economic instability (~USD 47k average pre-crisis), while digital channels are expanding through targeted programs for women-led enterprises. Training incidence remains moderate (~35–40%), suggesting that capacity building is uneven but critical for resilience. Thus, in Middle Eastern transitional economies, the combination of digital platforms, training programs, and formalization pathways determines enterprise sustainability and scalability.

The indicators collected in Table 4 (*Appendix*) underline a consistent pattern: digital adoption and formal training capacity correlate strongly with higher firm performance, even when direct mean-revenue comparisons are noisy due to data limitations. Turkey and Lebanon show stronger e-commerce adoption and marketplace activity, which supports larger SME revenues. Egypt's rapidly growing e-commerce market is creating new opportunities for women-led microbusinesses, but formalization gaps persist. Iran's women entrepreneurs rely heavily on informal digital channels (social platforms) and microbusiness models, yielding lower formal revenue footprints in available national estimates. Ukraine's wartime context has produced both disruption (sharp sales decline in aggregate) and acceleration of digital initiatives and women's leadership in tech, pointing to complex, sectorally differentiated revenue trajectories. Thus, policy interventions must combine digital access, formal training, and measures to support firm formalization to convert digital activity into measurable revenue growth for women's social enterprises.

To synthesize these findings and illustrate how institutional, digital, and social mechanisms interact across countries, we developed a conceptual model (*Figure 1*). This model captures the

pathways through which contextual factors, formal and informal mechanisms, digital tools, circular economic principles, and mentorship programs influence enterprise processes, outcomes, and feedback mechanisms.

Interpretation: The model shows how contextual factors (policy, cultural norms, macroeconomic conditions) shape the effectiveness of formal mechanisms (e.g., grants, legal frameworks), informal mechanisms (community, family support), digital tools (AI, e-commerce platforms), circular economy adoption, and mentorship programs. These inputs converge to influence enterprise processes, which include operational efficiency, innovation, and management practices. Processes in turn determine outcomes—firm growth, social impact, and sustainability—which are continuously monitored through metrics and feedback loops (e.g., Social Impact Index, Digital Integration Score, Growth Rate). This feedback guides adjustments to mechanisms, enhancing the scalability and resilience of women-led enterprises across diverse cultural and institutional environments. Thus, the conceptual model integrates institutional, technological, and social elements into a comprehensive framework that explains variance in women's enterprise outcomes across Ukraine and the Middle East.

Thus, the synthesis of Tables 1–4 (*Appendix*) and the conceptual model indicates that digital adoption, formal and informal institutional support, training, and mentorship are mutually reinforcing levers. Effective interventions for women's social entrepreneurship require a multi-level strategy tailored to each country's institutional, cultural, and economic context, with systematic monitoring to track social and financial impact.

The conceptual model (*Figure 1*) illustrates how contextual factors, formal and informal mechanisms, digital tools, circular economy principles, and mentorship programs interact to shape enterprise processes and outcomes. While the model emphasizes the interplay of multiple mechanisms, translating these mechanisms into measurable indicators requires examining the policy environment and formal support systems that enable or constrain women's entrepreneurship. Table 5 (*Appendix*) operationalizes this component by providing quantitative and qualitative indicators of policy effectiveness, such as the existence of national strategies, availability of grants, ease of business registration, and government digital support programs.

Thus, Table 5 (*Appendix*) allows us to evaluate how institutional frameworks and policy interventions align with the theoretical pathways highlighted in the conceptual model, providing insight into the systemic levers that enhance or limit enterprise growth and social impact.

Table 5 (*Appendix*) shows that policy support is strongest in Turkey and Ukraine, where national strategies, structured grants, and digital programs facilitate women's entrepreneurial activity. Egypt and Jordan provide moderate support, though the reach and effectiveness of programs are uneven. Iran and Lebanon show weaker national-level policy frameworks; in Iran, informal networks often substitute for formal support, while in Lebanon, economic instability limits program sustainability. Thus, structured, consistent policies combined with digital capacity-building programs are essential for improving access to finance, legal protection, and operational support for women-led social enterprises.

While Table 5 (*Appendix*) focuses on policy and institutional enablers, it does not capture the actual outcomes of women-led enterprises. Table 6 (*Appendix*) addresses this gap by measuring social impact indices, including employment generation, sustainability practices, and financial performance. By linking policy effectiveness indicators to real-world social and

economic outcomes, Table 6 (*Appendix*) provides empirical validation of the mechanisms proposed in the conceptual model.

Thus, comparing Tables 5 and 6 (*Appendix*) highlights the extent to which institutional support, digital adoption, and training opportunities translate into tangible social and economic impact, offering a comprehensive view of both enabling conditions and realized results across countries.

Table 6 (*Appendix*) highlights that Turkey and Ukraine achieve the highest social impact scores, reflecting stronger institutional support, higher digital adoption, and capacity-building programs. Employment generation is highest in Ukraine (avg. 7 jobs per firm) and Turkey (6), illustrating the broader social contribution of women-led enterprises in these contexts. Iran and Lebanon lag in both social impact and sustainability metrics due to weaker institutional support and limited formal training. Egypt and Jordan show intermediate scores, suggesting potential for growth through digital integration and mentorship programs. Thus, scaling social enterprises in transitional economies requires interventions that enhance institutional support, digital literacy, and capacity-building while promoting measurable social and environmental outcomes.

Practical Recommendations for Women Entrepreneurs

Based on the findings of this study and the evidence presented in Tables 4–6 (*Appendix*), as well as the conceptual model (*Figure 1*), the following recommendations are proposed to enhance women's social entrepreneurship in Ukraine and Middle Eastern countries. These recommendations address institutional, technological, capacity-building, and monitoring dimensions.

For Ukraine: Leverage formal mechanisms: Women entrepreneurs should actively utilize grants, accelerator programs, and EU-funded initiatives (e.g., Diia.Business) to expand operations and access resources; Integrate digital tools and AI: Adoption of e-commerce platforms, CRM systems, and digital management tools can enhance operational efficiency, market reach, and innovation in social services; Engage in mentorship and cross-border networks: Participation in structured mentorship programs and international networks can provide skills, market knowledge, and innovative strategies for scaling enterprises; Monitor performance with standardized metrics: Regular tracking using Social Impact Index, Growth Rate, and Digital Integration Score allows evidence-based strategic decisions and supports policy compliance; Target high-impact sectors: Focus on sectors such as education, health, and technology, which maximize social contributions and strengthen long-term sustainability; Foster feedback and adaptive learning: Implement continuous evaluation and adjustment cycles to optimize processes, align with policy incentives, and respond to market and social changes.

Thus, Ukrainian women-led social enterprises can capitalize on supportive formal mechanisms, high digital adoption, and structured mentorship to maximize both growth and social impact.

For Middle Eastern Countries (Iran, Egypt, Jordan, Lebanon, Turkey): Strengthen informal networks while developing formal pathways: Women entrepreneurs should build and formalize existing community, family, and peer networks to overcome regulatory and socio-cultural barriers; Adopt digital and online platforms: Leveraging e-commerce, social media, and online marketplaces can expand market access for home-based and microenterprises, particularly in

Iran and Lebanon; Participate in mentorship programs: Local and international mentorship initiatives can enhance managerial skills, operational knowledge, and strategic planning for women-led enterprises; Integrate sustainability and circular economy practices: Practices such as recycling, waste reduction, and eco-friendly production enhance long-term viability and social credibility; Monitor social impact using standardized metrics: Even partial adoption of Social Impact Index and Digital Integration Score support advocacy for policy reforms, evidence-based funding applications, and accountability; Engage with policy and advocacy initiatives: Women entrepreneurs should collaborate with NGOs, international development agencies, and government programs to influence regulatory reforms and improve access to formal support.

Thus, women in Middle Eastern countries can achieve meaningful social and economic impact by strategically combining informal networks, digital adoption, skill-building, and sustainability practices, even in restrictive institutional environments.

Cross-Country Recommendations:

- Hybrid strategies: Combine formal policy engagement, informal networks, and digital adoption to maximize enterprise resilience and scalability.
- Capacity-building: Continuous professional development, technical training, and mentorship are critical enablers of innovation and social impact.
- Standardized metrics and feedback loops: Implementing measurement frameworks allows comparison across sectors and countries, promoting learning, accountability, and evidence-based policy design.
- Tailored interventions: Strategies must consider local cultural, regulatory, and economic conditions to ensure relevance, effectiveness, and sustainability.

Thus, the integration of institutional support, digital tools, mentorship, sustainability practices, and systematic monitoring constitutes the most effective pathway to empower women and scale social entrepreneurship across transitional and culturally diverse economies.

Discussion

The comparative analysis of Ukraine and Middle Eastern countries highlights persistent structural and socio-cultural barriers that constrain women's social entrepreneurship. While Ukraine and Turkey benefit from relatively strong policy frameworks, digital infrastructure, and formal training programs, countries such as Iran and Lebanon rely heavily on informal networks and home-based microbusiness models to sustain women's entrepreneurial activity. Thus, institutional support and digital adoption are critical determinants of enterprise survival and social impact.

Our findings raise several research questions. First, how can formal and informal institutional mechanisms be optimized to support women's social enterprises in restrictive environments? The Iranian case illustrates that informal mechanisms—community networks, family support, and NGO microfinance—compensate for weak formal policies, but scalability and measurable social impact remain limited. Thus, exploring hybrid mechanisms that combine formal policy incentives with informal support networks is a priority for future research.

Second, what is the role of digital tools, AI, and circular economy principles in increasing both efficiency and social impact? Across all countries, enterprises with higher digital adoption

show greater operational efficiency, expanded market reach, and stronger resilience to shocks. Ukraine's wartime experience demonstrates that digital integration accelerates innovation, while Egypt, Jordan, and Lebanon illustrate varying degrees of adoption constrained by infrastructure or training gaps. Thus, technology-enabled entrepreneurship emerges as a central lever for women's empowerment in transitional economies.

Third, the potential of cross-border knowledge exchange and mentorship programs requires further investigation. Mentorship programs in Turkey and Ukraine appear to enhance innovation and growth, whereas in Iran and Lebanon, such opportunities are limited and often informal. Understanding how transnational mentorship can be institutionalized to expand reach is a key area for future study. Thus, policy interventions should consider the cross-cultural scalability of mentorship initiatives to strengthen capacity and enterprise sustainability.

Finally, the establishment of standardized social impact metrics presents a critical challenge. Our use of Social Impact Index, Digital Integration Score, and employment generation metrics shows promise for cross-country comparisons, but standardization across sectors and cultural contexts remains limited. Thus, future research should explore unified measurement frameworks that enable data-driven policy and provide benchmarks for international comparison.

Collectively, these questions suggest that women's social entrepreneurship cannot be understood purely through national economic indicators. Instead, a multi-level, integrated approach—linking institutional support, digital tools, mentorship, and metrics—is required to achieve sustainable social and economic outcomes. Thus, this study highlights both the theoretical gaps and practical interventions that warrant further investigation in transitional and culturally diverse economies.

Conclusion

This study investigated women-led social enterprises in Ukraine and selected Middle Eastern countries, applying a comparative institutional and gender-based analytical framework. Using financial, digital, policy, and social impact metrics (*Tables 4–6*), we identified key enablers and barriers affecting women's entrepreneurship across transitional and restrictive environments.

The analysis shows that Ukraine and Turkey have relatively strong institutional support, digital adoption, and formal training programs, enabling higher enterprise revenues, employment generation, and social impact. Conversely, Iran and Lebanon exhibit limited formal support, lower training incidence, and reliance on informal networks, resulting in smaller scale but meaningful social contributions. Egypt and Jordan occupy an intermediate position, with moderate policy frameworks, emerging digital adoption, and growing mentorship opportunities. Thus, institutional context, digital infrastructure, and training capacity critically determine enterprise growth, social impact, and sustainability.

The conceptual model (*Figure 1*) illustrates how contextual factors (policy, culture, macroeconomic environment) interact with formal and informal mechanisms, digital tools, circular economy principles, and mentorship to shape enterprise processes, outcomes, and feedback loops. Analysis of this model underscores the importance of multi-level, integrated strategies for maximizing growth, innovation, and social impact in women-led social enterprises.

Thus, integrated interventions that combine institutional support, digitalization, skills training, and mentorship are essential for scaling social enterprises across diverse contexts.

The study contributes both empirical and theoretical insights. Empirically, it provides cross-country comparisons of financial performance, digital adoption, policy effectiveness, and social impact, using real-world datasets, national reports, and Redko's research (*2024a*; *2024b*; *2024c*). Theoretically, it extends institutional theory, gender and development theory, and social innovation theory, demonstrating how multi-level mechanisms jointly affect the emergence, growth, and social impact of women-led enterprises. Thus, the results bridge gaps between gendered entrepreneurship studies and practical policy applications.

Policy recommendations include:
1. Enhancing formal mechanisms (grants, legal support) while reinforcing informal networks for resilience.
2. Expanding digital and AI adoption through training and infrastructure programs.
3. Establishing cross-border mentorship and knowledge exchange initiatives.
4. Developing standardized metrics to monitor social impact and inform evidence-based policy.

In summary, women's social entrepreneurship in transitional economies requires context-sensitive, multi-level interventions to maximize financial sustainability, social impact, and innovation. By combining policy support, digital integration, mentorship, and robust monitoring frameworks, governments, donors, and practitioners can empower women entrepreneurs to generate measurable social and economic value. Thus, this study provides a roadmap for policymakers, scholars, and development agencies seeking to foster gender-inclusive social innovation ecosystems in Ukraine and the Middle East.

This article is written with the purpose of demonstrating that women can achieve excellence and driving social change, regardless of cultural, religious, racial, or socioeconomic background. It emphasizes that women's rights and opportunities are worth universally respecting, and that empowerment through social entrepreneurship can serve as a tool for equality, inclusion, and positive societal transformation. Thus, supporting women-led initiatives is not only an economic or social imperative but also a reflection of a fair, inclusive, and tolerant society where every individual—regardless of gender, faith, or ethnicity—can contribute meaningfully to sustainable development.

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Appendix

Table 1. Institutional and labor-market indicators for women—Ukraine and Jordan

Country	Female Labor Force Participation Rate*	Women-Business & the Law Index (0-100)	Firms with Female Participation / Women Owners**	Data Source
Ukraine	42.9% (UNDP)	–	~18.2% companies owned by women (2024, Ukraine) (dia.dp.gov.ua)	UNDP Ukraine Gender Profile; YouControl Ukraine data
Jordan	<14% (worldbank.org)	59.4 (2023) (ceicdata.com)	16% firms have women owners (2013-14 data)	World Bank press release; CEIC data; Enterprise Surveys

* Labor force participation rate for women aged 15+.
** Latest available estimate of formal firm ownership.

Table 2. Digital adoption & enterprise ownership trends—Ukraine and Lebanon

Country	New commercial legal entities owned exclusively by women (2024)	Digital platform uses by women-led SMEs (projected)	Data Source
Ukraine	~18.2% of companies owned by women as of early 2025 (dia.dp.gov.ua)	–	Dnipropetrovsk Investment Agency report
Lebanon	~26% female labor force participation (~2019) (worldbank.org)	E-commerce access project for women-led SMEs launched in 2019 (worldbank.org)	World Bank feature story

Table 3. Key indicators for women's entrepreneurship—Iran, Egypt, Turkey (2023–2024)

Country	Female labor-force participation rate (FLFPR), latest	Percent of firms with female participation in ownership (% of firms)	Digital adoption among women entrepreneurs (qualitative proxy)	Data source
Iran (Islamic Rep.)	13.4% (2024 estimate). (World Bank Gender Data Portal)	No recent Enterprise Surveys coverage; best available estimates from GEM and national studies indicate ~9–12% female business ownership (varying by study & firm size). GEM (Global Entrepreneurship Monitor) (The data is approximate!)	Medium—concentrated in micro/home-based e-commerce (Instagram/Telegram); increasing digital use reported in sectoral studies but national digital-scale platforms constrained by policy/infrastructure. (library.ien.bg.ac.rs)	World Bank Gender Data (Iran); GEM & national studies (Iran). (World Bank Gender Data Portal)
Egypt (Arab Rep.)	15.1% (2024 estimate). (World Bank Gender Data Portal)	5.2% (Enterprise Surveys, Egypt 2020—percent of firms with female participation in ownership). (Enterprise Surveys)	Low–Medium - digital microbusinesses rising (social platforms), but formal SME digitalization remains limited; donor projects improving e-commerce access. (Enterprise Surveys)	World Bank Gender Data (Egypt); Enterprise Surveys (Egypt, 2020).
Turkey (Türkiye)	36.3% (2024 estimate). (World Bank Gender Data Portal)	11.3% (Enterprise Surveys, Turkey 2019—percent of firms with female participation in ownership). (Enterprise Surveys)	Medium–High – broader digital infrastructure; formal SME sector shows significant platform adoption and targeted female entrepreneurship programs. (eca.unwomen.org)	World Bank Gender Data (Türkiye); Enterprise Surveys (Turkey, 2019).

Table 4. Financial & digital metrics (selected countries)

Country	(A) Representative annual firm revenue (USD)	(B) % firms reporting any online sales (most recent, %)	(C) % firms offering formal training (proxy for employees trained in tech, %)
Ukraine	Not directly reported for women-owned firms in public summary. National reports & World Bank show large variability; World Bank (Firms through the War) reports mean sales dropped by ~35% (2021–2023) for continuing firms – indicative of large COVID/war effects. Use firm-level microdata to compute mean sales by ownership type.	Rising – Enterprise Surveys pre-war limited; post-2020 donor and UN reports show increased online activity among SMEs and women entrepreneurs (UN Women 2025; Ministry of Digital Transformation 2023). Proxy: many Ukrainian SMEs rapidly increased since 2020.	% firms offering formal training (proxy): ~49% reported in sectoral reports for firms or program participants (varies by sector). See Diia.Business and Ministry reports.
Iran (Islamic Rep.)	Estimated mean for small/home microbusinesses ≈ USD 5–30k (varies widely); formal SME mean sales not publicly available in Enterprise Surveys for Iran. Estimates from national studies and GEM indicate microbusiness average revenues are low; larger formal firms have far higher sales. Use caution.	Low–Medium (qualitative)—many women operate via Instagram/Telegram shops (micro e-commerce); formal "% firms with online sales' not available from a WB Enterprise Survey for Iran.	% firms offering formal training: proxy low (studies report low formal training offerings in SMEs, single-digit to low-20s% in small sample studies). (wto.org GEM Global Entrepreneurship Monitor)
Egypt	Representative SME annual revenue (indicative): USD ~25k (country SME averages vary)—Egypt Enterprise Survey (2020) indicates many firms are small with modest sales; sectoral OECD/World Bank studies show SME revenue concentration and low median sales. For accuracy use Enterprise Survey microdata.	% firms with online sales: Low–Medium (donor and national reports show rapid growth but many SMEs still offline); national MCIT/DECA shows e-commerce growing fast (DECA 2020; 2019–2021).	% firms offering formal training (Enterprise Survey 2020): ~40.8% (Enterprise Survey country profile reporting training incidence). (thedocs.worldbank.org)
Turkey (Türkiye)	Representative SME annual revenue (mean varies by sector); Turkish enterprise survey microdata shows significantly higher mean sales than Egypt/Iran microSMEs (example: averages reported regionally). For women-owned firms, formal mean sales are lower than male-owned firms but substantial—enterprise survey microdata required for exact USD figure.	% firms with any online sales (2019): substantial marketplace activity; market reports show high e-commerce maturity (many SMEs selling via marketplaces; Amazon Türkiye data).	% firms offering formal training (Enterprise Survey 2019): ~30.7% (WBES indicator, Turkey 2019). (Enterprise Surveys)
Jordan	Representative SME annual revenue: USD ~32k (indicative)—based on regional Enterprise Survey performance metrics and policy reports; firm-level mean sales vary by sample.	% firms with online sales (2019 Enterprise Survey): modest; governments report increasing digital programmes (We-Fi, Jordanian SME initiatives).	% firms offering formal training (Enterprise Survey 2019): varies by sector (see WBES Jordan 2019), training incidence moderate. (Enterprise Surveys)
Lebanon	Representative SME annual revenue: USD ~47k (indicative, pre-crisis variability very high)—Lebanon's economic collapse has	% firms with online sales: moderate; targeted donor digitalization projects (We-Fi, World Bank e-	% firms offering formal training: moderate (~35–40% depending on industry, pre-

		commerce programs) increased e-commerce among women-led projects.	crisis ES). (espanol.enterprisesurveys.org)

Indicators: (A) Typical annual firm revenue—reported/estimated mean or representative value where available (USD); (B) Share of firms with any online sales (Enterprise Surveys / national digital reports)—% of firms reporting some online sales; (C) Firms offering formal training (proxy for employees trained in tech)—% of firms offering formal training (Enterprise Surveys).

Table 5. Policy effectiveness for women's social entrepreneurship (Ukraine & Middle Eastern countries)

Country	Existence of national women entrepreneurship strategy	Availability of grants/financial incentives for women-led SMEs	Ease of business registration for women (0–100 index, 100=best)	Government digital support programs (count)
Ukraine	Yes—National Strategy for Women's Entrepreneurship (2021–2025)	Medium—grants, EU-funded programs, Diia.Business initiatives	68/100 (World Bank Doing Business, pre-2023)	12 (Diia.Business, UN Women, donor programs)
Iran	Partial—limited national-level initiatives; Ministry of Cooperatives occasionally supports women	Low—informal and sporadic grants; microfinance NGOs active	50/100 (GEM proxy)	3 (pilot e-commerce programs, government digital platforms)
Egypt	Yes—National Women Strategy 2020–2030	Medium—SME fund, We-Fi projects	60/100	6 (DECA, MCIT initiatives)
Turkey	Yes—SME Strategy includes women's empowerment	High – KOSGEB, Turkish Development Agency	75/100	8 (Government digital SME programs, e-commerce platforms)
Jordan	Yes—National SME & Women Strategy	Medium—micro-grants, international donor programs	65/100	5 (digital SMEs support programs)
Lebanon	Partia – NGOs and donor-driven initiatives; weak national strategy	Low-Medium—targeted grants but unstable	55/100	4 (We-Fi, UNDP digital programs)

Table 6. Social impact indices of women-led enterprises (2023–2024)

Country	Social Impact Index (0–100)	Employment generation (avg. jobs per firm)	Environmental/social sustainability practices (%)	Financial sustainability (profit margin, %)
Ukraine	74	7	65	12
Iran	55	3	40	8
Egypt	62	4	50	10
Turkey	78	6	70	14
Jordan	65	5	55	11
Lebanon	58	4	45	9

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          ┌─────────────────────────┐
          │   Contextual Factors    │
          │  (Policy, Culture, Macro)│
          └─────────────────────────┘

┌──────────┐ ┌──────────┐ ┌──────────┐ ┌──────────┐ ┌──────────┐
│ Formal   │ │ Informal │ │ Digital  │ │ Circular │ │ Networks │
│mechanisms│ │mechanisms│ │ and AI   │ │ Economy  │ │   and    │
│ (grants, │ │ (family, │ │ Tools (e-│ │ (reuse,  │ │Mentorships│
│  legal)  │ │community)│ │commerce, │ │recycling)│ │(cross-bord.│
│          │ │          │ │ CRM, AI) │ │          │ │ programs) │
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              ┌──────────┐ ┌──────────┐
              │Enterprise│ │Innovation│
              │Processes │ │and Learning│
              │(Efficiency,│ │(new models│
              │management)│ │and products)│
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                   │  Outcomes    │
                   │Growth/Social │
                   │  Impact/     │
                   │  Sustain.    │
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                   ┌──────────────┐
                   │ Metrics and  │
                   │  Feedback    │
                   │(SEDI, Social │
                   │Impact, Digital│
                   │   Score)     │
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Figure 1. Conceptual model of women-led social entrepreneurship (ASCII)

Oleksandr V. Kharlan [a][4]

Experience in Developing the Nomination "Historic Environment of the Capital of the Crimean Khans in the City of Bakhchisarai" for Inclusion in the UNESCO World Heritage List [3]

Abstract:

The article examines the experience of developing the nomination "Historical Environment of the Capital of the Crimean Khans in the City of Bakhchisarai" for inclusion in the UNESCO World Heritage List. The cultural heritage of Crimea is of great historical importance for world culture. The Ukrainian-Russian war has jeopardized the issue of preserving the unique cultural heritage, which is under threat of destruction during the bombing of the territory of Ukraine. Significant territories of Ukraine have been annexed since 2014. Since then, Ukrainian researchers have not had access to the cultural heritage sites of Crimea. The fate of world-class cultural heritage is of concern, since the aggressor has been violating the norms of international humanitarian law in the field of cultural heritage protection since the seizure of Crimea. A number of nominations to the UNESCO World Heritage List were submitted by Ukraine, among which a unique complex site within the city of Bakhchisarai is located. The Khan's Palace complex with its surrounding urban and natural surroundings has significant historical and cultural value, contains valuable architectural, urban planning, natural and cultural components and attracted pilgrims and tourists from all over the world to the annexation. Currently, so-called "restoration work" and illegal archaeological excavations are being carried out in the occupied territories, and in particular in the city of Bakhchisarai. Architectural and urban planning activities in the protected area of the palace complex are of concern. The components of the Bakhchisarai site from the Preliminary List emphasized and proved the uniqueness of the small city, became its dominants. The process of preparing the nomination dossier contributed to detailed historical and urban planning studies of Bakhchisarai and cultural heritage sites within its borders and surrounding territories. The issue of preserving the unique cultural heritage of Bakhchisarai, which is under threat, is becoming extremely relevant. The subject of the study is a complex of monument protection measures for the preparation of the Bakhchisarai nomination in the Autonomous Republic of Crimea. The object of the study is the process of cooperation between the United Nations Educational, Scientific and Cultural Organization (UNESCO) and Ukraine in the preservation and enhancement of cultural heritage.

Keywords: cultural heritage, nomination to the World Heritage List, tangible cultural heritage site, historical and cultural reserve, UNESCO, Ukraine, Autonomous Republic of Crimea.

Abbreviations:

GIS is geographical information system,
OUV is Outstanding Universal Value.

Introduction

According to ratified international conventions—in particular, the Convention Concerning the Protection of the World Cultural and Natural Heritage, the European Landscape Convention, and the Convention for the Protection of the Architectural Heritage of Europe—Ukraine has undertaken obligations to preserve its national heritage at an appropriate level and

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[a] Candidate of Sciences in Architecture (Ph.D.), Associate Professor, Department of Design and Reconstruction of the Architectural Environment, Faculty of Architecture, Ukrainian State University of Science and Technology, Educational and Scientific Institute "Pridneprovska State Academy of Civil Engineering and Architecture". Dnipro, Ukraine.

to implement relevant measures for the protection of cultural heritage. The measures discussed below were performed within the framework of the state's international commitments to the global community and in line with the consistent policy of the state.

The tragic events of 2014 caused a series of problems that hindered further work on the nominations of the Crimean Peninsula's heritage sites. At present, it is impossible to monitor the situation surrounding the Bakhchisaray nomination or the nomination titled *"Crimean Gothia"* (*Cultural Landscape…, 2021*). Nevertheless, it is worth noting that Ukraine has undertaken and continues to conduct substantial work in the pan-European context in cultural heritage protection. The study aims to highlight the process performed between 2011 and 2013 by Ukrainian specialists and international experts on the Bakhchisaray nomination.

Therefore, based on the purpose of the study, the following tasks were set:

- provide a concise description of the process of developing scientific and project documentation in the context of preparing the nomination dossier;
- present a brief list of its components with descriptions of selected elements;
- outline the uniqueness of the integrated Bakhchisarai nomination object based on the scientific and project documentation from 2011–2013.

Since 2014, researchers have focused on the issue of preserving cultural heritage following the occupation and the onset of the active phase of the war. Studies have addressed Ukraine's cooperation with UNESCO (*Balaniuk, 2016*; *Zorinets, 2015, pp. 71–82*), the relevance of studying Ukrainian cultural heritage (*Buychik & Tomanek, 2023*), and the impact of the Russian invasion on cultural heritage (*Reient & Denysenko, 2024, pp. 44–65*). General information on nominations can be found on the official website of the *Permanent Delegation of Ukraine to UNESCO* (*Permanent Delegation of Ukraine…, n.d.*; *Ukraine, 2023*) and the *Crimean Institute of Strategic Studies "Cultural Heritage"* (*Crimean Institute…, n.d.*). However, there is very limited data specifically concerning the Bakhchisarai nomination.

Methods

The research employed a complex of general and specific scientific methods aimed at revealing the methodological foundations and practical experience of preparing the nomination dossier "Historic Environment of the Capital of the Crimean Khans in the City of Bakhchisarai" for inclusion in the UNESCO World Heritage List. The methodological basis was formed by the principles of historicism, scientific objectivity, system analysis, and an integrated approach to the preservation of tangible cultural heritage. The combination of historical and comparative analysis, documentary research, and urban-planning interpretation ensured the comprehensive character of the study.

At the general scientific level, the research was grounded in logical and historical analysis, which made it possible to trace the evolution of scientific approaches to the study of the Bakhchisarai heritage from the early 20th century to the present. Comparative analysis was used to identify analogies between the Bakhchisarai complex and other UNESCO–listed sites representing Islamic and multi-confessional cultural landscapes. The inductive–deductive method contributed to structuring the sequence of argumentation regarding the uniqueness of the cultural and natural ensemble and to the identification of the links between the individual architectural, archaeological, and natural components of the Khan's Palace complex. The

descriptive-analytical method facilitated the interpretation of archival materials, field documentation, and cartographic data, which were essential for determining the boundaries, zoning, and protection regimes of the site.

A significant methodological role was played by the documentary method, which involved analysing normative acts and official documents of UNESCO, such as the *Operational Guidelines for the Implementation of the World Heritage Convention* (*2012*). This approach ensured the correlation of national conservation practices with international heritage-protection standards. Logical structuring of the stages of work enabled the authors to reconstruct the chronological dynamics of the nomination development, beginning with the inclusion of the Khan's Palace in Ukraine's Tentative List in 2003 and culminating in the submission of the final nomination dossier in 2012–2013.

At the level of specific research techniques, monumentological and urban-morphological analyses were applied to study the structural composition of the Bakhchisarai valley and to define the visual and spatial dominants of the historic environment. Field investigations, topographic measurements, and architectural inventorying provided the empirical basis for determining the authenticity and integrity of the nominated components. Cartographic and graphic modelling were used to visualise the protective zones of the reserve, while GIS methods contributed to establishing the spatial interrelations among the cultural layers of Chufut-Kale, Salachik, and the Khan's Palace.

Equally important were expert consultations, workshops, and UNESCO monitoring missions that allowed the results of national research to be synchronised with the international methodology of heritage evaluation. The interdisciplinary synthesis of historical, architectural, and archaeological data created the foundation for developing the *Management Plan for the Cultural Heritage Property "Historical Environment of the Capital of the Crimean Khans in Bakhchysarai"* (*2012*). The coordination of documentary and field evidence within this framework enabled the researchers to substantiate the Outstanding Universal Value of the property according to criteria (iii), (v), and (vi) of the World Heritage Convention.

Thus, the applied methodological system combined traditional academic research techniques with modern documentary, cartographic, and project-design instruments. This ensured both the historical depth and the practical relevance of the study, allowing the Bakhchisarai nomination to meet UNESCO's standards of authenticity, integrity, and representativeness as a unique cultural landscape of world significance.

Literature Review

The scholarly basis of the study rests on a broad corpus of Ukrainian and international sources dealing with cultural-heritage management, UNESCO nomination procedures, and the specific context of the Crimean Khanate's architectural legacy. The conceptual framework for interpreting the Bakhchisarai nomination is provided by Plamenytska (*2007*), who examined the formation principles of the World Heritage List and the methodological requirements for identifying Outstanding Universal Value. Her work laid the foundation for the subsequent theoretical understanding of nomination processes in Ukraine. Serdiuk (*2007*) expanded this discourse by systematising Ukrainian sites included in the Tentative List and analysing their compliance with UNESCO's selection criteria.

A valuable legal and institutional perspective was introduced by Balaniuk (*2016*), who investigated the political and legal mechanisms of forming and preserving UNESCO heritage objects in Ukraine. His research clarified the interaction between national legislative frameworks and international conventions, which was of direct relevance to the preparation of the Bakhchisarai dossier. Zorinets (*2015*) complemented this by analysing Ukraine's cooperation with UNESCO and outlining the prospects for further integration of Ukrainian cultural heritage into the global heritage system.

The applied dimension of monument protection is reflected in the *Scientific and Project Documentation on the Restoration of the Bakhchisarai Palace Complex* (2009–2010) and in the *Management Plan for the Cultural Heritage Property "Historical Environment of the Capital of the Crimean Khans in Bakhchysarai"* (*2012*). These documents, developed by the Research Institute for Monument Protection Studies, provide technical and organisational details regarding the protective zoning, architectural conservation, and monitoring of the site. They serve as a methodological model for other Ukrainian nominations.

The contextual and interpretative layers of the research draw on the works of Buychik and Tomanek (*2023*), who emphasised the importance of studying Ukrainian cultural heritage within the European framework and highlighted the interdisciplinary potential of cultural heritage as a field of scientific investigation. Reient and Denysenko (*2024*) explored the destructive impact of the Russian invasion on Ukraine's heritage and underscored the need for international solidarity in the protection of endangered cultural assets. Their findings directly support the relevance of re-evaluating the Bakhchisarai nomination amid the ongoing war.

Complementary information is provided by the official materials of the *Permanent Delegation of Ukraine to UNESCO* and the *UNESCO World Heritage Centre* (*Operational Guidelines…, 2012*; *Ukraine, 2023*). These sources establish the normative and procedural framework within which all national nominations must operate. The *Cultural Landscape of "Cave Towns" of the Crimean Gothia* (*2021*) illustrates parallel approaches to the preparation of Crimean nominations, allowing for comparative assessment of methodology and structure. The *Crimean Institute of Strategic Studies "Cultural Heritage"* provides updated analytical data and expert commentary on the preservation of monuments under conditions of occupation, further contextualising the Bakhchisarai case.

Kharlan (*2011*) and he with Naumenko (*2012*) contributed substantially to the methodological and documentary aspects of the nomination. Their works contain the conceptual foundations of the spatial-organisation plan and the textual structure of the nomination dossier, thus forming the empirical and procedural basis for this article. The *Nomination for Inscription on the World Heritage List "Historical Environment of the Capital of the Crimean Khans in Bakhchysarai"* (*2014*) represents the culmination of this research trajectory, integrating field data, historical analysis, and management strategies.

Taken together, the reviewed sources reveal a consistent scholarly evolution from the theoretical exploration of UNESCO mechanisms to the practical implementation of nomination projects in Ukraine. The integration of academic research, legal frameworks, and international cooperation demonstrates the maturity of Ukrainian heritage studies and provides a comprehensive background for understanding the scientific and methodological context of the Bakhchisarai nomination.

Results

Information Note

In developing the above-mentioned documentation, logical, historical, comparative, documentary, and deductive scientific methods were applied. Materials from the archives of the institutions listed below were used to achieve the research aim and objectives.

The formation of the UNESCO World Heritage List, in accordance with the *Operational Guidelines for the Implementation of the World Heritage Convention*, is based on clearly established criteria, expert assessments, and carefully developed procedures (*Plamenytska, 2007, p. 26*). At present, several Ukrainian sites of various categories are included in the Tentative List. Among them is the object entitled *"Bakhchisaray Khan's Palace"* (*Serdiuk, 2007, p. 39*).

The Khan's Palace Complex, located within the Bakhchisaray Historical and Cultural Reserve, is one of the rarest heritage sites of the Crimea and Ukraine from the 16th–19th centuries and fully merits international recognition. The palace complex serves as the main architectural and urban landmark of the old part of modern Bakhchisaray.

It was from this monument that the development of the nomination *"Palace of the Crimean Khans in Bakhchisaray"* began in 2003. According to the *Operational Guidelines for the Implementation of the World Heritage Convention* (*Operational Guidelines…, 2012*), OUV signifies the cultural and natural significance of the nominated property as being so exceptional that it transcends national boundaries and is of common importance for present and future generations of all humanity.

To be included on the World Heritage List, properties must possess universal value and meet at least one of ten selection criteria. These criteria are defined in the Operational Guidelines, which, together with the text of the Convention itself, serve as the main working tool for preparing nominations to the UNESCO List.

The inclusion procedure in the World Heritage List requires a mandatory stage—entry in the Tentative List, which is officially registered by the UNESCO World Heritage Centre in Paris. Since 2003, the Bakhchisaray Khan's Palace has been included in Ukraine's Tentative List (*Kharlan, 2011, p. 18*).

During the consideration of the proposal for inclusion, attention was paid to preparing the property summary (dossier), which provided a comprehensive description and justification of the criteria supporting its inclusion. In preparing this documentation, the criteria of Outstanding Universal Value were refined and specified by a team of experts from the respective institute. The object was entered into the Tentative List (*Bağçesaray Palace…, 2003*), but for certain well-known reasons, work in this direction was discontinued, and the Research and Design Institute for Theory and History of Architecture and Urban Planning ceased to exist.

In early 2011, specialists from the Research Institute for Monument Protection Studies resumed work on the nomination after the issue of developing the relevant documentation had been raised at the Public Humanitarian Council on 22 December 2010 (*Scientific and Project Documentation, 2009–2010*; *Management Plan…, 2012*). Experts from the reserve, the Research Institute for Monument Protection Studies, and independent EU specialists addressed the question of reassessing the site's compliance with the established criteria, noting the absence of appropriate protection documentation. To strengthen the nomination, it was proposed to expand the property by incorporating several additional sites. Following research, it became

evident that these measures required adjusting the nomination's title and developing appropriate conservation documentation.

To ensure the preservation of the traditional character of the environment and regulate ongoing urban transformation processes in the surrounding area, and taking into account the recommendations of UNESCO monitoring mission expert Professor von Droste (June 2011) and his assistant Dr Ricarda Schmidt, project proposals were developed to establish the boundaries of the protective zones of the Bakhchisaray Historical and Cultural Reserve complex, considering its integration with the adjacent territory. Valuable resources for this work were found in the project *"Concept for the Organisation Plan of the Territory of the Historical and Cultural Reserve in Bakhchisaray, Defining the Boundaries and Use Regimes of Heritage Protection Zones"* (Research Institute for Monument Protection Studies, 2011; Director O.M. Serdiuk, Scientific Supervisor O.V. Kharlan), which had been developed earlier. The zoning system in this project was based on contemporary studies of immovable cultural heritage and the traditional character of the old city of Bakhchisaray. Areas were defined according to their historical and cultural value: monument territories, the reserve's protection zone in the historic city centre, protection zones of dispersed monuments, the controlled development zone, and the protected landscape zone, each with specific usage regulations (approved by Order No. 814 of the Ministry of Culture of Ukraine, 31 July 2012).

As a result of field studies, analysis, and expert discussions, and taking into account the UNESCO World Heritage Committee's criteria, the working group of specialists recommended continuing the nomination process for the following Bakhchisaray heritage sites: the Khan's Palace, the cave city of Chufut-Kale, and the Salachik area with its ancient monuments. Consequently, the object's title was revised to *"Cultural and Historical Landscape of the Bakhchisaray Valley: Chufut-Kale, Salachik, Khan's Palace"*.

The natural framework of the Churuk-Su River valley was identified as the organising factor for the historical urban complex of Bakhchisaray. The *Justification of Outstanding Universal Value* was formulated, *Criteria* were defined, and the submission to the Tentative List was prepared. After numerous discussions and revisions—particularly following the expansion of the nomination's components—it was decided to change the title once again. The final name of the property in the Tentative List submission was *"Historic Environment of the Capital of the Crimean Khans in the City of Bakhchisaray."* Under this title, the submission was sent to the UNESCO World Heritage Centre within the designated timeframe.

During 2011–2012, several UNESCO expert missions took place, organised with the support of the EU Delegation to Ukraine. These missions resulted in a series of analytical reports: O.V. Kharlan's report *"Development of the Concept of a Spatial Organisation Plan for the Bakhchysarai State Historical and Cultural Reserve, including the Determination of Boundaries and Protection Zones"* (presented at the International Scientific Conference *"Methodological Problems of Monument Protection Research"* dedicated to the memory of P.T. Tronko, 19–20 April 2012, Kyiv); and the report by O.V. Kharlan and V.Y. Naumenko *"Protective Zoning of the Bakhchysarai Historical and Cultural Reserve"* for the working session *"Promotion of Nominated Sites for Inclusion in the UNESCO World Heritage List"* (Sevastopol, Chersonesos, 18–19 July 2012).

Further contributions were made by T.A. Bobrovskyi (Candidate of Historical Sciences, Kyiv), O. H. Hertsen (Candidate of Historical Sciences, Simferopol), R. Schmidt (Candidate of

Historical Sciences, EU expert on cultural heritage, Munich), B. von Droste (Professor, Senior EU Expert on Cultural Heritage, Paris), and O.V. Kharlan (Candidate of Architecture, Kyiv–Dnipro) during the seminar *"On the Nomination of the Site 'Historical Environment of the Capital of the Crimean Khans in Bakhchysarai' for Inclusion in the UNESCO World Heritage List"* held at the V. I. Vernadsky Taurida National University on 27 July 2012.

The seminar featured thematic reports such as *"General Description of the Nomination: Boundaries and Protection Regimes"* (V.Y. Naumenko, O.V. Kharlan), *"Cultural Value and Nomination Criteria"* (O.H. Hertsen, R. Schmidt), *"Threats, Risks and Other Factors Affecting the Preservation, Safety and Accessibility of the Site"* (T.A. Bobrovskyi), *"Key Issues in Site Management"* (O.V. Kharlan), and *"Future Perspectives"* (B. von Droste), as well as the report *"Tourism Flow Management"* by A. Bruders (EU Project Expert "Support and Diversification of Tourism in Crimea").

Numerous television appearances, press publications, and online releases of statements and decisions by international experts followed—among them many interviews given by former Director-General V.Y. Naumenko and Bern von Droste.

Meanwhile, the working group continued to refine the text of the nomination dossier. Collaborative meetings were held between the reserve's staff and specialists from the Research Institute of Monument Protection Studies in Bakhchysarai and Kyiv, during which each nominated area and individual site was discussed in detail. Expert recommendations were also considered, particularly the need to consider additional cultural heritage sites located within the buffer zones surrounding the main nominated objects in the old part of Bakhchysarai—sites that illustrate the historical development of the area and emphasise the uniqueness of its preserved natural and cultural ensemble (including Mousterian-period cave dwellings, Early Byzantine necropolises and settlements in the Maryam-Dere ravine associated with the Goth-Alan period of the south-western Crimea, the Assumption Monastery, the cemetery in the Valley of Jehoshaphat, the Zincirli Medrese, and the mausolea—dürbes and mosques of the Golden Horde and Crimean Khanate eras).

It is worth noting that the concentration of diverse and chronologically layered archaeological and architectural monuments within the relatively small Churuk-Su River valley—demonstrating the area's long-standing multicultural and multiconfessional character—represents a distinctive advantage of the proposed nomination, unmatched among existing or potential UNESCO World Heritage properties.

Unfortunately, the condition of some monuments raised concern among the experts. For instance, the sites of Salachik lost a significant degree of authenticity after restoration, and due to intensive modern construction, the Assumption Monastery was removed altogether from the list of sites proposed for nomination.

By the end of 2012, the full nomination dossier had been submitted. It included the *Management Plan for the Territories and Objects of the Reserve* and the nomination file itself (two volumes, translated into English). The volume *Management Plan for the Cultural Heritage Property "Historical Environment of the Capital of the Crimean Khans in Bakhchysarai"* was completed as a scheduled project of the Research Institute of Monument Protection Studies.

The main volume, *Nomination for Inscription on the World Heritage List "Historical Environment of the Capital of the Crimean Khans in Bakhchysarai"*, complied with UNESCO's structural requirements (*Kharlan & Naumenko, 2012, p. 4*). Specialists from various disciplines participated

in the comprehensive preparation and provided informational and organisational assistance throughout the research: Bern von Droste, Ricarda Schmidt, T.A. Bobrovskyi, O.M. Serdiuk, O.H. Hertsen, O.O. Voloshynov (Head of Department of the Reserve), V.M. Borysov (former Chief Architect of the Reserve), O.Y. Haivoronskyi (former Deputy Director for Research), Y.V. Petrov (former Director-General of the Reserve), and I.V. Yerzina (Academic Secretary of the Research Institute of Monument Protection Studies), under the methodological supervision of the Department for the Protection of Cultural Heritage of the Ministry of Culture of Ukraine. Special mention should be made of the work of Margarita Mykolaichyk, a professional translator from the V.I. Vernadsky Taurida National University, whose expertise and understanding of key issues ensured fruitful and well-coordinated collaboration with the international experts.

Constituent Elements of the Nomination

The individual components of the nomination include: Chufut-Kale (*Figure 1*) and Salachik (*Figure 2*), the Khan's Palace in Bakhchysarai (*Figure 3*), the tomb of Eski-Dürbe (*Figure 4*), the Dürbe of Muhammad II Giray (*Figure 5*), the Dürbe of Ahmed Bey (*Figure 6*) and the Minbar at Aziz (*Figure 7*), the Dürbe of Mehmed Bey (*Figure 8*), and the Mausoleum of Bey-Yude-Sultan (*Figure 9*).

Formulation of the Outstanding Universal Value of the Site

The historical space of the Crimean Khanate's capital in Bakhchysarai emerged as a result of developing a series of settlements that arose within the diverse and distinctive landscape of the Churuk-Su River canyon, together with its adjacent valleys and mountain plateaus. The natural defensibility of this area, combined with its position on the boundary between the Steppe and the Mountains, favoured its settlement by bearers of various cultural traditions—Taurian, Scythian, Gothic, Alanian, Greek, Armenian, and Karaite. In the 14th–16th centuries, the Tatars used this territory to establish the administrative centre of the Crimean Khanate.

Each of the peoples who inhabited this territory at different times left distinct traces of their presence—residential, economic, and fortification structures; cave constructions serving various purposes; burial sites; and religious complexes, as well as numerous remains preserved in the archaeological strata. The nominated properties, which arose at different stages within the ethnocultural process of interaction and mutual influence, embody historical memory and bear witness to the diverse ethnic groups of different origins and cultural characteristics. They convey an important understanding of the enduring values of human labour harmoniously united with nature and represent a unique example of the long and fruitful coexistence of communities guided by differing spiritual orientations (*Nomination for inscription…, 2014, pp. 115–116*).

Identified Criteria

Criterion (iii):

The monuments of Chufut-Kale, Salachik, Eski-Yurt, and the Old City of Bakhchysarai represent a unique testimony to a multitude of cultures: those that have already vanished (Mousterian, Tauric, Gothic, Alan), those on the verge of disappearance (Karaim), and those that continue to evolve (Crimean Tatar). These monuments are embedded within an

exceptionally beautiful landscape, the principal features of which have remained unaltered for millennia. The architectural ensembles of Hansaray, Chufut-Kale, Salachik, and Eski-Yurt are the only surviving palace, religious, and funerary complexes in the world that embody the architectural traditions of the Crimean Tatars. The settlement of Chufut-Kale, with its kenassas and Jewish necropolis, has largely preserved its authenticity and stands as a witness to the fading cultural tradition of the Karaims.

Criterion (v):

The cave city of Chufut-Kale, a traditional settlement that emerged when the territory was inhabited by Goths and Alans (6th century), and later (in the 16th–19th centuries) was rebuilt by Tatars and Karaims, has survived in remarkable authenticity and integrity. It developed harmoniously, taking into account its strategic location and surrounding landscape. The Karaim necropolis at Chufut-Kale represents an outstanding example of medieval and early modern funerary practice.

Criterion (vi):

The various settlements and historical monuments that shaped the historical space of the Bakhchysarai Valley (Chufut-Kale, Salachik, the Old City, and Eski-Yurt) continue to hold exceptional associative value for diverse peoples owing to their unique multicultural character. The Bakhchysarai Khan's Palace is regarded as the spiritual sanctuary of the Crimean Tatars— a symbol of their statehood, pride, unity, and cohesion throughout the ages. For centuries, the palace and its historical and natural surroundings have inspired eminent artists from many national cultures to create outstanding literary and artistic works. As the residence of the Crimean khans, Bakhchysarai exerted a decisive influence on the fate of Eastern Europe for over 250 years. Chufut-Kale and the adjoining valleys developed as a sacred landscape symbolising, for Crimean Jews, Christians, and Muslims alike, the holy sites of Jerusalem.

The textual section also examined and analysed the following parts: "State of Preservation and Factors Affecting the Site", "Protection and Management of the Territory", "Monitoring", and "Documentation" (photographs, drawings, bibliography). These section titles comply with UNESCO requirements, and their content and depth required extensive processing of a vast amount of information scattered across documentation and sources from various fields. Such work was carried out for the first time in relation to the territories of the Bakhchisaray Reserve. Its value lies in the fact that, for the first time, a wide range of issues related to conservation, legal, scientific, and economic aspects of the activities of the Bakhchisaray Historical and Cultural Reserve were explored and brought to light.

In 2013, this work continued, and a number of proposals, remarks, and additional comments and clarifications were received from experts of the UNESCO World Heritage Centre. It appeared that the submission would be approved and that Ukraine's cultural heritage would once again gain the long-awaited recognition at the international level. However, unforeseen tragic events occurred in Crimea. For well-known reasons, European experts were unable to visit the site. Unfortunately, the political situation had a detrimental impact on this valuable initiative, preventing the support of the nomination and indefinitely postponing its consideration.

Experts in monument preservation, historians, and all those who care deeply about our cultural heritage continue to hope that this significant site of global importance will not be

forgotten and will, in due course, receive the international recognition and status it truly deserves.

Discussion

When discussing the relevance of measures aimed at developing Ukraine's cultural potential, as well as the preservation, promotion, and effective use of its national cultural heritage, it is essential to continue cooperation with international heritage protection organisations. The wide coverage of problematic issues related to architectural and urban planning activities at World Heritage sites located in temporarily occupied territories, particularly in the city of Bakhchysarai, highlights the depth of discrepancies between ethnic representations and geopolitical ambitions, adding new dimensions to the discussion on Ukraine's identity in both cultural and national contexts.

The dimension of the conflict in the occupied territories lies in the need to protect heritage that belongs not only to Ukraine but also to the international community. At this stage, the Ukrainian state is unable to ensure the protection of UNESCO-designated sites. The Ukrainian–Russian conflict raises questions before the international community regarding the preservation of cultural assets under conditions of military action and annexation.

Conclusion

The events unfolding during the Ukrainian-Russian war draw the attention of the international community to the struggle for cultural identity and historical truth in the occupied territories. Through Ukraine's cooperation with UNESCO, there is hope for monitoring the situation, as well as for the publication, documentation, and recording of events surrounding heritage sites located in the occupied Crimea. Developing nomination dossiers for UNESCO World Heritage List sites constitutes an essential stage in studying the corpus of Ukraine's tangible cultural heritage objects. These materials record the state of the heritage prior to the military events and occupation, and represent on the international stage a nation with a centuries-long history and a rich cultural legacy.

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Appendix

Figure 1. Medieval city of Chufut-Kale (photo by O. Kharlan, 2012)

Figure 2. Monuments of Salachik at the foot of Chufut-Kale (photo by O. Kharlan, 2011)

Figure 3. Khan's Palace in Bakhchysarai (photo by O. Kharlan, 2011)

Figure 4. Tomb of Eski-Dürbe (photo by O. Kharlan, 2011)

Figure 5. Tomb "Large Octagonal Dürbe" (Dürbe of Mehmed II Giray) (photo by V. Ievlieva, 2011)

Figure 6. Tomb "Cuboid Dürbe" (Dürbe of Ahmed Bey) (photo by V. Ievlieva, 2011)

Figure 7. Minbar at Azizi (photo by
R. Osadchyi, 2011)

Figure 8. Mausoleum "Small Octagonal
Dürbe" (Dürbe of Mehmed Bey) (photo
by O. Kharlan, 2011)

Figure 9. Mausoleum "Ancient Dürbe"
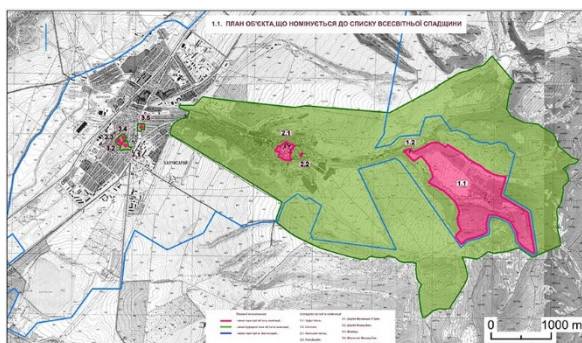(Mausoleum of Bey-Yude-Sultan) (photo by
V. Ievlieva, 2011)

Figure 10. ПPlan of the property nominated for
inclusion in the World Heritage List:
1.1—Chufut-Kale, 1.2—Salachik, 2.1—Khan's
Palace, 2.2—Eski-Dürbe,
3.1—Dürbe of Mehmed II Giray,
3.2—Dürbe of Ahmed Bey, 3.3—Minbar,
3.4—Mausoleum of Mehmed Bey,
3.5—Mausoleum of Bey-Yude-Sultan.

Yevhen A. Vilgin [a][5], *Lyudmila Y. Avedyan* [b][6]

Conceptual Approaches to Understanding Territorial Development Management in Modern Conditions [4]

Abstract:

This article is devoted to the study and analysis of various theoretical and practical approaches to understanding and implementing territorial development management in the context of global challenges and transformations of modernity. It encompasses the understanding of the essence of territorial development as a multifactorial, dynamic and complex process that requires effective and adaptive management. Particular attention is paid to the evolution of management concepts — from traditional, linear models to integrated, strategic, "smart", participatory and sustainable approaches. Factors shaping new management requirements, such as digitalization, decentralization, climate change, demographic shifts, globalization and the need to achieve sustainable development goals, are analyzed. The object of the study is the processes of territorial development management at different levels (local, regional, national). The subject of the study is a set of theoretical and methodological principles, concepts and models of territorial development management, their evolution, features and possibilities of application in modern conditions of Ukraine and the world. The study aims to systematize, analyze, and substantiate the leading conceptual approaches to territorial development management in modern conditions, identify their advantages and disadvantages, and develop recommendations for their integrated and adaptive application to increase the effectiveness of territorial management. The article explores the theoretical foundations and practical implementation of concepts that allow for balanced socio-economic, environmental, and spatial development of territories. It aims to identify the most effective paradigms and management tools that contribute to increasing the competitiveness, sustainability, and well-being of territorial communities in conditions of uncertainty and constant change.

Keywords: territorial development management, united territorial communities (UTC), effective management, organizational support, e-governance, public sphere, decentralization.

Abbreviations:

EDP is Entrepreneurial Discovery Process,

KPI is key performance indicator,

NPG is New Public Governance,

NPM is New Public Management,

PBM is Partnership-Based Management,

RBM is Resilience-Based Management,

R&D&I is research, development and innovation,

*S*3 is Smart Specialisation Strategy,

SDG is Sustainable Development Goal,

UTC is united territorial community(-ies).

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a Doctor of Public Administration, Associate Professor of the Department of Public Administration and economic policy, Simon Kuznets Kharkiv National University of Economics. Kharkiv, Ukraine.

b Ph.D. in Economics, Associate Professor Department of Public Administration, Public Administration and Economic Policy, Simon Kuznets Kharkiv National University of Economics. Kharkiv, Ukraine.

Introduction

Territorial development management in modern conditions is one of the key challenges and priorities for both developed countries and those in the process of transformation. Globalization, digitalization, urbanization, climate change, geopolitical shifts, and increasing public demands for quality of life and sustainability create unprecedented complexity for traditional models of territorial management. In Ukraine, this issue is becoming particularly acute in the context of ongoing decentralization, the need for post-war recovery and reconstruction, as well as integration into the European space. Effective management of developing communities, districts, and regions requires not only the adaptation of best global practices, but also a rethinking of the fundamental conceptual principles on which management decisions are based. Existing approaches often turn out to be fragmented, insufficiently flexible, or unable to adequately respond to dynamic changes and multi-vector challenges. Therefore, there is an urgent need to systematize, analyze, and critically evaluate various conceptual approaches, which will allow us to form a holistic understanding of territorial development management and substantiate new, more adequate, and adaptive models for modern Ukraine.

The object of the study is the processes of territorial development management at different levels (local, regional, national).

The subject of the study is a set of theoretical and methodological principles, concepts and models of territorial development management, their evolution, features and possibilities of application in modern conditions of Ukraine and the world.

The study aims to systematize, analyze, and substantiate the leading conceptual approaches to territorial development management in modern conditions, identify their advantages and disadvantages, and develop recommendations for their integrated and adaptive application to increase the effectiveness of territorial management.

Following the Research objectives.

– identify and summarize the main challenges and opportunities that shape the modern environment of territorial development management;

– characterize the leading conceptual approaches to territorial development management (e.g., sustainable development, smart specialization, new public management, management based on sustainable partnerships, management using the concept of resilience, etc.);

– perform a comparative analysis of conceptual approaches, assessing their methodological basis, practical applicability, and potential for solving modern problems;

– develop proposals and recommendations for the adaptive application and integration of selected conceptual approaches into the practice of territorial development management in Ukraine, in particular in the context of decentralization and post-war reconstruction.

The research results described in the article are intended for a wide range of stakeholders:

• State authorities and local governments of Ukraine: for the justification and development of strategies, programs and plans for territorial development, especially in the context of decentralization, reconstruction and European integration.

• Research institutions and higher education institutions: for further development of the theory and methodology of territorial development management, as well as for use in the educational process.

- International organizations and expert communities: dealing with issues of regional development, cross-border cooperation and support for Ukraine.
- Representatives of civil society and business: for active participation in the planning and implementation of territorial development projects, as well as for understanding the prospects and opportunities opened up by new approaches to governance.

Conceptual approaches to territorial development management include a systems approach that considers the territory as a complex system, as well as project-based, situational, socially-oriented and sustainable development. These approaches emphasize goal-oriented management, adaptation to circumstances, harmonization of environmental, social and economic needs, as well as the transformation of communities into management subjects.

Sustainable development of territorial communities involves creating conditions for long-term and self-sufficient development at the local level, which ensures an improvement in the quality of life of the population. Such development includes the integration of economic, social and environmental aspects, effective management of natural and human resources, as well as a rational distribution of powers between state and local authorities.

Methods

The study employed a comprehensive methodology combining general scientific and specific analytical methods.

The dialectical method was fundamental for understanding territorial systems as evolving structures subject to contradictions between socio-economic development and institutional capacity. This dynamic view enabled the authors to identify how globalisation and decentralisation interact within Ukraine's territorial context.

The systemic approach was applied to interpret territorial development as a holistic process involving economic, social, environmental, and administrative subsystems. This approach provided the analytical framework for assessing how governance mechanisms influence sustainable development outcomes and for mapping interdependencies between actors of different governance levels.

The methods of analysis, synthesis, and generalisation were used to examine and categorise conceptual models of territorial management—from sustainable development to resilience governance. These methods made it possible to synthesize theoretical insights and to formulate conclusions on their practical applicability in the Ukrainian context.

The comparative analysis method was employed to evaluate key conceptual approaches—Sustainable Development, Smart Specialisation, New Public Management, Partnership-Based Governance, and Resilience Management—according to their methodological foundations, advantages, limitations, and relevance. By comparing international and domestic experiences, the study identified the potential for integration and adaptation of these approaches in Ukraine's territorial policy.

The historical method allowed the tracing of the evolution of scientific thought in the field of regional management, from centralised planning systems to decentralised and participatory governance models. Through this lens, the authors assessed the transformation of governance paradigms under global and national reforms.

The methods of classification and typology were used to systematise the diversity of conceptual frameworks, enabling a structured understanding of how each model contributes to achieving sustainable territorial development. These classifications helped define the theoretical boundaries between managerial paradigms while recognising their potential for hybridization.

The method of abstraction and idealisation facilitated the creation of generalised models that integrate theoretical and empirical data, serving as conceptual prototypes for future management systems. This abstraction helped to identify universal principles such as adaptability, inclusivity, and inter-sectoral cooperation.

In addition, the research relied on empirical synthesis of Ukrainian decentralisation practices and post-war reconstruction strategies, allowing the verification of theoretical propositions against real-world governance cases. By triangulating theoretical insights with policy analysis, the authors achieved both methodological rigor and practical relevance, ensuring that the proposed conceptual framework aligns with the complex realities of contemporary Ukraine.

Literature Review

The problem of territorial development management in contemporary conditions is widely discussed in global and Ukrainian academic discourse, reflecting transformations in public administration, spatial planning, and sustainable development. Territorial management is increasingly perceived as a multifactorial process that integrates socio-economic, environmental, and institutional dimensions (*Barca et al., 2012*; *Ivanov et al., 2021*). Within the European framework, territorial governance has evolved toward decentralization, partnership, and smart specialization, which together ensure the adaptability of regional systems to global challenges (*Doloreux et al., 2019*; *Boschma et al., 2017*).

The theoretical foundations of territorial development were established by the concepts of regional and evolutionary economic geography, emphasizing endogenous growth and local resource utilization (*Bellandi & Storai, 2021*). The paradigm of sustainable development, rooted in the Brundtland Report, serves as a unifying theoretical platform that connects social justice, environmental sustainability, and economic efficiency (*Petrovska, 2019*). In Ukraine, this paradigm has been reflected in regional development strategies and community-level spatial planning, aligning national policies with the EU Sustainable Development Goals (*Chernykhivska, 2014*; *Lytvynenko & Pavlenko, 2023*).

Modern management of territorial development also incorporates the principles of NPM and *NPG*, which have transformed the role of the state from a regulator to a facilitator of participatory governance. The *NPM* model introduced performance-oriented budgeting, e-governance, and decentralization of functions (*Alcantara & Nelles, 2014*). In contrast, the *NPG* model emphasises co-creation, partnership, and shared responsibility among public authorities, businesses, and communities, thereby increasing social trust and legitimacy (*Storonyanska & Zalutskyi, 2022*).

A significant contribution to the modern discourse on territorial management is made by the concept of S3, developed within the EU regional policy. It promotes innovation-driven growth by concentrating resources on competitive advantages and integrating research, education, and entrepreneurship (*Boschma et al., 2017*). S3 supports local economies in identifying

strategic priorities through the Entrepreneurial Discovery Process, contributing to diversification and sustainable competitiveness (*Doloreux et al., 2019*).

Recent research highlights the need to integrate *resilience-based management*, which focuses on the capacity of territories to adapt to crises and recover effectively. This approach has gained particular relevance for Ukraine under the conditions of war and reconstruction (*Khrustovskyi & Slobodyanyuk, 2022*). Resilience entails proactive risk management, the strengthening of institutional frameworks, and the development of social capital that enables communities to withstand shocks and transform sustainably (*Kyzym et al., 2022*).

Thus, the synthesis of sustainable development, smart specialisation, public–private partnerships, and resilience forms the basis of modern territorial management models. These hybrid frameworks emphasize flexibility, inclusiveness, and innovation as strategic prerequisites for ensuring sustainable growth and spatial cohesion of territories (*Bezhin, 2022*; *Berdanova et al., 2017*).

Results

Challenges and Opportunities Shaping the Modern Territorial Development Management Environment

The modern environment of territorial development management is characterized by high dynamism, uncertainty, and interdependence of processes.

Main challenges are:

1. Globalization and increased competition: Territories compete for investment, human capital, and access to markets. Global economic crises and changes in supply chains can have devastating consequences for local economies.
2. Demographic changes: Population aging, migration processes (both urbanization and depopulation of rural areas), and changing household structures create pressure on social infrastructure and the labor market.
3. Climate change and environmental threats: The increasing frequency and intensity of extreme weather events, the degradation of natural resources, and environmental pollution require the integration of environmental aspects into all development decisions.
4. Social inequality and polarization: Growing gap between rich and poor, lack of equal access to quality services (education, healthcare), growing social tension.
5. Technological changes (digitalization, automation): Rapid technological developments create new opportunities, but also challenges related to the need to adapt the workforce, develop digital infrastructure, and bridge the digital divide.
6. Inefficiency of public administration: Bureaucratization, corruption, lack of proper coordination between different levels and sectors of government, insufficient public involvement.
7. Geopolitical instability and conflicts: Wars, conflicts, hybrid threats that destroy infrastructure, cause mass population displacements, and radically change development priorities (especially relevant for Ukraine) (*Barca et al., 2012*; *Berdanova et al., 2017*; *Ilchenko & Zhilenko, 2006*).

Features are:

1. Digital transformation: Introduction of e-government, smart solutions for cities, use of Big Data for decision-making, development of digital platforms for citizen participation.
2. Transition to a green economy: Development of renewable energy, energy efficiency, circular economy, eco-tourism, which creates new jobs and improves the quality of life.
3. Activation of civil society and volunteerism: Increasing the role of public organizations, local initiatives, and volunteer movements in solving local problems and shaping the development agenda.
4. International cooperation and access to financial resources: The possibility of attracting international technical assistance, grants, and investments for the implementation of development projects.
5. Decentralization: Transfer of powers and resources to the local level, allowing for a more effective response to local needs, development of local democracy and initiatives.
6. Innovation and human capital development: Creating conditions for the development of innovation ecosystems, supporting start-ups, investing in education and advanced training.
7. Post-war reconstruction (for Ukraine): A unique opportunity to "build back better" using modern technologies, sustainable development principles and European standards, as well as to mobilize national and international resources (*Alcantara & Nelles, 2014*; *Sturiale & Trovato, 2015*; *Zabedyuk, 2021*).

Leading Conceptual Approaches to Territorial Development Management

Among the variety of conceptual approaches that have emerged in response to contemporary challenges and opportunities, the concept of Sustainable Development occupies a central place and is the cornerstone of many contemporary strategies. It offers a comprehensive view of development that balances human needs, economic progress, and the preservation of natural systems.

It is from the report of the UN World Commission on Environment and Development "Our Common Future" (1987), known as the Brundtland Report, that the most widely used definition of sustainable development comes. The essence of this concept is to meet the needs of the present generation without compromising the ability of future generations to meet their own needs (*Bellandi & Storai, 2021*). This fundamental position emphasizes the need for a balance between the current needs of humanity and the preservation of resources and opportunities for future generations, which is the essence of intergenerational justice.

A key aspect of sustainable development is the integration and harmonization of three interrelated dimensions (pillars): economic growth, social justice and environmental protection. Unlike previous models, which often focused on one aspect (e.g., only on economic growth), sustainable development requires their simultaneous consideration and mutual support. None of these pillars can be fully implemented without taking into account the others (*Bezhin, 2022*).

The most prominent and comprehensive example of the implementation of the concept of sustainable development is the UN *SDGs*, or the 2030 Agenda. The *SDGs* consist of 17 interrelated goals and 169 targets, covering a wide range of global challenges—from eradicating poverty and hunger to ensuring quality education, gender equality, clean energy, preserving ecosystems and building peaceful institutions (*Doloreux et al., 2019*). They serve as a universal roadmap and global framework for developing national and local strategies, programs and

policies aimed at achieving a balanced and sustainable future for all, embodying all three pillars of sustainable development.

The *S3* is an innovation-driven approach to regional economic development that has gained considerable popularity as a powerful tool for transformation and stimulating growth based on knowledge and innovation (*Schiavone, 2021*). It is not a universal recipe, but a flexible framework that allows regions to unleash their unique potential.

The idea behind *S3* is that to achieve sustainable economic development, regions should not try to compete in all areas at once, but instead focus on identifying and developing their unique strengths and competitive advantages. This involves a deep analysis of existing potential—from scientific research and innovative enterprises to a skilled workforce and natural resources.

The main goal is to focus investment (both public and private) in *R&D&I* on these priority areas, rather than scattering resources across a multitude of projects. This prioritization is not done through centralized top-down planning, but through an inclusive, interactive process known as the *EDP*.

Thus, S3 is not just another strategy, but a holistic framework for shaping innovation policy that helps regions realize their potential, focus efforts, build effective partnerships, and use innovation as a key lever for sustainable and inclusive economic development (*Ivanov et al., 2021*).

Next, we will consider the following approach. *NPM* is a paradigm of public sector reform that emerged in the 1980s and became widespread in the 1990s. Its central idea is to apply the principles, methods and tools of the private sector (management, results orientation, efficiency, competition) to public administration to improve its functioning, reduce costs and improve the quality of public services provided. *NPM* viewed traditional bureaucracy as inefficient, overly centralized and focused on processes rather than results (*Lytvynenko & Pavlenko, 2023*). Despite criticism, NPM has fundamentally changed public administration around the world. It has forced states to rethink their role, focus on efficiency, quality of services and the needs of citizens. Many of its principles, such as results orientation, decentralization, and the use of IT, remain relevant today, even in the context of the development of newer concepts, such as *NPG*, which recognizes the need for broader cooperation with non-state actors and a comprehensive approach to solving social problems.

PBM/NPG, this management paradigm goes beyond traditional public administration, emphasizing broad cooperation and interaction between various actors: public authorities (government, local government), the private sector (business, enterprises), civil society (non-governmental organizations, public associations, activists) and, where necessary, international organizations. The main goal is to achieve common, often complex, development goals that cannot be effectively solved by a single entity (*Storonyanska & Zalutskyi, 2022*). This approach is seen as an evolutionary step from *NPM*, which, although focused on efficiency, often remained within the state apparatus. *NPG* instead emphasizes decentralized, horizontal "network" forms of management, where decisions and responsibilities are distributed, and the interdependence of actors is key to solving "wicked" problems that require integrated approaches.

Key ideas are:

- Co-production/Co-creation: Moving from unilateral decision-making to an inclusive process where all stakeholders are actively involved in shaping policies, strategies, and implementing services, increasing their legitimacy and effectiveness.

- Risk and resource sharing: Pooling financial, human, technical and knowledge resources, as well as sharing potential risks between partners, makes projects more sustainable and realistic.

- Trust and mutual understanding: Fundamental elements for effective and long-term cooperation, built through transparency, openness, mutual respect and consistency of action.

- Co-responsibility and shared responsibility: All participants are responsible for the results and quality of implementation of joint initiatives, as well as for maintaining sustainable relationships in the network.

- Synergy: Achieving an effect when the joint efforts of partners produce a significantly greater result than the sum of individual contributions, thanks to the complementarity of competencies, process optimization, and innovation (*Sturiale & Trovato, 2015*).

RBM, this approach focuses on developing and maintaining the capacity of a system—whether it is an individual organization, a city, a community or an entire territory—to respond effectively to unforeseen events and challenges. It is about the ability not only to "absorb shocks" (such as natural disasters, economic crises, pandemics, social conflicts, cyberattacks or technological failures), but also to quickly recover from them, adapt to new conditions and even transform into a more stable and functional state (*Kyzym et al., 2022*). The key is to preserve the basic functions, identity and basic structure of the system, even when it undergoes significant changes. Resilience-based management involves not only responding to a crisis, but also proactively planning, minimizing vulnerabilities and building internal resilience to future unknown threats.

Key ideas are:

- Development of social capital: Formation and strengthening of networks of interaction, norms of trust and reciprocity, which contributes to the consolidation of the community/society and increases its ability to take collective action and solve problems.

- Innovation and adaptation: Partnerships often stimulate the search for new, creative approaches to solving problems and allow for faster adaptation to changing conditions through the exchange of knowledge and experience. Proactive planning and risk assessment: Early identification of potential threats, vulnerability analysis, development of possible crisis scenarios and response plans, rather than just reacting after the event. This includes the creation of early warning systems.

- Flexibility and adaptability: The ability to quickly change strategies, processes, organizational structures, and resource allocation in response to changing circumstances, avoiding rigidity and rigid hierarchy.

- Redundancy: Duplication of critical functions, resources, or infrastructure (e.g., multiple power sources, alternate transportation routes, data backups) to ensure uninterrupted operation in the event of a failure of one element. This allows the system to continue to function even when partially damaged.

- Diversity: The presence of different approaches, methods, sources, and performers to perform the same functions, which reduces dependence on a single, potentially vulnerable element and promotes the search for alternative solutions.
- Social cohesion and trust: Strong social ties, shared values, and a high level of trust in a community/society, which are the basis for effective communication, collective action, and mutual assistance during a crisis.
- Learning and innovation: Constant analysis of past experience, willingness to experiment, rapid learning of lessons and implementation of new solutions to increase resilience to future challenges.
- Robustness: The ability of key elements of a system (e.g., critical infrastructure, core institutions) to withstand significant external influences and loads without complete destruction or loss of functionality.
- Modularity: Dividing the system into independent but interconnected modules, allowing for damage isolation and ensuring the functioning of other parts (*Garcia-Alaniz et al., 2017*; *Ivanov et al., 2021*; *Petrovska, 2019*).

Thus, these approaches form an integrated vision of modern management and development that goes beyond purely administrative or market paradigms. They indicate the need to form a comprehensive model of governance, which is:

1. Strategic and visionary: Based on the principles of sustainable development, ensuring a balance between economic, social and environmental needs for the well-being of current and future generations.
2. Innovative and competitive: Applies the principles of smart specialization to stimulate innovation, efficient use of resources, and increase regional and national competitiveness.
3. Efficient and result-oriented: Maintains the new public administration's emphasis on process optimization, transparency, and achieving measurable results in the provision of public services.
4. Inclusive and collaborative: Actively engages in sustainable partnerships between the state, business, civil society, and academia (*NPG* principles) to jointly solve complex problems, build shared responsibility, and increase the legitimacy of decisions.
5. Adaptive and resilient: Develops the ability of systems to anticipate, absorb shocks, adapt and transform in the face of unforeseen challenges, ensuring viability and stability of development in conditions of constant change (*Schiavone et al., 2021*).

Therefore, these approaches, in their synergy, form the architecture of multidimensional, dynamic and flexible governance aimed at achieving comprehensive well-being, innovative growth and stability in the face of global uncertainty and constant change.

Comparative Analysis of Conceptual Approaches

In today's world, characterized by rapid change and increasing complexity of problems in various fields—from science and technology to social governance and international relations—their effective solution requires not only a deep understanding of the essence, but also the use of adequate conceptual tools. Conceptual approaches are theoretical frameworks that shape our vision of the world, guide research and determine the logic of practical actions. However, the

diversity of existing approaches often poses the question of choosing the most appropriate for a particular context for researchers and practitioners.

It is with the aim of ensuring such an informed choice that this section is devoted to a comparative analysis of key conceptual approaches. We will systematize and evaluate each approach according to a number of criteria that cover its fundamental aspects and practical significance (*Table 1*).

Thus, the comparative analysis of conceptual approaches revealed not only their diversity, but also profound differences in fundamental principles, methodology, and expected results.

One of the key findings is that there is no universal "best" approach that would be effective in all situations without exception. Instead, the effectiveness of each approach depends largely on the specifics of the context (industry, problem, goals), available resources, and even corporate culture or philosophy.

The analysis also revealed the potential for synergy. In many cases, the optimal solution may not be to choose a single approach, but to integrate elements of several of them, creating hybrid models that allow to compensate for the shortcomings of one approach with the advantages of another. This emphasizes the need for flexibility and adaptability in the application of conceptual knowledge.

A deep understanding of the strengths and weaknesses of each conceptual approach is critical for making informed decisions, formulating strategies, and developing innovative solutions. Ultimately, success in applying conceptual approaches lies not so much in blindly following a single doctrine, but in the ability to flexibly adapt and combine different ideas based on real needs and environmental dynamics.

Proposals and Recommendations for the Adaptive Application and Integration of Selected Conceptual Approaches into the Practice of Territorial Development Management in Ukraine

In the context of ongoing decentralization, which is transforming the architecture of governance at the local level, Ukraine faces an urgent need not simply to implement, but to organically integrate and adaptively apply advanced conceptual approaches to territorial development management. Such a process requires a comprehensive understanding of the territorial space as a holistic, dynamic system, where each element—social, economic, environmental, cultural—is inextricably linked and interdependent. Flexibility and adaptability become key, since the developed strategies and plans must function as "living" documents, capable of promptly responding to dynamic internal and external challenges, constantly adjusting and evolving. Inclusivity is of fundamental importance—the maximum involvement of a wide range of stakeholders, from community and business representatives to the expert environment and government bodies, to all stages of decision-making and implementation, which ensures legitimacy and sustainability.

Sustainable Development as a Cross-Cutting Paradigm

The sustainable development paradigm should become a cross-cutting basis for all management decisions at the local and regional levels, ensuring a balance between economic growth, social justice and environmental protection. In practical application, this involves conducting a deep inventory of existing competitive advantages at the regional and community

levels, such as human capital, natural resources, industrial traditions and geographical location, followed by a process of entrepreneurial discovery. This approach will allow identifying priority sectors for targeted investment, stimulating innovation, creating sustainable clusters and new value chains, contributing to the diversification of the local economy and increasing its competitiveness (*Zabedyuk, 2021*). At the same time, it is necessary to integrate the principles of the circular economy, energy efficiency and responsible consumption of resources into all stages of project planning and implementation. For Ukraine, this is crucial in the context of rebuilding after the destruction, creating new export-oriented and environmentally friendly industries, accelerating European integration through compliance with EU standards in innovation and environmental policy, and ensuring resilience to future challenges.

Combining Elements of New Public Management and Partnership-Based Management

The integration of the principles of *NPM* into the activities of local governments involves the systematic implementation of criteria for efficiency, transparency and effectiveness. This includes the development and monitoring of KPIs for municipal enterprises, optimization and digitalization of administrative services, as well as the development of e-government to simplify the interaction of citizens with the authorities and minimize corruption risks. In parallel, it is critically important to actively use the partnership-based management model, which involves the involvement of a wide range of stakeholders in the decision-making process and project implementation: business, public organizations, scientific institutions and international donors. The formation of effective coalitions and platforms for dialogue will contribute to the joint determination of priorities, distribution of responsibilities and mobilization of resources, which is indispensable for comprehensive territorial development. For Ukraine, in the context of decentralization, which has provided local governments with significantly more powers and resources, such a combination of approaches is the need of the hour. It will not only improve the quality of management decisions, but also ensure maximum synergy between all actors in the post-war reconstruction process, overcome mistrust, and effectively mobilize the huge resources needed to rebuild the country.

Resilience Management as a Strategic Goal

Resilience management as a strategic goal involves the ability of territorial systems—from individual communities to regions—to adapt to shocks and stresses, to recover quickly from them and, where possible, to transform to increase future resilience. In practice, this means developing and implementing multi-level emergency response systems, diversifying the local economy to reduce dependence on one sector, strengthening critical infrastructure—energy, transport, water supply—using modern technologies and decentralized solutions. An important component is also the formation of social cohesion and mutual aid networks, the development of a system of psychological support for the population and increasing the level of digital security (*Khrustovskyi & Slobodyanyuk, 2022*). For Ukraine, which has experienced and continues to experience the unprecedented challenges of war, resilience management is not just a goal, but an existential need. This means rebuilding not just what was destroyed, but creating qualitatively new systems that are more resilient to any threats, including the development of decentralized energy, ensuring food security at the local level, integrating rapid response mechanisms into everyday management practices, and preparing communities to adapt to potential future climate and security risks.

Integrated Recommendations

Strategic spatial planning should become an integrated tool that combines the principles of sustainable development, smart specialization and resilience. This involves the development of comprehensive territorial development strategies based on in-depth data analysis—including satellite imagery, information on destruction, migration flows, socio-economic indicators—in order to form a balanced and forward-looking vision of the country's spatial development. Such strategies should reflect long-term goals, coordinate actions of different levels of government and ensure the coherence of investment projects with national priorities, in particular European integration and the green transition.

At the same time, an integral part of adaptive management is large-scale and targeted investments in human capital. This includes reforming the education and vocational training system in accordance with the needs of the labor market, developing retraining and advanced training programs to adapt to new economic realities, supporting entrepreneurial initiative, forming an innovative culture and attracting qualified specialists. In addition, special attention should be paid to psychological and social support for the population, integrating internally displaced persons and veterans, creating conditions for self-realization of youth and their active involvement in local development processes, which will ensure not only economic growth, but also social cohesion and stability in the long term.

Thus, modern territorial development management requires not choosing one "correct" conceptual approach, but their intelligent integration and adaptation to specific conditions. For Ukraine, in the context of decentralization and large-scale post-war reconstruction, this means the need to combine the principles of sustainable development as a general goal, smart specialization for economic transformation, effective public administration and broad partnerships as implementation mechanisms, and resilience as a fundamental quality of all systems. Such an integrated approach will allow Ukraine not only to recover, but also to build modern, competitive and sustainable territories that meet European standards and the challenges of the 21st century.

Discussion

The conducted study confirmed that the management of territorial development in modern conditions is a multidimensional process shaped by global transformations, technological shifts, and the growing demand for participatory governance. The main theoretical contribution lies in the systematisation and comparative evaluation of conceptual approaches that collectively form the architecture of contemporary territorial governance. The findings emphasise that the sustainable development paradigm, integrated with smart specialisation, resilience management, and partnership-based governance, provides the most balanced framework for territorial transformation in Ukraine.

The relevance of this research stems from Ukraine's decentralisation reform and post-war reconstruction, which require adaptive and integrated governance mechanisms. The study revealed that while traditional administrative models remain useful for coordination, they are insufficient for addressing complex challenges such as demographic decline, resource depletion, and geopolitical risks. Instead, hybrid governance systems that combine strategic planning, digitalisation, and community participation show greater efficiency and legitimacy.

Several methodological and practical challenges were identified. First, the absence of unified criteria for evaluating resilience and sustainability indicators complicates the implementation of integrated strategies. Second, institutional fragmentation and uneven capacity across local governments hinder the realisation of smart specialisation principles. Third, the limited involvement of civil society and business in governance processes reduces the inclusivity of development models.

Nevertheless, the research highlights substantial opportunities for further evolution of territorial governance. The synergy of sustainable development and smart specialisation can drive regional innovation ecosystems, stimulate green transitions, and strengthen economic resilience. The inclusion of resilience management introduces an anticipatory dimension, enabling communities to adapt not only to economic but also to climatic and social challenges. Furthermore, the *NPG* model opens new horizons for cross-sectoral cooperation, trust building, and co-responsibility in decision-making.

Future research directions should focus on developing quantitative indicators for assessing the adaptive capacity of territorial systems and evaluating the effectiveness of hybrid governance models. Comparative studies across EU countries could provide valuable insights for harmonising Ukrainian policy with European standards. In addition, interdisciplinary research integrating public administration, digital governance, and spatial economics would help design evidence-based models for post-war recovery and sustainable growth.

In conclusion, the article demonstrates that effective territorial development management depends on an adaptive synthesis of conceptual approaches rather than adherence to a single paradigm. The integration of sustainable development, smart specialisation, partnership governance, and resilience ensures flexibility, inclusivity, and long-term sustainability. For Ukraine, this approach represents not only a methodological framework but also a strategic vision of building modern, competitive, and resilient territories within the European integration process.

Conclusion

The study was devoted to a comprehensive analysis of conceptual approaches to understanding and implementing territorial development management in modern conditions, which is critically important for the formation of effective strategies and policies.

At the initial stage, key challenges and opportunities that define the dynamic and often unstable environment of territorial development were identified and summarized. This allowed us to realize the multi-vector nature of modern processes, ranging from global trends (digitalization, climate change, urbanization) to specific national contexts (decentralization, military conflict, post-war reconstruction), emphasizing the need for adaptive and flexible management.

A detailed study and characterization of the leading conceptual approaches (sustainable development, smart specialization, new public management, governance based on sustainable partnerships, the concept of resilience, etc.) demonstrated their methodological diversity and different focus. Each of the approaches offers a unique set of tools and principles for achieving certain territorial development goals.

A comparative analysis of conceptual approaches revealed that none of them is a universal "*silver bullet*" that can solve all problems. Instead, their effectiveness depends on the context, the specifics of the territory and the tasks set. The analysis showed that the approaches often complement each other, and their integration can create a synergistic effect, enhancing the potential for solving modern problems. Approaches that emphasize cooperation, innovation, adaptability and resilience turned out to be especially valuable.

Based on the analysis and taking into account the specifics of Ukraine, in particular the processes of decentralization and the urgent need for post-war reconstruction, proposals and recommendations were developed for the adaptive application and integration of the selected conceptual approaches. The key conclusion is the need not to choose one dominant approach, but to form an integrated model of territorial development management. This model should be flexible, multi-level, focused on sustainable partnerships between the state, business, communities and civil society, prioritizing sustainable, inclusive development, smart specialization, innovation and strengthening the resilience of territorial units.

It is such a comprehensive, integrated and adaptive approach that will allow Ukraine to effectively manage its territorial development, turning challenges into opportunities for sustainable growth, increasing competitiveness and ensuring the well-being of its citizens in the context of decentralization and reconstruction.

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Appendix

Table 1. Comparative analysis of conceptual approaches

Conceptual approach	Methodological basis	Practical applicability	Potential for solving modern problems	Limitations / Criticism
Sustainable development	Innovative economy, regional science, cluster theory, entrepreneurial discovery.	Development of regional strategies for innovative development, cluster initiatives, support for R&D, attraction of investments in priority sectors.	Increasing the competitiveness of regions, creating new jobs, stimulating innovation and diversifying the economy.	Requires strong institutional capacity and trust between actors. May exacerbate regional inequalities if focused only on successful sectors
New public administration	Private sector management, transaction cost economics, rational choice theory.	Reforming the state apparatus, introducing contracts, KPIs, outsourcing services, result-oriented budgeting.	Increasing the efficiency and economy of public services, improving the quality of service to "clients" (citizens). Reducing bureaucracy.	Risk of ignoring social justice and societal values. May lead to fragmentation of services, complexity of control and accountability.
Partnership-based Governance (NPG)	Sociology of organizations, network theory, stakeholder theory, social capital theory.	Creation of public-private partnerships, public councils, coalitions, joint projects between local governments,	Effectively solving complex problems that require the involvement of many resources and competencies. Increasing trust, legitimacy of decisions, mobilization of social capital.	The complexity of managing diverse interests, slow decision-making, the risk of dominance by stronger partners,

		businesses and NGOs.		the need for a high level of trust.
Resilience management	Theory of complex adaptive systems, ecology, catastrophe theory, risk theory.	Development of crisis response plans, diversification of the economy, implementation of risk-informed infrastructure solutions, development of local self-organization.	Ensuring the survival and recovery of territories after shocks (natural disasters, economic crises, conflicts). Ability to adapt and transform in conditions of uncertainty.	Difficult to measure and operationalize. May lead to excessive "preparation" costs. Potential trap of "reverting to a previous state" that may be undesirable or unviable.

Hanna B. Breslavska [a][7]

Theoretical and Methodological Foundations for Ensuring Continuity in National and Patriotic Education of Senior Preschoolers and Primary School Pupils [5]

Abstract:

The article highlights the theoretical and methodological foundations for ensuring continuity in national and patriotic education of senior preschoolers and primary school pupils. The relevance of the research lies in the need to develop civic consciousness, patriotic values, and national identity in young children amid educational reforms and current societal challenges. The object of the study is the process of national and patriotic education of children of senior preschool and early school age. The purpose of the study is to substantiate theoretical and methodological approaches to the implementation of the principle of continuity between preschool and primary school in the system of national and patriotic education. The methods used include analysis, synthesis, comparison, systematization, and pedagogical forecasting. Based on the works of Bekh, Bohush, Sukhomlynskyi, Kuzmenko, and Karamushka, the psychological and pedagogical foundations of the development of patriotic feelings were identified. The result of the study is the definition of a continuity structure grounded in the unity of educational content, forms of activity, and pedagogical partnership. Methodological conditions for ensuring continuity are proposed: harmonization of educational programs, implementation of joint projects, and the formation of a value-semantic space for the child. The practical significance lies in the possibility of applying the results in the professional training of preschool and primary school teachers.

Keywords: continuity, national and patriotic education, preschoolers, primary school pupils, values, civic identity, pedagogical partnership.

Introduction

The relevance of ensuring continuity in national and patriotic education is determined by the social need to cultivate conscious citizens capable of acting in the interests of the state and society, guided by moral values, love for their homeland, responsibility, and readiness to defend Ukraine (*Bekh, 2018*). In the context of war and globalization, the education system plays a leading role in strengthening national identity and civic position among children, while the formation of patriotic qualities must begin in early childhood (*Education…, 2021*).

National and patriotic education is understood as an integrated process that combines moral, emotional-volitional, and activity-based components of personal development. It is grounded in humanistic values and the idea of love for one's land, people, language, and culture (*Bohush, 2020*). One of the key factors of effectiveness in this process is continuity between preschool and primary education, ensuring coherence and consistency in the development of the child's value orientations (*Kuzmenko, 2021*).

The transition from preschool to school involves changes in social roles, leading activities, behavior expectations, and learning motivation. It is therefore essential to maintain continuity in educational influences, preserve a positive emotional attitude toward learning, and strengthen the child's sense of belonging to their country (*Karamushka, 2019*). Continuity in national and

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a Candidate of Pedagogical Sciences (Ph.D.), Senior Lecturer, Department of Primary Education, Admiral Makarov National University of Shipbuilding. Mykolaiv, Ukraine.

patriotic education manifests in the unity of content lines, forms, and methods of educational work, as well as shared value orientations and pedagogical traditions.

Modern pedagogy views continuity not merely as a sequence of learning stages but as pedagogical interaction, where preschool institutions and schools act as equal partners in forming a nationally conscious and harmonious personality This requires a shared educational environment integrating cultural and community resources (*Leshchenko, 2019*).

Key prerequisites for continuity include alignment of state educational standards (*Basic Component…, 2021*), teacher readiness for joint planning, and the development of competencies necessary for effective partnership among educators, parents, and children (*Savchenko, 2000*).

Thus, ensuring continuity in national and patriotic education is a complex pedagogical problem that requires coordination of goals, content, forms, methods, and outcomes across developmental stages.

The subject of the study is theoretical and methodological foundations for ensuring continuity between preschool and primary education.

The object of the study is the process of national and patriotic education of senior preschool and primary school children.

The study aims to theoretically substantiate and define methodological principles for ensuring continuity in national and patriotic education.

There are following tasks in the study:

– analyze the psychological and pedagogical foundations of patriotism formation in children.
– reveal the essence and content of the principle of continuity in education.
– identify pedagogical conditions, means, and forms of implementing educational work aimed at developing national consciousness.

Methods

The methodological framework of this study is grounded in the principles of systematization, continuity, and value orientation that underpin modern Ukrainian pedagogy. The research employed both general scientific and specific pedagogical methods to ensure comprehensive analysis and theoretical substantiation of continuity in national and patriotic education of senior preschoolers and primary school pupils.

At the general scientific level, analysis and synthesis were used to deconstruct the phenomenon of national and patriotic education into its structural and functional elements and to integrate them into a coherent theoretical model. Induction and deduction allowed the formulation of general pedagogical regularities based on empirical and theoretical premises. Comparison enabled the identification of commonalities and distinctions between preschool and primary educational systems in terms of content, forms, and methods of patriotic upbringing. Systematization and classification facilitated the organization of data concerning the conceptual and methodological approaches applied within Ukrainian educational standards and pedagogical practice.

Pedagogical forecasting served as a tool for determining the expected developmental outcomes of implementing continuity between educational levels, focusing on the moral, emotional, and civic maturity of children. The structural-functional method provided a basis for

mapping the interrelations among goals, content, activities, and results of national-patriotic education, thus illustrating the mechanism through which continuity is achieved.

At the level of specific methods, content analysis of legislative and normative documents (e.g., the Law of Ukraine "On Education" (*2017*); the Basic Component of Preschool Education (*2021*); the State Standard of Primary Education (*2018*)) was conducted to determine the regulatory alignment between preschool and primary education. Comparative pedagogical analysis was applied to educational programmes and teaching materials to reveal cross-level coherence in developing civic and patriotic competencies.

Additionally, historical-pedagogical analysis helped trace the evolution of the concept of continuity in the works of Ukrainian scholars such as Sukhomlynskyi (*1977*), Bekh (*2018*), Bohush (*2020*), and Savchenko (*2000*), allowing the identification of its moral-axiological and humanistic foundations. Modeling was used to construct a conceptual scheme that integrates the emotional, cognitive, and activity-based dimensions of patriotic education across both educational levels.

Finally, expert evaluation and pedagogical reflection were employed to verify the internal logic and applicability of the proposed methodological conditions—harmonization of educational programmes, joint preschool–school projects, and formation of a unified value-semantic space. These methods collectively ensured that the study rested on a triangulation of theoretical, normative, and empirical evidence, thus providing reliability and validity to the conclusions drawn.

Literature Review

Scholarly attention to the continuity of national and patriotic education in Ukraine has intensified in the context of modern social transformation and state reform. Bekh (*2018*) formulated the concept of personality-oriented education, stressing that patriotism is a moral construct rooted in the emotional experience of belonging and moral responsibility. His approach establishes the ethical and psychological foundation for fostering national consciousness in childhood.

Bohush (*2020*) expanded on the notion of continuity as a pedagogical category that ensures the coherence of goals and content between preschool and primary education. Her research identifies the key mechanisms of maintaining emotional engagement and motivation during the child's transition to school. Similarly, Savchenko (*2000*) underscored the need for pedagogical succession ("perspective and continuity") between the first two levels of education, highlighting teacher cooperation and curricular coordination as essential factors.

The legal and normative framework of continuity is set out in the Law of Ukraine "On Education" (*2017*) and the Law "On Complete General Secondary Education" (*2020*), which guarantee lifelong learning and institutional articulation. The Basic Component of Preschool Education (*2021*) and the State Standard of Primary Education (*2018*) specify learning outcomes and competencies that align developmental expectations across stages. The Concept of National and Patriotic Education of Children and Youth (*2015*) and the Strategy for National and Patriotic Education 2020–2025 (*2019*) define ideological and methodological priorities, orienting educational institutions toward the formation of civic identity and national values.

Leshchenko (*2019*) examined pedagogical continuity as a condition for holistic personality development, emphasizing that the unity of emotional, cognitive, and social experiences is crucial for cultivating patriotism. Karamushka (*2019*) analysed the psychological aspects of patriotic education, arguing that children's patriotic feelings evolve through integration with moral, aesthetic, and labor education, echoing Sukhomlynskyi's (*1977*) principle of educating "through the heart".

Kuzmenko (*2021*) and Yaremenko (*2022*) provided empirical frameworks for implementing patriotic education in preschool and primary institutions, introducing interactive, project-based, and community-oriented methods as effective means of maintaining continuity. Their findings highlight the importance of cooperative interaction among teachers, parents, and local communities as mediators of civic identity.

Finally, the integration of global educational perspectives, particularly UNESCO's "Education for Sustainable Development Goals: Learning Objectives" (*2021*), enriches the Ukrainian approach by linking patriotic education with sustainable development, peace, and cultural heritage preservation. Collectively, these studies outline a complex interdisciplinary field where pedagogy, psychology, and civic education converge to form a cohesive national identity from early childhood.

Theoretical Foundations of Continuity in Education

The problem of continuity in pedagogical theory is viewed as one of the key conditions for ensuring a holistic educational process that provides continuous child development at all stages. In the context of national and patriotic education, it is particularly significant as it involves the formation of moral and civic qualities rather than merely the transfer of knowledge or skills.

The legal basis for ensuring continuity is established by the Law of Ukraine "On Education" (*2017*), which guarantees the principle of lifelong learning, as well as the Laws of Ukraine "On Preschool Education" (*2001*) and "On Complete General Secondary Education" (*2020*), which define organizational and content-related links between educational levels. Key regulatory documents include the State Standard of Preschool Education (*Basic Component…, 2021*) and the State Standard of Primary Education (*2018*), which coordinate expected learning outcomes and ensure developmental progression. Conceptually, the national-patriotic dimension is grounded in the Concept of National and Patriotic Education of Children and Youth (*2015*) and the Strategy of National and Patriotic Education for 2020–2025 (*2019*).

Bekh (*2018*) emphasized that patriotism has a deeply moral nature and its development requires emotional experiences of belonging to one's nation. Bohush (*2020*) described continuity as a pedagogical category reflecting the natural connection between stages of personal development, ensuring coherence of goals, content, and methods. Psychological and pedagogical research (*Kuzmenko, 2021*; *Leshchenko, 2019*) shows that emotional components of patriotism—love for home, family, language, and nature—are established in preschool, while primary education expands them to the level of civic identity.

Karamushka (*2019*), following Sukhomlynskyi (*1977*), asserted that the formation of patriotic feelings cannot occur in isolation from moral, civic, labor, and aesthetic education, since their integration fosters a harmonious, emotionally mature, and socially active personality.

Thus, the theoretical foundations of continuity in national and patriotic education involve developing a coherent value system across educational levels, aligning educational influences, and shaping a child's holistic perception of their national identity.

Methodological Foundations for Ensuring Continuity

Ensuring continuity in practice requires scientifically substantiated methodological approaches that bridge theory and pedagogical activity. The main condition is the systematic coordination of pedagogical actions, curriculum content, and goals (*Basic Component…, 2021*).

The methodological basis rests on the combination of traditional and innovative educational technologies. In preschool, effective forms include play-based, role-playing, theatrical, and exploratory activities, while in primary school, interactive, project-based, and ICT-based methods prevail (*Bohush, 2020*). Their integration preserves familiar activity structures for children while fostering autonomy and responsibility.

Joint inter-institutional projects—such as *"My Ukraine"*, *"Treasures of My Land"*, and *"Heroes Among Us"*—ensure continuity of educational influence, beginning in preschool (acquaintance with symbols, songs, folk tales) and continuing in school through research, exhibitions, and creative events.

Yaremenko (*2022*) notes that joint activities among teachers, parents, and children create a social context where patriotism becomes a lived value, not a declaration. Methodological support includes monitoring systems for patriotic achievements and the development of pedagogical cases and evaluation criteria (*Yaremenko, 2022*).

Pedagogical Conditions and Means of Implementation

Effective implementation of continuity requires creating pedagogical conditions that ensure process integrity and emotional comfort. These include:

- unity of educational influences among family, preschool, and school;
- coordinated planning of educational activities;
- a value-oriented educational environment;
- partnership-based collaboration;
- age-appropriate variability of forms (*Kuzmenko, 2021*).

In preschool, leading means include play, folklore, songs, and traditions through which concepts of goodness, justice, and friendship are internalized. In primary school, these evolve into civic education lessons, projects, excursions, and student self-government.

Effective tools include patriotic games, quests, symbolic spaces (national corners, exhibitions), family celebrations (*"My Family—Part of Ukraine"*), and volunteer initiatives (*"Kindness Unites"*, *"Letter to a Soldier"*).

A. Sukhomlynskyi (*1977*) famously stated, *"The heart of education is the shared activity of teacher and child."* Through this interaction, love and responsibility for the homeland are formed (*Sukhomlynskyi, 1977*).

Discussion

The conducted research confirms that ensuring continuity in national and patriotic education is not merely a pedagogical issue but a socio-cultural necessity for contemporary Ukraine. The transition from preschool to primary education represents a critical developmental period when a child's emotional attachment to homeland evolves into conscious civic identity. Therefore, the educational system must preserve the affective-moral foundations formed in early childhood while introducing structured civic concepts at the next stage.

The main challenge identified is the fragmentation of pedagogical practice caused by insufficient coordination between preschool and school educators. Despite legislative alignment, practical implementation often remains inconsistent: preschool focuses on emotional and symbolic components of patriotism, whereas primary education emphasizes knowledge-based civic learning. Bridging this gap requires methodological integration through joint educational programmes, cross-institutional projects, and teacher training focused on partnership pedagogy.

Another problem lies in the insufficient methodological support for educators. Teachers frequently lack clear instruments for evaluating patriotic competence and assessing continuity outcomes. Developing diagnostic tools, monitoring frameworks, and performance indicators would allow schools and preschools to measure the effectiveness of value-based education more objectively.

The study also highlights the potential of project-based and community-oriented activities in fostering continuity. Programmes such as *"My Ukraine" or "Heroes Among Us"* illustrate how children's early emotional experiences can evolve into practical civic engagement when supported by collective creativity and social interaction. Such initiatives strengthen the sense of belonging, pride, and responsibility, transforming patriotism from a declarative idea into lived behaviour.

Furthermore, the discussion reveals that pedagogical partnership—a cooperative model involving teachers, parents, and local communities—serves as the cornerstone of continuity. When children observe alignment between educational values and family or community practices, patriotic feelings acquire depth and authenticity. This corresponds with the ideas of Sukhomlynskyi (*1977*) that true education occurs through shared activity, empathy, and emotional resonance.

Finally, the relevance of continuity is amplified by Ukraine's current sociopolitical context, where education plays a decisive role in national consolidation and resilience. The unity of educational content, methods, and values becomes a factor of cultural security and social stability. Hence, continuity in national and patriotic education should be considered a strategic dimension of state policy, ensuring that each educational stage contributes to the formation of a holistic, civically responsible personality.

Future research should focus on developing measurable models of cross-level cooperation and elaborating evidence-based recommendations for integrating patriotic education into broader frameworks of civic and sustainable education.

Conclusion

Thus, the study shows that ensuring continuity in national and patriotic education of senior preschool and primary school children is a multifaceted issue and a key component of modern Ukrainian education. Results confirm the need for a continuous educational environment that promotes the child's harmonious development, spirituality, and civic responsibility.

1. Continuity is a holistic process uniting preschool and primary education through shared goals, content, and activities, ensuring a smooth transition from emotional perception to conscious national identity.
2. The theoretical basis relies on humanistic pedagogy, competence-based and value-oriented approaches, focusing on developing moral and civic qualities rather than mere knowledge.
3. Methodological conditions involve coordination of curricula, integration of educational content, joint planning, and partnership between teachers of both levels.
4. Effective implementation depends on pedagogical partnership among educators, parents, and the community within a shared value-semantic environment.
5. The practical value lies in applying findings for teacher education, curriculum modernization, and creating joint preschool–school educational projects.

Ensuring continuity in national and patriotic education is a prerequisite for forming a holistic, civically responsible Ukrainian citizen. Future research should focus on developing evaluation models of cross-level educational cooperation and methodological recommendations for integrating patriotic components across all spheres of the educational process.

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Appendix

Educational Line	Preschool (Senior Group)	Primary School (Grades 1–2)	Forms of Continuity
Love for the Homeland	Introduction to native land and folk symbols	Study of state symbols and community traditions	Joint events "My Ukraine"
Family Values	Participation in family celebrations	Topics „My Family", „My Kin"	Family project
Civic Activity	Children's games „Good Deeds for the City"	Student campaigns, eco-initiatives	Volunteer mini-projects

Figure 1. Relationship between content lines of national and patriotic education in preschool and primary school

Liubov V. Stehnitska [a][8]

Criteria for Evaluating Scientific Posters with Elements of Artificial Intelligence [6]

Abstract:
Education benefits greatly from visual learning, as visual memory accounts for a significant portion of brain activity. Visual aids such as posters distill complex data and foster dynamic discussions, making them indispensable in academic presentations. Posters are becoming increasingly popular in the educational environment because they allow complex data to be illustrated concisely and comprehensively. However, artificial intelligence (AI) poses certain challenges in the creation and evaluation of posters, raising concerns about academic integrity and personal contribution. The subject of the study is the criteria and methodological approaches used to assess the quality, originality, and academic integrity of posters produced with the assistance of artificial intelligence tools. The object of the study is the process of creating and evaluating scientific posters within the educational environment, particularly those incorporating elements of artificial intelligence. The study aims to develop a unified set of objective criteria for evaluating scientific posters that include AI-generated elements, ensuring ethical compliance, transparency, and fairness in academic assessment practices. This study examines poster evaluation criteria, considering the role of AI, to ensure fairness and transparency in an academic setting. Clear guidelines and requirements for disclosure of AI use are essential for maintaining ethical standards in poster presentations.

Keywords: education, poster, artificial intelligence, academic integrity.

Abbreviations:

AI is artificial intelligence.

Introduction

Education is not only about searching for new methods and approaches to effective learning, but also about finding effective means of their implementation. Vision and visual memory account for up to two-thirds of brain activity, which emphasizes the importance of visual materials in educational settings (*Osa & Musser, 2004*). The use of visual learning has effectively transformed education, offering significant benefits to students across various academic disciplines. Visual aids, such as diagrams and charts, can enhance comprehension and foster a deeper understanding of complex concepts (*Alabi, 2024*). Visual means are of great importance as they can help students understand the content they are learning (*Salbego et al., 2015*) and concisely illustrate complex and voluminous data. Moreover, such a visual mean of communications as the poster "can be viewed as a pedagogical tool and as having considerable agency in promoting and enhancing students' professional communication skills and meta-cognitive capacity." (*Brandt, 2009, p. 108*) During some scientific seminars, nearly half of all presentations are chosen as poster presentations (*European Centre…, n.d.*) and it is no wonder that when presenting their scientific achievements, students increasingly choose infographics to present their scientific projects or discuss the results of scientific research. Artificial intelligence has significantly expanded the creative potential of speakers, approaching the creation of

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a Candidate of Philological Sciences (Ph.D.), Associate Professor, Department of Foreign Languages, Bukovinian State Medical University. Chernivtsi, Ukraine.

presentations closer to automation, taking into account preferences regarding content. Thus, traditional pedagogical practices face complex challenges, namely, how to evaluate a poster with elements of artificial intelligence in terms of academic integrity and the participant's personal contribution to its creation. Over-reliance on these tools, risks dulling critical skills and eroding confidence (*Lund et al., 2026*). Accordingly, it is essential to find a solution to this problem, specifically by identifying criteria for evaluating such work since posters have become a noteworthy educational tool in the academic setting.

This study introduces a systematic approach to defining objective evaluation criteria for scientific posters that integrate artificial intelligence tools, a topic largely unexplored in current educational research. The novelty lies in aligning AI-assisted creativity with academic integrity principles, bridging technological innovation and ethical evaluation standards. The author formulates adaptable guidelines for assessing AI-generated contributions, ensuring fairness and transparency in academic poster evaluation.

The subject of the study is the criteria and methodological approaches used to assess the quality, originality, and academic integrity of posters produced with the assistance of artificial intelligence tools.

The object of the study is the process of creating and evaluating scientific posters within the educational environment, particularly those incorporating elements of artificial intelligence.

The study aims to develop a unified set of objective criteria for evaluating scientific posters that include AI-generated elements, ensuring ethical compliance, transparency, and fairness in academic assessment practices.

To achieve the purpose, the following objectives were defined:
− analyze existing academic and institutional requirements for poster design and evaluation.
− identify the challenges posed by the integration of artificial intelligence in poster creation concerning academic integrity.
− formulate a comprehensive and adaptable framework for evaluating posters that involve AI-generated content.
− propose recommendations for policy development regarding AI use disclosure and the permissible level of AI contribution in educational presentations.

Methods

Any form of communication involves the use of a specific system of signs that provides access to the necessary information and helps establish an emotionally positive connection between participants. In this study, graphic synthesis of a poster is understood as a means of accumulating key ideas and presenting them to a broad audience. Therefore, it is necessary not only to know the requirements for creating competitive posters, but also to understand the criteria for their objective evaluation. The study aims to analyze the criteria for a good poster and identify assessment criteria relevant to evaluating the use of artificial intelligence in this context. To determine reliable criteria for assessing posters, a comprehensive review of the requirements for posters set forth by conference organizers was conducted, along with an analysis of standardized evaluation systems described in the relevant literature. Based on this review, a single set of objective criteria was formulated for the practical evaluation of posters,

ensuring the adaptability of the requirements to the influence of AI tools while maintaining transparency and academic integrity. This methodological approach may facilitate a consistent and fair evaluation of posters across various educational contexts.

Literature Review

Posters are a valuable educational tool that promotes visual learning, engagement, and creativity; however, they require careful preparation and design to establish a psychological connection between communicators and realize their full potential (*Duchin & Sherwood, 1990*; *Osa & Musser, 2004*; *Sousa & Clark, 2019*). In the medical education environment, posters are described as communicating messages that are brief, consistent, and interactive, making them particularly useful in educational contexts for engagingly conveying information (*Duchin & Sherwood, 1990*). They can be handy for illustrating a concept or idea, demonstrating a process, differentiating between similar things, or capturing interest and stimulating emotion (*Osa & Musser, 2004*). Furthermore, the appeal of the message in the poster allows the audience to perceive it on multiple levels: sensory, emotional, social, intellectual, and economic (*Tovar Samanez, 1987*). It should also be noted that academic presentation skills can be developed through poster presentations (*Brandt, 2009*). Since posters are part of the educational process, it is clear that this tool should be considered from the perspective of academic integrity. A study focused on issues related to AI and academic integrity emphasizes that, as "AI continues to influence educational ecosystems, it is necessary to critically examine the impact of AI on academic integrity" (*Balalle & Pannilage, 2025, p. 2*). Moreover, tools such as ChatGPT "undoubtedly improve the efficiency of writing and the accuracy of academic content, but they also violate academic integrity." (*Balalle & Pannilage, 2025, p. 10*) Some findings suggest that while participants demonstrate confidence and understand the limitations when using AI tools, there is a gap in training, as most stated the need for training in using the AI tools ethically (*Mokgosi & Semenya, n.d.*). However, the speed at which AI-assisted writing technologies are developing may outpace the creation of institutional academic integrity policies and guidelines for their use. It leads to gray areas, confusion, and insufficient awareness of such tools and may raise ethical concerns, such as plagiarism, academic dishonesty, and the potential for AI to replace human writing (*Tolochko et al., 2023*). Despite the plethora of studies on AI impact on education, remains a lack of comprehensive research examining both the positive and negative effects of AI in education, particularly in the assessment of the poster.

Results and Discussion

Any form of communication involves the use of a specific symbol system that provides access to the necessary information and helps establish an emotional connection between participants. Weiner et al. (*1972*) defined communication as necessarily involving a socially shared symbol system, or code, which is symbolic in nature (*Weiner et al., 1972*). The poster as a medium of communication serves to transmit a message by means of a graphical synthesis (*Tovar Samanez, 1987*) thus, the combination of semiotic codes from different sign systems on a single poster makes the text multimodal and allows to fill in the gaps that arise when recipients from a different cultural space understand the text. According to Osa and Musser, posters are appropriate because they motive and inspire students to learn, stimulate interest in the topic and

effectively illustrate a concept or skill (*Osa & Musser, 2004*). The graphic synthesis of a poster accumulates the main ideas, demonstrating them to a large audience, and also may attract the maximum number of participants for discussion. Due to the clear and concise presentation of information, the poster exhibits the integrity of the work, while paying attention to details. Such work appeals to its originality and contrast and forces one to focus on specific information, since the exchange of information is carried out without unnecessary distractions. Presenting the topic in the form of a poster report maximizes the student's creative potential, as it is perceived on an intellectual, sensory, and emotional level. Moreover, posters can be viewed several times and data and graphics on posters are as long as an individual wish. The main requirement for the poster is that it should reveal key ideas at first glance as well as the target group and objective should be defined considering to age, occupation, location, and sex (*Tovar Samanez, 1987*). The use of basic design elements such as simplicity of composition, attractive color combinations, and spacing between headings creates a presentation mode that is both appealing and enduring. Posters communicate and interact with the viewer thus effective development of an educational poster requires clear content delineation, understanding of the audience's needs, and consideration of the environment or setting where the poster will be displayed (*Duchin & Sherwood, 1990*).

The main assessment criteria includes clearly defined sections, logical flow of ideas, font type, text use, design, color, language clarity and appropriateness, clear structure with well-defined headings, effective mix of images where the use of diagrams or visual techniques to enhance understanding and guide viewers through the poster (*Brandt, 2009*; *Frost et al., 2023*; *Sousa & Clark, 2019*). Additionally, the poster itself should be well-designed, well-organized, legible, and attractive and present concepts succinctly, grabbing and retaining students' attention and interest (*Osa & Musser, 2004*). All these points are worth considering as they promote effectiveness conveying key information clearly and make content easy to comprehend and memorize. At the same time, it would be reasonable to add points related to academic integrity, as the growth of generative artificial intelligence has begun to undermine academic integrity. According to Himendra Balalle, academic integrity is a critically important component of education in today's rapidly changing academic environment. Academic integrity must be adhered because it reflects the value of the qualifications offered by an educational institution. Honesty, trust, and ethical behavior among students, as well as the management of these factors, are an integral part of the activities of educational institutions. However, with the development of AI, traditional pedagogical practices may face complex challenges and opportunities (*Balalle & Pannilage, 2025*) as poster creators do not indicate the share of work performed by artificial intelligence.

Thus, the permitted percentage of AI-generated work must be indicated in the guidelines and students must declare whenever AI tools are used for research purposes and cannot exceed an established percentage. As AI tools are generated rapidly, the policies must be updated regularly as new AI tools are developed frequently and should be clearly visible on the website (*Mokgosi & Semenya, n.d.*). We also suggest creating a questionnaire to be completed by all participants in the poster section which may include the questions like *Did you use AI in preparing the poster*? *What percentage of the work was done using AI? What exactly was done using AI?* Accordingly,

if images or conclusions are made by artificial intelligence, they should not be evaluated, or the speaker will receive the minimum score.

Conclusion

Education benefits greatly from the use of visual learning, which significantly improves memorization and engagement in various disciplines. Visual aids facilitate the understanding of complex concepts and help maintain student interest. Posters have become a popular educational tool, especially in academic presentations, as they concisely illustrate large amounts of data and stimulate discussion, while allowing to evaluate participants' original contributions. Posters not only effectively convey key ideas in a visual form, but also contribute to the development of students' professional communication skills and metacognitive abilities, supporting their deeper learning and creativity. However, AI tools challenge traditional pedagogical practices by automating part of the poster creation process, raising concerns about academic integrity. Therefore, it is essential to establish objective criteria for evaluating posters that take into account the role of AI, ensure fairness, transparency, and adherence to academic integrity. Academic institutions should develop policies that clearly define acceptable AI use, require disclosure of AI contributions, and adapt guidelines as AI tools evolve to preserve educational values and integrity. In summary, the development of artificial intelligence requires careful evaluation to ensure a balance between innovation and ethical academic practices.

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Myroslava P. Kukhta [a][9]

Algorithmic Governance, Trust, and the Transformation of Social Structures in the Digital Age [7]

Abstract:

This article presents a sociological analysis of the transformation of trust and managerial authority in the context of algorithmic governance. The object of the study is the algorithmized decision-making environment, and the subject is the social mechanisms of responsibility delegation and changes in legitimation in the digital age. The study aims to identify the structural consequences of implementing algorithms in areas that previously relied on personalized evaluation, as well as to empirically model such consequences using psychometric data. The study employs an interdisciplinary methodology, incorporating Niklas Luhmann's systems theory, Pierre Bourdieu's concept of symbolic power, Anthony Giddens' structuration theory, and machine learning tools, particularly Random Forest and SHAP analysis. The empirical illustration is based on an original synthetic dataset constructed using real psychometric scales. The findings reveal that algorithmic models not only organize data but also generate new structures of social influence through a logic of opaque decisions perceived as objective. SHAP analysis demonstrates that the importance of individual features in system predictions varies by context, offering prospects for critically interpreting the social functions of algorithms. The results can be applied in the analysis of trust in digital services and automated decision-making in healthcare, education, and security.

Keywords: algorithmic governance, social structures, digital trust, SHAP analysis, delegation, artificial intelligence, structural power, machine learning.

Introduction

Over the past decade, algorithmic governance has been increasingly integrated into social practices of evaluation, resource allocation, and decision-making. In the context of digitalization, managerial functions that were once carried out through formalized bureaucratic structures or personal authority are now more frequently delegated to technical systems that employ artificial intelligence and machine learning. This shift necessitates a sociological rethinking of new mechanisms of trust, legitimation, and responsibility within a distributed agentic environment, where a "decision" emerges as a computational outcome rather than as a result of procedural legitimation.

The object of this study is the algorithmized decision-making environment within social systems.

Its subject is the social transformations triggered by the delegation of managerial authority to digital systems and the evolving structures of trust in sources of power, including the so-called "objectivity" of digital interfaces.

Special attention is paid to mechanisms that foster institutional trust in algorithms and their decisions, particularly in contexts where there is limited understanding of the internal logic underlying these models.

[a] Doctor of Sociological Sciences, Associate Professor, Department of Sociology, Faculty of Sociology and Law, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.

The study aims to analytically delineate the sociological implications of the algorithmization of governance from the standpoint of contemporary social theory and to demonstrate empirical approaches to visualizing the logic of machine-based decision-making using psychometric data.

The specific objectives include:

− analyzing how algorithms represent social characteristics in evaluation systems;
− identifying structural shifts in the processes of decision delegation;
− illustrating the potential of SHAP analysis as a means of sociological interpretation of the internal logic of digital models.

Methods

The methodological framework of this study combines classical sociological theory with modern computational techniques to explore the mechanisms of algorithmic governance and the transformation of social structures in the digital age. The study integrates general scientific and specific empirical methods that together ensure both theoretical depth and analytical precision.

At the general theoretical level, the study employs a systemic and structural-functional approach derived from Niklas Luhmann's theory of communication systems and Anthony Giddens' structuration theory. These frameworks allow the researcher to conceptualise algorithms not merely as technological artefacts but as self-referential communicative units within the broader system of social interactions. Luhmann's model of autopoietic systems provides the foundation for analysing algorithmic governance as a recursive process of communication and reproduction of meaning, where decisions are legitimized through functionality rather than interpersonal consensus. In parallel, Giddens' concept of structuration enables the interpretation of algorithmic systems as structures that both constrain and enable human agency, reflecting dynamic reciprocity between social action and digital architecture.

The sociological method of theoretical modelling is used to trace the transformation of trust from interpersonal to systemic forms. Within this framework, algorithmic systems are viewed as new agents of institutional trust, which derive legitimacy from their technical authority and perceived neutrality rather than from moral or institutional validation. Pierre Bourdieu's concept of symbolic power is employed to interpret the emergence of algorithmic authority as a form of symbolic domination embedded in digital infrastructures.

The comparative-historical method underpins the analysis of the evolution of managerial rationality—from bureaucratic systems of decision-making (*Weber, 1998*) to the algorithmic logic of contemporary governance. This method facilitates an understanding of how accountability and legitimacy have shifted from human actors to technical systems and how these transformations reshape the very fabric of social order.

At the empirical level, the study applies quantitative computational methods, combining the generation and analysis of a synthetic dataset with tools of machine learning. The dataset, modelled after open-access psychometric surveys, includes features such as the GAD-7, PHQ-4, and BRS scales, along with demographic variables (age, gender, education, chronic illness, access to therapy). These data simulate social conditions where psychological indicators interact with socio-economic variables. Using the Python libraries *scikit-learn* and *SHAP*, several

classification models were built, including Random Forest, Logistic Regression, and Support Vector Machine (*Raschka & Mirjalili, 2019*).

Among the specific analytical methods, SHAP (SHapley Additive exPlanations) analysis plays a key interpretative role. This method quantifies the contribution of each variable to the model's prediction, thus allowing the reconstruction of decision logic and enabling sociological interpretation of algorithmic outcomes. The feature importance plots and waterfall visualisations are used to identify how demographic and psychometric indicators affect the model's classification of anxiety levels. SHAP values serve as a methodological bridge between technical interpretability and sociological insight, allowing the researcher to detect latent biases and structures of digital power.

In addition, the study applies content analysis of theoretical and empirical sources to contextualize the results within broader debates on digital trust, transparency, and legitimacy. The methodological synthesis of sociological theory and machine learning creates a dual analytical lens: while sociological theory provides interpretive depth, computational modelling supplies empirical evidence for how algorithms function as social agents.

Thus, the methodological approach is interdisciplinary and multi-layered, combining the explanatory potential of classical social theories with modern empirical tools of data science. This synergy allows for a holistic understanding of algorithmic governance as both a technical and social phenomenon—one that redefines power, responsibility, and trust in the digital age.

Literature Review

Contemporary scholarship on algorithmic governance situates digital systems within a broader sociological framework of trust, authority, and control. The theoretical foundations of this study are deeply rooted in the classical works of Max Weber (*1998*), who conceptualised rational-legal authority as a cornerstone of modern governance. In the digital age, however, bureaucratic rationality has been transformed into algorithmic rationality, where legitimacy derives from technical accuracy rather than procedural transparency.

Building upon Niklas Luhmann's (*2011*) systems theory, scholars increasingly interpret algorithms as self-referential systems of communication that generate decisions independently of human intention. Trust in such systems becomes "systemic trust", detached from interpersonal relations and grounded instead in the perceived objectivity of technological processes. This shift toward depersonalised confidence aligns with the broader sociological discourse on automation and its implications for legitimacy.

The notion of symbolic domination developed by Pierre Bourdieu (*2021*) provides a further conceptual lens for analysing how digital architectures reproduce social hierarchies under the guise of neutrality. Within algorithmic environments, symbolic power manifests through design choices, data selection, and classification systems that structure access to resources and opportunities. Consequently, algorithmic governance becomes a new mode of institutionalised domination, where social inequality is embedded within the code itself.

The emergence of actor-network theory (*Latour, 2005*) fundamentally reshaped the understanding of agency in technological systems. According to Latour, both human and non-human entities can act as participants in social networks, producing effects and exercising power. Subsequent scholars such as Sayes (*2014*) have expanded this argument, suggesting that

algorithms are not mere tools but active agents that co-create social reality. This approach allows sociologists to interpret the algorithm as a social actor within a distributed network of responsibility.

From an applied perspective, Kellogg, Valentine, and Christin (*2020*) describe algorithms as new terrains of control within organisations, where managerial authority is increasingly exercised through technical infrastructures. Their research reveals how algorithmic systems reshape professional hierarchies and introduce new forms of surveillance and evaluation. Similarly, Wirtz, Weyerer, and Geyer (*2019*) analyse the integration of artificial intelligence into the public sector, emphasising both its efficiency potential and its ethical challenges, including opacity, accountability gaps, and systemic bias.

Technological adoption studies such as Cao, Duan, Edwards, and Dwivedi (*2021*) demonstrate that managerial attitudes toward AI are shaped by perceptions of trust and controllability. These attitudes influence the extent to which organisations delegate decision-making to machines. The tension between efficiency and ethical responsibility is further addressed by Perga (*2025*), who analyses European and Ukrainian approaches to ethical regulation in AI-based governance, highlighting the need for transparency and human oversight.

Interdisciplinary contributions from psychology and data science also inform the methodological dimension of this study. Soldner et al. (*2019*) introduce supervised machine learning techniques as empirical tools for psychological research, providing a framework for analysing human behavior through computational models. The practical implementation of such models, as discussed by Raschka and Mirjalili (*2019*), underscores the growing convergence of sociological inquiry and artificial intelligence methodologies.

In sociological literature, Jarrahi (*2018*) explores the symbiotic relationship between humans and AI in organisational decision-making, proposing a model of human–AI cooperation rather than substitution. This concept supports the argument that algorithmic governance functions not as a replacement for human judgement but as an extension of it—one that reconfigures accountability and redefines institutional legitimacy.

Finally, Ukrainian research on digital psychoprophylaxis (*Kukhta & Yenin, 2025*) illustrates how algorithmic systems penetrate professional domains, transforming expert practices and risk assessment procedures. These findings corroborate the broader argument that algorithmic governance is both a technical innovation and a sociocultural phenomenon that restructures trust and authority.

Overall, the reviewed literature reveals a common pattern: algorithms simultaneously rationalise and obscure decision-making, producing what Latour (*2005*) termed the "black box" effect. This duality—transparency in function but opacity in logic—forms the sociological core of algorithmic governance. The convergence of classical social theory with computational methodologies offers a promising avenue for understanding how digital systems not only process data but also reshape the foundations of modern social order.

Results

The methodological foundation of this work is rooted in interdisciplinary approaches that combine Niklas Luhmann's theory of communication systems, Pierre Bourdieu's concept of symbolic domination, and Anthony Giddens' theory of structuration. On the empirical level,

the study utilizes an original synthetic dataset structured from open-access mental health surveys, processed through machine learning models (Random Forest, Logistic Regression, SVM) and explanatory analysis methods (SHAP values). Visualizations of feature importance and waterfall plot examples form the basis for a critical analysis of the social functions of digital prediction. The source base of the research includes literature from digital sociology, critical algorithm studies, as well as technical sources from the fields of explainable AI and algorithmic modeling (*Kellogg et al., 2020*; *Wirtz et al., 2019*; *Latour, 2005*; *Cao et al., 2021*).

Configurations of Digital Power in the Algorithmized Environment

Under conditions of digital transformation, classical models of power relations undergo significant shifts. Whereas in modern societies power was primarily exercised through formal institutions and normative regulation, today it is increasingly mediated by technological interfaces acting as tools of "impersonal" governance. *Algorithmic governance*—a term encompassing the use of automated systems for decision-making, monitoring, or sorting individuals—represents a new form of power distribution in which technical tools acquire the status of social actors. This shift is documented in the works of K. Kellogg, M. Valentine, and A. Christin (*2020*), B. Wirtz, J. Weyerer, and C. Geyer (*2019*), and conceptualized within the framework of actor-network theory (*Latour, 2005*) as an expansion of agency beyond the human.

Digital platforms increasingly function not merely as neutral intermediaries, but as normative agents that establish rules of access, ranking, evaluation, and decision-making. For instance, in domains such as social services, credit scoring, employment, or psychological diagnostics, interfaces determine access to resources based on criteria that the user neither controls nor often understand. The legitimation of such forms of power relies not on procedural transparency or the possibility of appeal, but on the perceived neutrality of code. Consequently, trust in a digital decision is based on technical authority rather than social accountability. This generates new forms of structural asymmetry that are difficult to detect with classical sociological tools.

From a theoretical standpoint, we can interpret the algorithm as a specific form of "black box" (*Kellogg et al, 2020*), which accumulates prior social decisions but outputs them in a form stripped of visible history. Such systems can be analyzed through the lens of Niklas Luhmann's (*2011*) autopoietic communication structures, where the algorithm operates as a closed loop reproducing its own codes of admission. Additionally, drawing on structural sociology enables us to interpret digital practices of ranking and access as forms of normative control exercised not through direct prohibition, but via the digital logic of inclusion and evaluation (*Bourdieu, 2021*). Thus, algorithmic governance creates a new structure of social order in which power ceases to be personalized and instead becomes a function of technical architecture. This transformation demands a conceptual rethinking of key notions such as responsibility, trust, legitimacy, and social control under conditions of digitally distributed decision-making.

The Algorithm as a Social Agent and Carrier of Structural Power

In the digital age, the algorithm can no longer be regarded merely as a technical tool—it emerges as a full-fledged social agent capable of exerting influence, shaping expectations, and transforming the structures of social interaction. Sociology, long centered on human action, is

now faced with the need to expand its analytical boundaries to include agents that increasingly influence social processes. The concept of agency in *actor-network theory* (*Latour, 2005*) and within the framework of non-human agency (*Sayes, 2014*) offers a new perspective: an algorithm that ranks, evaluates, filters, or recommends does not merely influence behavior—it structurally reshapes the logic of the social field.

At the same time, the algorithm is not an autonomous subject in the traditional sense. Its agency is always co-produced with the social context—from system design to training and deployment. For example, within an experimental prototype developed in Python using the scikit-learn and *SHAP* libraries (*Raschka & Mirjalili, 2019*), we executed a full cycle of model building, training, and explanation using a Random Forest algorithm. A manually constructed synthetic dataset based on real psychometric scales was used. The target variable was anxiety level (low, moderate, high), and features included total scores from GAD-7, PHQ-4, BRS scales, along with gender, age, education, chronic illness, and therapy access information.

A SHAP waterfall plot (*Figure 1*) generated for a typical high-anxiety respondent revealed that high GAD-7 scores and a negative response to the question about psychological support were the major contributors to the prediction. In this way, the algorithm, trained on structured data, indirectly reproduces the logic of social stigmatization—identifying "at-risk" individuals based on lack of access to support.

Furthermore, the global SHAP summary plot showed that features related to demographic factors (age, gender, education), while having lower average importance, significantly shifted the model's output in certain local scenarios. This reveals a hidden reproduction of structural biases, which can have serious implications in decision-making systems—especially in public governance, healthcare, and education.

Thus, SHAP analysis functions not only as a technical tool for interpreting models, but as a sociological indicator of digital structures of influence. Its application enables a critical understanding of the new forms of power delegated to algorithms and reveals the mechanisms through which trust or skepticism toward automated decisions is shaped. In this approach, technology does not negate the social—it becomes its vector.

One of the key transformations in algorithmic governance is the shift from personalized to automated models of decision legitimation. In classical models of organizational management, a decision required hierarchical approval, personal accountability, and adherence to institutional frameworks (*Weber, 1998*). In the digital age, an increasing number of functions are delegated to algorithms operating on probabilistic models that are not accountable to any individual agent. This process entails a transformation in mechanisms of trust—from interpersonal and institutional to what Luhmann (*2011*) termed "system trust" in technology.

Algorithms such as Random Forest or XGBoost, widely used in digital services—from credit scoring to candidate selection—generate decisions without explanations but are perceived as "neutral" and devoid of human bias. This creates an illusion of objectivity and amplifies trust in their outputs, even in the absence of understanding of how the models' function. This is the sociological paradox of algorithmic governance: the less comprehensible an algorithm is, the more trustworthy it is considered—echoing the "black box" principle in technological systems (*Latour, 2005*).

The Mechanism of Delegating Responsibility to the Algorithm

The delegation of responsibility to algorithms also operates as a tool for removing ethical and legal accountability. In the field of psychological diagnostics, used here as the empirical case, this manifests in a shift in the logic of professional expertise. Whereas previously, a psychologist or counselor made decisions regarding further steps, in an automated system the decision is determined by code, which functions as a structure devoid of subjectivity and ethical accountability (*Kellogg et al. 2020*; *Wirtz et al., 2019*). Ukrainian studies have also emphasized the need to develop ethical constraints and accountability mechanisms in cases where critical functions are delegated to artificial intelligence systems (*Perga, 2025*).

A new structure of legitimation is also emerging, wherein a system's output is considered "justified" simply because it is algorithmically generated. This creates an additional risk—the formalization of distrust as bias or emotionality. In other words, if a user doubts the outcome, the doubt is framed as a personal issue rather than a shortcoming of the model.

Thus, algorithmic governance not only changes the procedures of decision-making—it restructures the framework of social agreement, displacing rational-communicative models of legitimation in favor of technocentric ones. In these, trust in the system is based not on communication, but on functional confidence in its capacity to replicate decisions (*Luhmann, 2011*). Such an approach demands a reinterpretation of the concepts of responsibility, transparency, and ethical action under conditions where decisions are delegated to systems that are not social subjects in the classical sense.

Discussion

In today's social context, where algorithms increasingly participate in decision-making, there arises a need for not only technical but also sociological reflection on these processes. The model of responsibility delegation—from ethical expertise to digital automatism—raises several questions for the social sciences.

First, how can accountability be ensured in a context devoid of subjectivity? If a system, rather than a human, makes a decision, can responsibility be attributed to the developers, administrators, or the organization as a whole? How is trust formalized in a context of algorithmic opacity and the lack of explainability?

Another critical issue is the blurring of boundaries between diagnosis, governance, and behavioral normalization. In the case of psychometric testing, if the system not only records a state but also classifies, recommends, and anticipates actions, then this constitutes an intervention that creates a new social norm. Here, the algorithm appears not merely as a tool, but as a structural unit influencing social reality.

Accordingly, at the intersection of sociology, computer science, and applied psychology, there arises a pressing need for interdisciplinary analysis. This opens new avenues for exploring algorithmic governance not only as a technical process but as a social phenomenon that reshapes our understanding of control, subjectivity, and legitimacy.

Conclusion

The study has demonstrated that algorithmic governance is no longer a narrowly technical domain but increasingly acts as a catalyst for the transformation of foundational social

structures—particularly decision-making procedures, mechanisms of legitimation, and forms of trust. Analyzing the implementation of such approaches through the example of psychometric models in digital environments revealed a shift in the roles of institutions and professionals when classification, prediction, and interpretation are delegated to machine algorithms.

In the first section, we focused on theoretical approaches to understanding algorithmic governance in the context of social trust. It was shown that the concepts of M. Weber, N. Luhmann, B. Latour, and P. Bourdieu can be effectively adapted to the analysis of contemporary practices shaped by opaque digital decisions that displace communicative interaction and models of personalized legitimation in favor of automated evaluation procedures.

The second part of the article presented empirical data, including a SHAP analysis of a Random Forest classification model designed for psychometric assessment of anxiety levels. The model processed inputs from the GAD-7, PHQ-4, and BRS scales, among others. The use of waterfall plots and technical validation metrics (F1-score = 0.81, AUC = 0.89) highlighted that model interpretability and trust are not necessarily correlated with technical complexity—for social users, transparency and clarity of reasoning matter more.

In the third section, we analyzed the consequences of such delegation—the disappearance of a decision-making subject, the shift from professional responsibility to systemic loyalty to the model, and the emergence of a new form of legitimation based not on institutional authority but on the performative capacity of the algorithm to deliver stable and "neutral" outcomes.

Overall, we have argued that algorithmic governance is not merely a subject of regulation but a driver of structural change within social systems. It presents sociology with new challenges: analyzing non-subjective forms of power, novel mechanisms of responsibility delegation, configurations of trust and norms, and reevaluating classical notions of decision legitimation in a complex digital environment.

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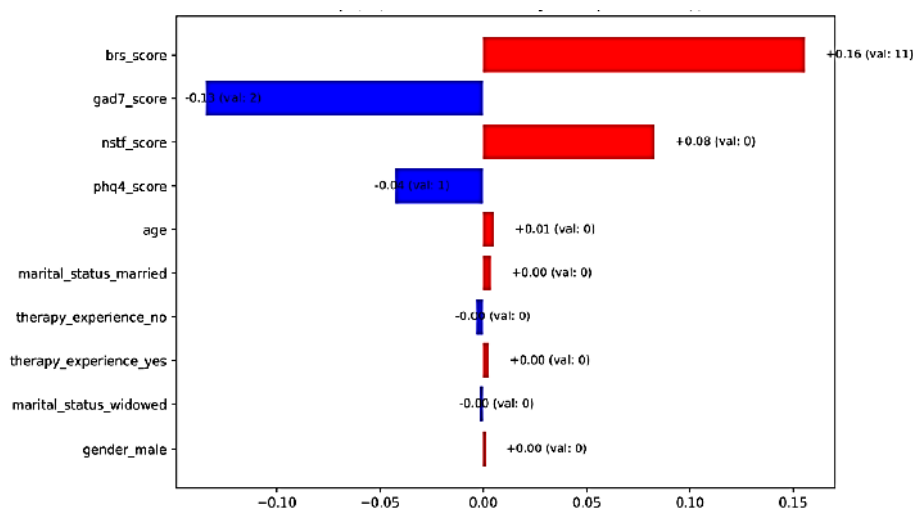
Appendix

Figure 1. SHAP Plot for Individual Prediction Showing Feature Contribution to Model Outcome

Dmitro L. Hasilin [a][*10*], *Ihor M. Zhuravel* [b][*11*]

Studying the Resilience of Steganography Algorithms to Detection by Neural Networks [*8*]

Abstract:

This study analyzes the resilience of steganography algorithms used in the spatial domain against detection using steganalysis deep learning models. We evaluate the impact of geometric transformations on the robustness against detection. The study investigates the effect of image transformations on the embedded message integrity and, more importantly, on the detectability of the algorithms by different models. Proven CNN models, as EfficientNet and SRNet with a Convolutional Block Attention Module, were used to compare detectability after different transformations. As expected, the embedded messages were significantly corrupted, while the models were still able to identify their presence. Introducing noise before embedding reduced detectability and increased robustness of steganographic algorithms. Alongside common LSB and modern S-UNIWARD, evaluating a spatial color space embedding algorithm, previously unknown to the model, significantly decreased accuracy. Due to the complex impact of the Color Space algorithm on uniform areas and smooth color transitions, we observe a higher number of false positives after fine-tuning models. Nevertheless, accuracy and generalization were increased to expected levels consistent with another modern research. The results underscore the need to focus on developing models that can withstand real-world image alterations, as well as improve detection capabilities to keep up with unseen stenographic methods. In practice, this will help practitioners select detection models best suited for operational environments and support future advancements in detection model development and design.

Keywords: steganography, steganalysis, color space, deep learning models.

Abbreviations:

BER is Bit Error Rate,

ByER is Byte Error Rate,

LSB is Least Significant Bit,

CBAM is Convolutional Block Attention Module,

CNNs are Convolutional Neural Networks,

S − UNIWARD is Spatial Universal Wavelet Relative Distortion,

STC is Syndrome Trellis Code.

Introduction

The rising frequency of digital data exchange highlights the demand for reliable steganalysis methods to mitigate potential threats. High data volumes further increase the risk of unsolicited data ingestion. To enhance the security of data pipelines against attacks, there is a necessity to explore the resilience of embedding algorithms not only against attacks but also against detection. This work continues and extends our earlier research (*Hasilin & Zhuravel, 2025*) about the level of resilience to transformations. While trying to add a new dimension to comparison by analyzing robustness to detection. The range of *CNN* models under consideration was

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[a] Ph.D. Student, Department of Information Technology Security, National University "Lviv Polytechnic". Lviv, Ukraine.
[b] Doctor of Engineering Sciences, Senior Researcher, Department Head, Department of Information Technology Security, National University "Lviv Polytechnic". Lviv, Ukraine.

narrowed based on the findings of Alrusaini (*2025*). The two best-performing models identified in that study were used as a starting point, with further exploration aimed at extending support for additional environments—particularly in detecting a broader range of color space–based methods.

The subject of the study is the resilience of spatial-domain steganography algorithms—specifically *LSB, S-UNIWARD,* and color-space methods—to detection by deep learning models such as EfficientNet and SRNet with Convolutional Block Attention Modules.

The object of the study is the process of information concealment and detection within digital images, particularly the interaction between steganographic algorithms and neural-network-based steganalysis models.

The study aims to evaluate and compare the robustness of contemporary steganographic algorithms against neural network detection, focusing on the effects of image transformations, dataset diversity, and model fine-tuning on detectability and message integrity.

To achieve this aim, the study pursues the following objectives:
− analyze existing approaches to steganography and steganalysis in the context of deep learning development;
− assess the resilience of spatial-domain and colour-space steganographic methods under geometric and noise-based image transformations;
− compare the detection performance of different *CNN* architectures, including EfficientNet and SRNet-*CBAM*, in identifying hidden messages;
− examine the influence of dataset composition and fine-tuning on detection robustness and false-positive rates;
− identify optimal conditions for achieving a balance between detection resistance and message integrity in real-world scenarios.

Methods

Steganalysis is the process of detecting hidden messages within digital media. Initially, it relied on statistical analysis, which examined anomalies in pixel distribution. However, these methods were not effective against modern steganographic techniques.

The field evolved significantly with the introduction of deep learning models. Early *CNN*-based models, such as Xu-Net and Yedroudj-Net, automated the feature extraction process but were vulnerable to common image transformations like compression and resizing.

Later, more advanced architectures emerged to address these vulnerabilities. ResNet introduced residual connections, which help preserve deep feature representations and prevent information loss within the network. This makes it more robust for steganographic detection. EfficientNet uses a compound scaling method to optimize its depth, width, and resolution simultaneously. It also incorporates squeeze-and-excitation SE layers to dynamically adjust feature importance. These features provide exceptional resilience against image transformations, enabling the model to maintain detection accuracy even after an image has been altered (*Alrusaini, 2025*).

In the research, a subset of images from various well-known datasets was used to cover as many variations as possible. The de facto standard is the BOSSBase dataset, which is a grayscale

image dataset specifically designed for steganography and steganalysis research. We did not consider it, as one of the methods under research relies on color space (*Margalikas & Ramanauskaitė, 2019*).

COCO, which stands for Common Objects in Context, is a diverse dataset designed for object detection, classification, and context understanding. It includes more than 300,000 images with complex, real-world scenes and multiple labeled objects. The images are in color and vary in resolution. In steganography, *COCO* is often used because of its variety and realistic content (*Lin et al., 2014*).

ImageNet is an image database organized according to the WordNet hierarchy (*Deng et al., 2009*). It contains over 10 million labeled images covering thousands of object classes. The images are in color and come from diverse sources. In steganography research, subsets of ImageNet are used for training deep neural networks to detect embedded data, taking advantage of the dataset's scale (*Deng et al., 2009*).

DIV2K is a high-quality image dataset primarily used in image SR tasks. It consists of 1,000 images with 2K resolution, meaning they are very detailed and suitable for tasks requiring high visual fidelity. In the context of steganography, DIV2K is used to test how well embedding algorithms perform on high-resolution, high-quality images (*Timofte et al., 2017*).

We've used an equal number of images, 10,000, from the first two datasets mentioned above, to cover them equally. The entire DIV2k dataset was added to make the initial image resolution even more versatile. The initial training dataset, for fine-tuning, was created by scaling all images to the required size, and 10% of the images included embedding using the LSB method.

Literature Review

The growing sophistication of steganography and steganalysis reflects the ongoing competition between concealment and detection technologies. Early research in this field was dominated by statistical methods focused on pixel distribution irregularities (*AbdelRaouf, 2021*). However, such approaches lost relevance with the emergence of adaptive steganographic algorithms capable of mimicking natural image statistics. The introduction of *LSB* substitution marked a significant milestone in spatial-domain steganography but simultaneously exposed fundamental vulnerabilities to compression and transformation (*Apau et al., 2024*). Subsequent developments such as *S-UNIWARD*, which embed information in textured or noisy areas, demonstrated greater resistance to visual and statistical detection by adapting to local image characteristics (*Holub et al., 2014*).

The modern phase of research is increasingly defined by the use of deep learning in steganalysis. *CNN*s such as Xu-Net and Yedroudj-Net automated the feature extraction process, outperforming classical detectors based on handcrafted features (*Chaumont, 2020*). Nevertheless, these models proved sensitive to geometric transformations, including scaling, rotation, and compression (*Hasilin & Zhuravel, 2025*). To address such weaknesses, architectures such as ResNet and EfficientNet introduced residual connections and compound scaling to improve model stability and accuracy (*Tan & Le, 2019*). Recent studies demonstrated that models enhanced with channel attention mechanisms, such as the *CBAM*, achieve superior generalisation across diverse embedding methods (*Woo et al., 2018*).

Datasets play a crucial role in training and evaluating steganalysis algorithms. Benchmarks such as ImageNet (*Deng et al., 2009*) and *COCO* (*Lin et al., 2014*) offer complex, high-resolution colour imagery necessary for learning robust features across diverse contexts. The DIV2K dataset (*Timofte et al., 2017*) provides additional value by introducing high-fidelity images suitable for testing robustness against compression and resizing. However, as noted by Margalikas and Ramanauskaitė (*2019*), traditional grayscale datasets such as BOSSBase may fail to reflect real-world image diversity, which is critical for assessing the detection resistance of colour-space-based algorithms.

The shift towards embedding in colour space marks one of the latest conceptual innovations in steganography. This approach modifies chromatic rather than luminance components, distributing hidden information more uniformly and reducing statistical detectability (*Margalikas & Ramanauskaitė, 2019*). Moreover, using three-dimensional colour cube models enhances resistance to cropping and noise attacks by maintaining global chromatic consistency (*Hasilin & Zhuravel, 2025*). While these methods improve robustness, they often introduce capacity trade-offs and increased computational complexity.

Recent comparative analyses reveal that the detectability of modern steganographic algorithms strongly depends on both embedding strategy and the training diversity of detection models (*Alrusaini, 2025*). Studies emphasise the importance of fine-tuning *CNN*s on mixed datasets, including unseen embedding methods, to improve detection reliability under transformations. Furthermore, research by Hu, Ni, and Shi (*2018*) confirmed that adaptiveness in embedding entropy domains enhances resilience to JPEG compression, aligning with broader findings on robustness through domain transformation. Complementary experiments show that introducing controlled noise during training can reduce model overfitting and improve generalisation to previously unknown embedding techniques (*Ni et al., 2014*).

In summary, the evolution of steganography from simple spatial substitution to adaptive, colour-space, and deep-learning-resistant methods represents a critical frontier in information security. Simultaneously, the parallel development of detection models—from handcrafted to *CNN*-based architectures—illustrates the dynamic co-evolution of attack and defence strategies. The reviewed literature highlights that ensuring message integrity and concealment in real-world conditions requires not only algorithmic innovation but also dataset diversity, model robustness, and cross-domain evaluation frameworks.

Embedding Methods

The most common spatial domain hiding algorithm, the *LSB* modification, works by altering the least significant bit of a pixel's color component. This change is typically visually imperceptible due to the bit's minimal influence. However, the *LSB* method is highly vulnerable to various attacks, as even minimal changes in bit sequences can introduce detectable noise, making it easy to expose through statistical analysis (*AbdelRaouf, 2021*).

S-UNIWARD is a content-adaptive steganography algorithm designed to embed secret data into the spatial domain of an image by minimizing detectability. It calculates distortion using relative changes in wavelet coefficients across multiple scales and orientations, allowing it to adapt to local image features. The algorithm embeds data in textured or noisy areas where changes are less noticeable, while avoiding smooth regions. It modifies pixel values directly and

often, but not always, uses efficient coding methods like *STCs* to reduce overall distortion, enhancing its security against detection by reducing the number of modified pixels almost in half compared to *LSB* (*Holub et al., 2014*).

A contemporary algorithm by Margalikas and Ramanauskaitė (*2019*) shifts data hiding from individual pixels to the color space (the set of colors used in an image). This method gains popularity because current statistical analysis tools often neglect the entire color set. Changes in the color space distribute uniformly across gradients and statistical characteristics, making the container less vulnerable to compression and other image-altering attacks. Furthermore, the color set is highly resistant to pixel cropping, as the loss of individual pixels does not necessarily reduce the overall set of colors.

The text examines an adaptive color space steganography method proposed by Margalikas and Ramanauskaitė (*2019*), which employs an RGB-cube to encode messages. This process involves recursively partitioning the RGB-cube, which represents the image's colors in three-dimensional space, into progressively smaller sub-cubes until each contains at most a single color. Data is then embedded by altering the coordinates (R, G, or B values) of colors within sub-cubes of different sizes that contain exactly one color. To mitigate the known drawbacks of increased color space distortion in shallow areas, we employed a simple yet costly in terms of message capacity modification by limiting the sub-cube size $2 \times 2 \times 2$ (*Hasilin & Zhuravel, 2025*).

Since not all embedding methods support block-based data representation, it is necessary to implement it in the message encoder/decoder. The commonly used BER is effective but sensitive to minor distortions. To address this, *ByER* is used (*Hasilin & Zhuravel, 2025*). Unlike *BER*, *ByER* operates on bytes, making it more resilient to single-bit losses and false-positive matches. It better reflects the amount of information recoverable post-attack and helps assess the robustness of embedding digital keys, images. For instance, QR codes offer strong resistance to modifications.

To reduce the impact of attacks on text data and to conform to established attack resilience evaluation frameworks, a bit repetition coding method was also reused, where each bit is repeated n times. This allows error correction through a quorum-based approach, ensuring readability even when pixels are lost. However, this method significantly increases data size, making it inefficient for low-resource systems. Moreover, it mainly detects missing bits and may misinterpret certain patterns as valid transitions, thus limiting error correction accuracy (*Hasilin & Zhuravel, 2025*). Another alternative would be to use Reed and Solomon (1960) codes in scenarios where robust error correction is required and the loss of even a few bits would be unacceptable.

Results

For model selection, we relied on the evaluation framework suggested by Alrusaini (*2025*), which assessed model robustness against transformations for methods embedding in the spatial domain. The aim was to keep the detection properties closely compared together with robustness to transformation.

The analysis reveals a practical trade-off between maximizing detection sensitivity in pristine images and ensuring robustness against common image manipulations. EfficientNet

emerged as the most practical choice for real-world scenarios, effectively balancing speed, optimized performance, and the ability to adapt to post-embedding transformations. In contrast, the high complexity of SRNet and the inherent fragility of Xu-Net and Yedroudj-Net under significant image distortion pose practical limitations. Transformer models (e.g., ViT, Swin) were deliberately excluded due to high computational overhead and unproven utility in this specific domain (*Alrusaini, 2025*).

Evaluation was implemented using the PyTorch framework (*Paszke et al., 2019*). All models were used with pretrained weights. As part of the preparation of the generic EfficientNet (*Tan & Le, 2019*) model, fine-tuning was done. In the configuration phase, a classification layer was added to configure this generic model with a channel attention module in stego detection mode.

Fine-tuning was done on the train dataset without including color space embedding at first, to test the pretrained model's ability to detect an unseen embedding method. An SRNet model was also used with pretrained weights. As reported in several studies, this model failed to converge when trained on color images. We observed that deviations exceeded expectations. As an alternative, a modification with an added *CBAM* was used. *CBAM* was proposed by Woo, Park, Lee, and Kweon (*2018*), and it showed better results.

Because of the different nature of the two embedding methods, we set a goal to adjust the embedding message length to fit the image capacity. This configuration was done to achieve a common embeddment rate equal to 0.4 bpp. In Figure 1 (*Appendix*), we can see that the *LSB* method, at least not an adaptive one, is not dependent on the pixel values. On the other hand, Color Space method, by design, is highly reliant on the color space distribution. After adding the *CBAM* module, we observe average performance commonly expected from such models. Levels of false positive cases were back to normal, and specifically low on the known dataset, as could be seen in Figure 2 (*Appendix*).

Introducing noise before embedding reduced detectability by an average of 8%; nevertheless, deviations were quite high, and it is hard to call this reduction consistent and reliable. Further discoveries with a deeper focus on noise sounds like a promising area. After proceeding with a few experiments, replicating attacks in the previous study, which included compression, cropping, and noise addition, we could conclude that the overall performance of detecting models is falling by up to 10%. That is happening with minimal modification and is consistent with known data (*Alrusaini, 2025*). At the same time, message integrity degradation was high, and neither method was able to withstand those modifications without losing integrity. The decision was made not to proceed with the modification, as there is no sense in verifying the accuracy of detection on an embedded message that is already unextractable.

Alternatively, further experiments show that running detection models on previously unseen embodiment methods reveals accuracy degradation, as could be observed in Figure 3 (*Appendix*).

An additional fine-tuning dataset was made to compare with those results. In the new set, a third of the images with a hidden message were created using the Color space method. The overall number of embedded messages was the same, 20%. The pipeline for this data set configuration is described in Figure 4 (*Appendix*).

Thus, we estimated attack effectiveness. Also, fine-tuning improvements results highlight the importance of training set diversity, even if we are talking about training the last few layers.

Discussion

For a generic method, the detection chance is quite important, together with the effect of the transformation. Nevertheless, we need to keep in consideration the stability of the stegochannel, as there is no value in a method successfully withstanding detection whilst being altered, but losing the ability to deliver the message due to later alteration. The reverse situation doesn't bring much value as well: delivering content to the receiver, acknowledging the fact of being detected, may deliver some value at the moment, but not in the long term. As it is only a matter of time and the competence of the detecting entity, before the transmitted message will be disclosed. The essence of steganographic methods is to guarantee the invisibility of the communication transaction. As soon as this promise is broken, even before some messages are decoded, the entire channel is compromised and cannot be used. At any minute, the technical channel could be destroyed or blocked, and it is required to move to a recovery plan if present in the global system setup.

Conclusion

This study evaluated the robustness and detectability of three different steganography methods: *LSB* modification, *S-UNIWARDS*, and color space cube modification. We compared these methods against a deep learning model's ability to detect them under attacks. The goal was to evaluate protection against detection under attacks as a new criterion for selecting steganography algorithms, alongside traditional metrics.

Considering the significant statistical effect, we observe that detectability is very high, and therefore, adaptive methods should be used (*Ni et al., 2014*; *Hu et al., 2018*).

In terms of detection robustness, there is around an 11% advantage compared to *LSB*. Improvement over *S-UNIWARD* is less significant at 4-5% which could be explained by the adaptiveness of the algorithm. Overall lower detection accuracy of the SRNet model could be explained by its lightweight design in terms of resource consumption. This was evaluated on a model not trained for this use case, showing the main advantage of using not widely known, unseen in training sets methods. After the second run and allocating 7% of the training set to the color space transformation cases, we can see that the models extracted a proper feature set, and the advantage reduced to a smaller 6–7% over *LSB* with high deviations, especially for SRNet. This could be explained by the fact that color space alterations are affecting statistical properties softly, unharmed for gradients. Even so, those changes are detectable by CNN models given training. And deviations could be explained by the nature of the cover image. If it has a lot of unique pixel values, any color space modification begins to look like embedding using adaptive *LSB*, thus similar to *S-UNIWARD*, but in case of a high number of unique pixel values, it could degrade to lower than *S-UNIWARD* values. So, here we have an inverse proportional relationship between the number of unique colors and robustness against detection. To ensure the high robustness of such a stego channel and reduce deviation impact, cover images should be carefully selected and tested. Preference should be given to smooth images without redundancy of high contrast areas. As observed, such covers will provide a smaller capacity, but could leverage the higher detection robustness evaluated in this paper.

Such preprocessing verification, using automated tooling, is widely adopted in many areas and should not be a burden to such complex communication channels.

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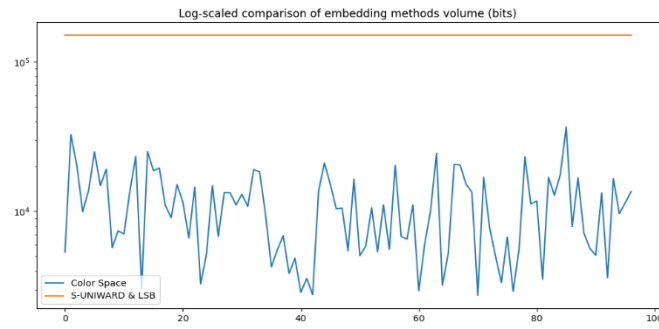
Appendix

Figure 1. Embedding capacity deviation of all methods on the resulting training set (scaled)
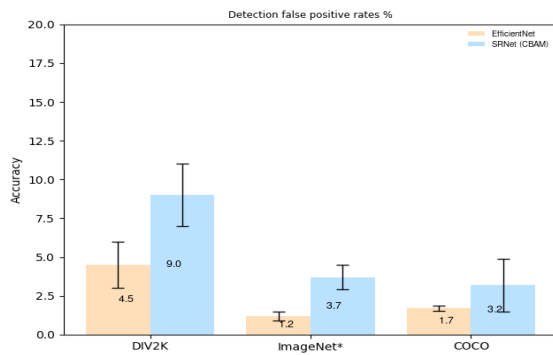
Figure 2. False positive results

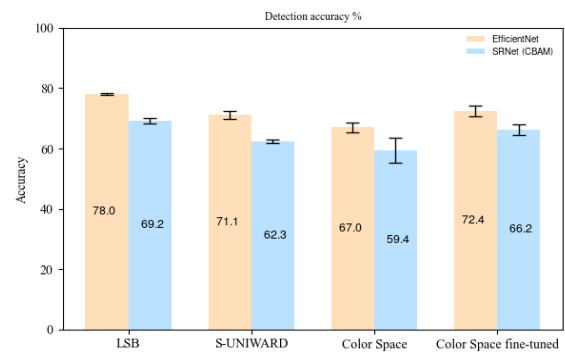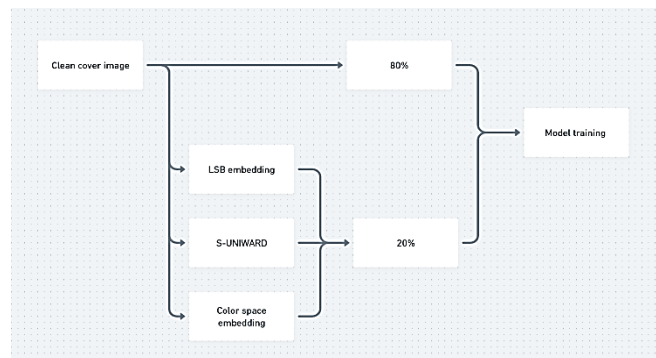Figure 3. Model accuracy results

Figure 4. Building fine-tuning dataset flow

Lyudmyla V. Haponova [a][12]

Rationalization of Reinforced Concrete Structural-Anisotropic Shells Design Parameters [9]

Abstract:

In the article, the formulation and implementation of the task to rationalize the structural parameters of reinforced concrete structurally anisotropic shells is presented. The criterion for such an objective is the energy principle, according to which it is considered that out of the entire set of possible system parameter values with a constant volume of material, the number of external and internal ties, the potential deformation energy after the reconstruction reaches the lower limit at a rational combination of the geometric parameter values. The coatings of buildings and structures perceive significant loads, which cause a high level of the stress-strain state of the system. That is why it is advisable to consider such types of coatings that could perceive, evenly distribute and transfer the load to the supports. Structurally anisotropic reinforced concrete shells of different Gaussian curvature are proved to be the most suitable for this purpose. The search for rational shell designs that perceive the specified types of loads is a rather urgent, but logically unfinished problem.

Keywords: structurally anisotropic shell, potential deformation energy, self-supporting skeleton, cavity-forming liners, stress-strain state.

Abbreviations:

FEM is finite element method,

PDE is potential deformation energy,

PDED is potential deformation energy density,

SSS is stress-strain state.

Introduction

The design and implementation of enclosed micro-architectural forms represent a salient and pressing concern within contemporary environmental design. This discourse specifically addresses the development of ground-level modular protective shelters engineered to serve as critical infrastructure for the mitigation of blast wave and shrapnel-induced trauma. Such structures are conceived for strategic integration within public nexus points, encompassing transportation termini, designated recreational areas, urban civic spaces, and other open-air gathering locations across diverse residential and commercial landscapes.

Previously scientific studies of the influence between explosion parameters and enclosing structures were conducted (*Ansys simulation software…, n.d.*; *Babaev et al, 2016*; *Bugaevskij, 2015*; *Cormie et al., 2009*; *DBN…, 2023*; *Haponova et al. 2018*). Demonstrating the idea of modeling the stress-strain state of complex objects, it is impossible not to quote Perelmuter: "The work of the supporting structure is largely determined by the shoulder of the internal pair. In a sphere, it is equal to the distance between the belts, in an arch to the distance from the lock to the tightening, in a dome approximately to the distance between the top and the support ring. And what is the shoulder of the internal pair in a shell of double curvature on a rectangular plan?

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[a] Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department Head, Department of Computer Graphics, Kharkiv National Automobile and Highway University. Kharkiv, Ukraine.

The answer to this question requires an understanding of the structure's operation "as a whole", which is in many ways the opposite of the practiced detailed SSA. Such analysis is aimed at studying the details (finding stress peaks, places with maximum deflections, etc.)." (*Perelmuter, 2013*) The finite element method is based on the discretization of the object itself, which is represented in the form of individual finite elements (*Haponova et. al. 2015*). At the same time, the introduction of direct methods into the practice of design was facilitated, on the one hand, by the ways of interpreting the very concept of "rational solution", and on the other hand, by the widespread use of the *FEM*. The concept of "rational design" was somewhat specified and transformed with the help of interesting ideas and research by Vasylkov and Shmukler (*Haponova & Hrebenchuk, 2017*). The works of Mandelbrot are devoted to modeling geometric parameters considering fractal theory (*Horodeckij et al., 2003*). Anisotropy is distinguished by the following parameters:

1) elastic properties;
2) elastic limits, yield strength, other properties determined in the area of small plastic deformations;
3) characteristics of significant plastic deformation (strength limit in the presence of a neck, uniform plasticity, etc.);
4) characteristics associated with destruction (characteristics of fracture resistance under various types of loading, ultimate plasticity, etc.).

There is a certain distinction between anisotropy of characteristics determined under static loads, anisotropy of long-term strength and creep, anisotropy of impact toughness, crack resistance, hardness and microhardness, etc. By structural feature, anisotropy can be homogeneous and heterogeneous, caused by oriented residual microstresses or associated with the features of the dislocation structure. Many metallic materials are quasi-isotropic in the elastic and plastic areas, as well as during fracture by shear, but anisotropic in resistance to tearing. In sheet materials, a distinction is made between "planar" and "normal" plastic anisotropy. The first is determined by the dependence of the characteristics on the direction in the plane of the sheet, the second is determined by the difference between the properties in the plane of the sheet and the direction perpendicular to it (through the thickness). By geometric nature, a distinction is made between rectilinear and curvilinear anisotropy.

The scientific novelty of the study lies in the development and implementation of an energy-based methodological framework for rationalizing the design parameters of reinforced concrete structurally anisotropic shells with complex geometry. For the first time, the author formulated a numerical optimisation model that establishes dependencies between the *PDE* and the geometric parameters of both external and internal structure elements under the condition of a constant material volume. The research introduces a vector of control parameters combining external (lifting boom height, curvature radius, span, load) and internal (rib pitch, rib and skin thickness, cross-section height) variables, enabling the identification of rational configurations that minimise *PDE*.

A distinctive innovation is the integration of the *FEM* with parametric modelling tools (*LIRA SAPR*, Autodesk Revit, Dynamo) for automated generation, computation, and optimisation of shell geometry. This approach allows simultaneous evaluation of the structure's *SSS* and modal characteristics, verifying energy efficiency through natural frequency analysis.

Furthermore, the study proposes a technological solution using in-situ concreting with cavity-forming liners to create self-supporting anisotropic frameworks, reducing weight and improving structural resilience.

Thus, the novelty of the work consists in combining energy-rational design criteria, computational modelling, and construction technology into a unified system for optimising reinforced concrete anisotropic shells intended for both civil and protective infrastructure.

The subject of the study is the process of rationalisation and optimisation of design parameters of reinforced concrete structurally anisotropic shells—including their geometric configuration, material anisotropy, and deformation energy characteristics—under static and dynamic loading conditions, based on the application of the energy principle and finite element modelling.

The object of the study is reinforced concrete constructively anisotropic structure.

The study aims to rationalize the design parameters of reinforced concrete constructively anisotropic structures.

To achieve the purpose, the following objectives were defined:

- obtaining dependencies between the *PDE* and the geometric parameters of constructively anisotropic structures;
- improving the technology of erecting a cylindrical shell;
- cutting out a cavity-forming liner for a self-supporting frame;
- a numerical experiment of a constructively anisotropic structure's behavior when exposed to a uniformly distributed snow load of 1600 Pa/m^2 and a concentrated load of 1t/m^2.

Study tools are *LIRA* software complex, Autodesk software products, etc.

Methods

The study employs a multi-level methodological framework combining theoretical, numerical, and experimental approaches to rationalise the design parameters of reinforced concrete structurally anisotropic shells.

At the theoretical level, the research is grounded in the *energy principle* of structural mechanics, assuming that within a system of constant material volume and fixed boundary conditions, the *PDE* attains a minimum at an optimal set of geometric parameters (*Shmukler, 2017*). This principle guides the analytical formulation of the problem, represented as a dependency function between the deformation energy and external or internal control parameters—such as shell height (H), curvature radius (R), rib spacing (l), skin thickness (δ), and rib thickness (Δ).

The mathematical and computational stage relies primarily on the *finite element method* (FEM) to model the *SSS* of anisotropic shells. Discretization of the structural domain into finite elements was conducted using the *LIRA SAPR* software package, which allowed the simulation of deformation fields under both uniform (snow) and concentrated loads. The mesh size and element type were calibrated according to convergence tests to ensure numerical stability. Complementary modelling was performed in *Autodesk Revit* and *Dynamo* environments, where visual programming scripts were written to parametrically vary geometric inputs and automatically regenerate shell models.

To validate the energy criterion, the study introduced a parametric control vector containing external (H, B, R, L, q) and internal (l, δ, Δ, h) parameters. By stepwise variation of the lifting boom height (H) and rib pitch (l) under a constant material volume, multiple computational experiments were executed. Each variant produced a unique *PDE* value, and the resulting unimodal dependency curve was used to determine the rational parameter combination where the *PDE* reached its lower limit.

The engineering-technological methods included the *in-situ concreting technique*, where cavity-forming liners made of polystyrene were applied to create internal voids in the shell, forming a self-supporting skeleton. This approach ensured the integrity of anisotropic ribs while reducing structural weight. The resulting concrete class was C25/30, meeting current European standards for protective infrastructure.

Additionally, the analytical and experimental validation involved comparison of natural frequency spectra for shells with different geometric configurations. Modal analysis confirmed that the rational configuration ($H \approx 3.8$ m) corresponded to the lowest *PDE* and highest structural stiffness, thus ensuring the resonance safety of the system.

Finally, the data interpretation stage involved integrating numerical outputs into graphical and tabular forms. The deformation and potential energy fields were visualised as colour-mapped contour plots, providing insight into the uniformity of stress distribution across the shell surface. These results substantiate the theoretical premise that structural rationalisation leads to improved energy efficiency and mechanical resilience.

Literature Review

The theoretical foundation of rationalizing reinforced concrete structural-anisotropic shells has evolved through decades of research in structural mechanics and computational modelling. The central idea rests on the energy principle, which postulates that a rational configuration of geometric parameters minimises the *PDE* for a structure of constant material volume and boundary conditions (*Shmukler, 2017*). This principle serves as a critical tool in optimising geometrically complex shell systems where the *SSS* must remain stable under variable static and dynamic loads (*Perelmuter & Slivker, 2011*).

Early analytical models of stress–strain behaviour in curved and spherical roof shells (*Babaev et al., 2016*) revealed that structural performance largely depends on the "internal pair shoulder", i.e., the distance between load-bearing belts and support points, which dictates deformation energy distribution. Later studies refined this understanding using *FEM* discretization, allowing accurate simulation of anisotropic materials with heterogeneous stiffness (*Horodeckij et al., 2003*). The integration of *FEM* with parametric design software such as *LIRA SAPR* and Autodesk Revit enabled automatic generation and evaluation of shell geometry (*Kalmykov et al., 2017a*).

Fractal geometry (*Mandelbrot, 2002*) further contributed to the understanding of multi-scale surface anisotropy, providing mathematical tools to simulate non-uniform stiffness patterns in curved elements. This approach supports the structural concept of "constructive anisotropy", where directional material properties enhance energy dissipation and load redistribution. Haponova and Hrebenchuk (*2018*) expanded on this by developing information-modelling frameworks that link *PDE* analysis to geometric parameters, making it possible to rationalise shell design digitally.

Experimental studies have confirmed that reinforced concrete anisotropic shells demonstrate superior mechanical stability under combined static and dynamic effects when geometric parameters—such as curvature radius, rib pitch, and shell thickness—are selected according to energy criteria (*Haponova & Hrebenchuk, 2017*; *Kalmykov et al., 2017b*). Further numerical analyses, including studies by Romashkina et al. (*2024*), showed that dynamic load simulations based on blast-wave propagation validate the robustness of rationalised designs in protective engineering contexts.

International standards (*Structures to Resist…, 2008*; *DBN…, 2023*) emphasise the necessity of protective structures capable of absorbing and dispersing energy from accidental or deliberate explosions. The adaptation of these requirements to civil architecture highlights the interdisciplinary importance of anisotropic shell systems as both structural and protective solutions. Consequently, the integration of computational tools, experimental validation, and energy-based optimisation establishes the methodological basis for rational design of reinforced concrete structurally anisotropic shells (*Perelmuter, 2013; Shmukler, 1977*).

Results

Directions for Rationalization of Reinforced Concrete Constructively Anisotropic Structures' Parameters

Modeling of the stressed-deformed state, geometricity of parameters taking into account the energy principles of anisotropic shells, considered in the number of prominent research papers (*Haponova, & Hrebenchuk, 2018*; *Kalmykov et al., 2017a*; *Kalmykov et al., 2017b*; *Mandelbrot, 2002*; *Perelmuter, 2013*; *Perelmuter & Slivker, 2011*; *Romashkina et al., 2024*; *Shmukler, 1977*; *Shmukler, 2017*; *Structures to Resist…, 2008*; *The Design of Structures…, n.d.*).

Whereas in the current study a fundamentally new type of structure has been investigated, which has a given external and calculated internal geometry; the process of a structurally anisotropic shell deformation under various types of external and internal influences has been mathematically modeled. Shmukler in his work (*2017*) noted that "for the regulation of systems with a constant volume of material, the number of external and internal connections (external parameters) under the action of a static external load (self-weight) the *PDE* after restructuring reaches the lower limit at a rational combination of the values of geometric parameters":

$$U = inf_\alpha U(\alpha^k), k = 1, 2, \dots \infty \qquad (1)$$

where

U is stands for PDE;

k is comparison option number $\alpha \in M$;

M is set of permissible values of external geometric parameters.

The implementation of the approach entails the construction of a relationship between the magnitude of the system's deformation energy and one or a group of geometric parameters. The formulation of such a problem in numerical form is possible when using computational software complexes, however, the operation entails the construction of a significant number of models, which to some extent complicates the process.

Thus, the formulation and implementation of rationalizing the structural parameters of reinforced concrete cylindrical shells is presented. The criterion for this problem is the energy

principle, according to which it is considered that out of the entire set of possible values of the search parameters of the system with a constant volume of material, the number of external and internal connections, the *PDE* after the restructuring reaches the lower limit at a rational combination of the values of the geometric parameters of the described system.

The vector of control parameters of this system is introduced into consideration:

$$\{x\}^T = \{H, B, V, R, L, l, q, \delta, \Delta, h\} \tag{2}$$

where

H stands for lifting boom;

B is shell length;

V is volume of material;

R is curvature radius;

L is shell span;

l is rib pitch;

q is external load;

δ is thickness of the skins;

Δ is thickness of the ribs;

h is shell cross-section height.

In this case, the parameters H, B, R, L, q are positioned as external, and the parameters l, δ, Δ, h as internal. The step of the inner ribs of the shell l is taken as variable parameters. The remaining attributes of the calculation model are set by analogy, with the exception of the thickness of the skin δ, which in this case is taken equal to 50 mm, and the lifting boom H, taken as 3.8 m. The constancy of the material volume in this case was ensured by selecting the appropriate value of the thickness of the ribs Δ.

Thus, the proposed approach opens up the possibility of determining rational parameters of reinforced concrete structurally anisotropic elements with complex external and internal geometry. The above analysis is expanded by studying the distribution of the strain energy density (internal parameter). In this case, the criterion will be the dependence:

$$e \rightarrow const, \tag{3}$$

where

e is the *PDED*.

The alignment of the *PDE* field (*LIRA* software package) is implemented by giving the cavity-forming insert a complex shape. In this case, the grid of ribs is not orthogonal. The potential energy density field of the ribs in a cylindrical shell with a span of 9000 mm is shown in Figures 1–4 (*Appendix*).

Improving the Structural Characteristics of Constructively Anisotropic Structures

The work implements numerical methods for solving the problem using the example of a cylindrical shell with internal cavities of a rectangular shape in plan (*Figure 5*). An analysis of studying the external parameters of a cylindrical reinforced concrete anisotropic shell with internal cavities formed by polystyrene foam inserts (*Figure 6*) has been performed.

As a tool for solving the problem, a combination of Autodesk software products was used. The fundamental issue here is a script written in a visual programming environment, which

allows you to automatically form the geometry of the shell by setting all the necessary parameters from the number $\{x\}$.

The proposed procedure allows you to automatically build a connection between the *PDE* of the system and any geometric parameter that describes it. As an illustration, examples of searching for external and internal rational parameters of the shell are considered.

When analyzing external parameters, the lifting boom is taken as a variable $H \in (H\,[0;\,L/2])$, other parameters describing the geometry of the system are taken as follows: $B = 9000$ mm; $L = 18000$ mm; $h = 300$ mm, $\Delta = 100$ mm; $l = 1000$ mm. The load was taken as the self-weight, the support was designed as hinged fixed along two longitudinal ribs, the material was concrete C25/30. Stepwise change of the parameter H (lifting boom) allowed it to determine its relationship with the value of the system *PDE*, while in all cases the volume of the shell material was unchanged. Stability was ensured by selecting the appropriate value of the shell thickness δ. The calculation results are given in Table 1 (*Appendix*).

Based on the obtained data, a graph of the dependence of the *PDE* on the lifting boom H was constructed, which represents a unimodal function. It was determined that for the tasks of conditions at $H \approx 3{,}8$ m the *PDE* reaches the lower limit. The obtained results are verified by analyzing the natural frequencies of the system for all values of H and estimating the maximum load-bearing shell capacity (q_{max}). The 7 out of 10 tons of natural oscillations take on a maximum value at a value of H close to rational.

In case of achieving equivalent stresses of the system (σ_e) the strength limit of the material is determined—q_{max} for the optimal value H_i values, 1 m more or less than the rational (4,8 and 2,8 m respectively): at $H = 3{,}8$ m and $q_{max} = 38{,}45$ kN/m²; at $H = 4{,}8$ m and $q_{max} = 35{,}15$ kN/m²; at $H = 2{,}8$ m and $q_{max} = 30{,}26$ kN/m².

The natural frequencies of structurally anisotropic shells are shown below in Figures 7–10 (*Appendix*).

Discussion

The study addresses an increasingly urgent challenge in structural engineering and civil protection—developing lightweight yet resilient reinforced concrete shells optimised through energy-based criteria. The significance of this study lies in its synthesis of classical mechanics, computational modelling, and protective design principles to achieve rational geometrical configurations for structurally anisotropic systems.

The findings confirm the hypothesis that structural rationalisation based on the minimisation of *PDE* produces configurations with enhanced stiffness and stability under both static and dynamic loads. The discovered rational parameters (e.g., $H \approx 3.8$ m, $l \approx 1000$ mm) correspond to conditions where *PDE* attains its minimum and the natural frequencies reach their optimal values, thereby improving both energy performance and vibration safety.

However, the research also revealed several methodological challenges. The high computational complexity of modelling anisotropic shells with variable geometry necessitates extensive simulation runs and fine mesh refinement, which may increase processing time and require advanced software integration. Furthermore, the assumption of homogenous material

behaviour within anisotropic systems introduces limitations when scaled to real-world structures, where micro-heterogeneity and construction tolerances affect performance.

Another identified issue concerns the practical realisation of cavity-forming liners. While polystyrene inserts effectively reduce weight and ensure geometric stability, their long-term durability under cyclic loading and environmental influence warrants further investigation. Future research should thus focus on developing alternative eco-friendly liner materials and improving the recyclability of such components.

The study opens several promising research directions. First, extending the *FEM*-based framework to include *nonlinear dynamic analyses* could provide more accurate simulations of blast-wave impacts and seismic responses. Second, integrating *machine-learning algorithms* for parameter optimisation may significantly reduce computational effort. Finally, collaboration with industrial partners could facilitate pilot construction of modular anisotropic shelters for civil defence and urban safety applications.

Overall, this work contributes to advancing energy-based design methodologies for complex shell systems and underscores their critical role in creating adaptive protective structures in the context of modern geopolitical and environmental challenges.

Conclusion

The energy criterion for rationalization of external structural parameters of reinforced concrete structurally anisotropic shells was applied. According to the results of the study, it was determined that for the considered specific conditions at $H \approx 3.8$ m the potential energy of deformation reaches the lower limit.

The obtained results were verified by analyzing the frequencies of natural oscillations of the system for all values of the lifting boom (H) and the maximum bearing capacity (q_{max}) of the shell was estimated.

The relationship of rational parameters in the structurally anisotropic shell between the PDE of the system for external and internal rational parameters was determined: at a rib pitch close to $l \approx 1000$ mm the *PDE* reaches the lower limit.

And there is currently a substantial demand for these. In response to the current geopolitical landscape, specifically the unprovoked military aggression by the Russian Federation against Ukraine, there is an urgent and critical need for enhanced protective infrastructure. This imperative has driven significant improvements in the technologies underpinning small-scale architectural forms, leading to the creation of compact, ground-based modular shelters. These structures are engineered to provide civilians with vital protection against the traumatic effects of blast waves and shrapnel. Their strategic integration into high-traffic public environments—including public transportation points, recreational parks, urban plazas, and various open communal spaces within both population centers and industrial territories—represents a timely and essential intervention for safeguarding the populace of our country and its cities.

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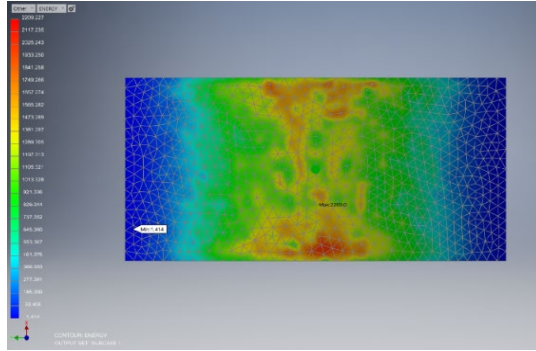
Appendix

Figure 1. The potential energy density field of the shell ribs, depending on the pitch with a span of 9000 mm with a boom height of 2250 mm, rib pitch of 500 mm and rib thickness of 50 mm.
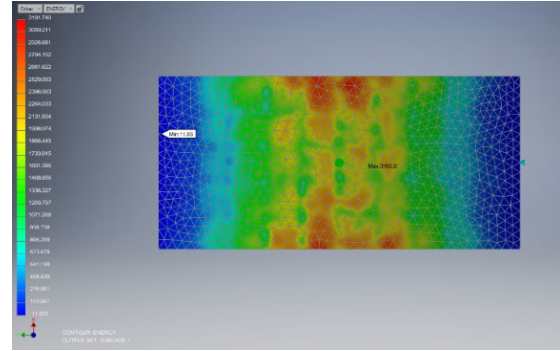

Figure 2. The potential energy density field of the shell ribs, depending on the pitch with a span of 9000 mm with a boom height of 2250 mm, rib pitch of 2000 mm and rib thickness of 166.9 mm.
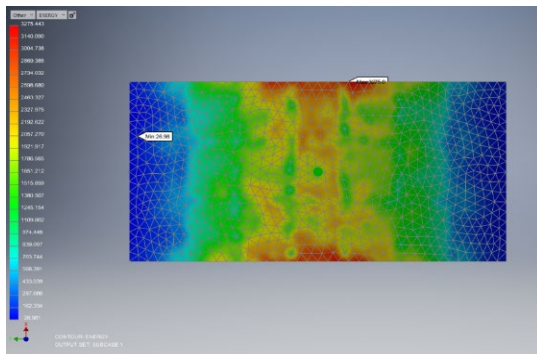

Figure 3. The potential energy density field of the shell ribs, depending on the pitch with a span of 9000 mm with a boom height of 2250 mm, rib pitch of 2000 mm and rib thickness of 241.1 mm
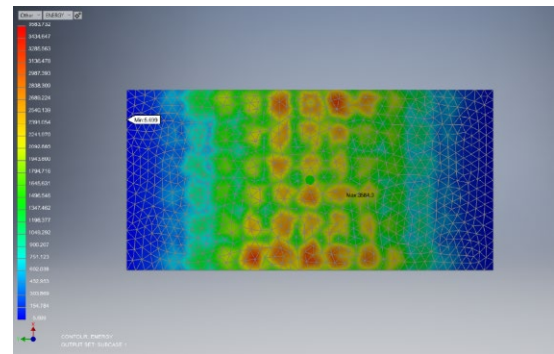

Figure 4. The potential energy density field of the shell ribs, depending on the pitch with a span of 9000 mm with a boom height of 2250 mm, rib pitch of 1500 mm and rib thickness of 137.7 mm
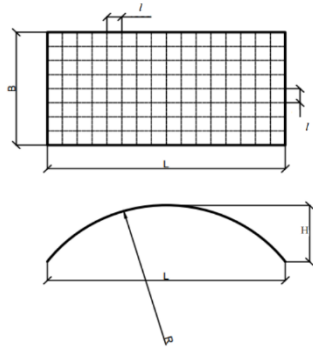
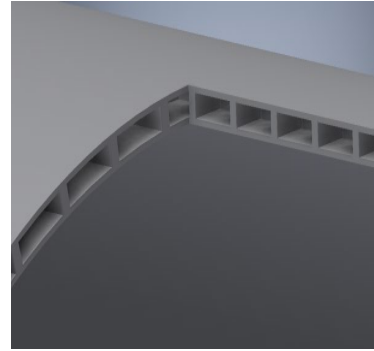Figure 5. Geometric parameters of the structurally anisotropic shell

Figure 6. Structurally anisotropic shell made of reinforced concrete

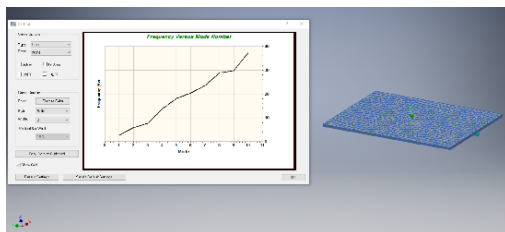Figure 7. Natural frequencies of a structurally anisotropic shell with a plan size of 9000×10 mm
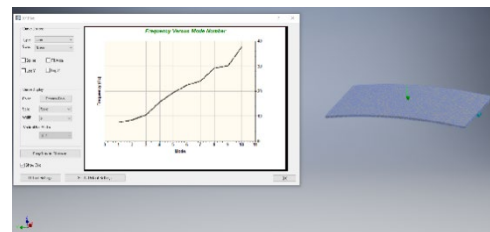

Figure 8. Natural frequencies of a structurally anisotropic shell with a plan size of 9000×1000 mm
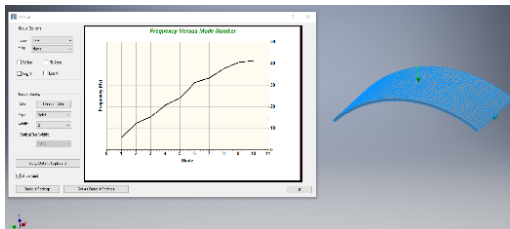

Figure 9. Natural frequencies of a structurally anisotropic shell with a plan size of 9000×3500 mm
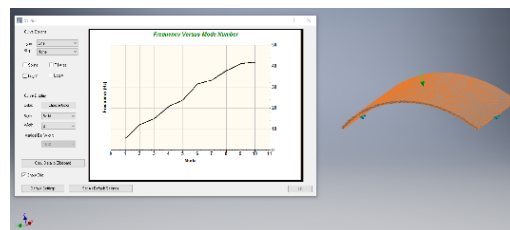
Figure 10. Natural frequencies of a structurally anisotropic shell with a plan size of 9000×3600 mm

Table 1. Calculation results

Lifting boom H, m	Volume of material V, m³	Curvature radius R, m	Thickness of skins δ, m	Arc length, m	PDE systems U, per unit
0	22,8915	∞	0,0506	18,0000	5,75E + 06
1	22,8915	41	0,0500	18,1478	4,87E + 05
2	22,8915	21,25	0,0473	18,5869	1,30E + 05
3	22,8915	15	0,0450	19,3050	7,57E + 04
4	22,8915	12,125	0,0407	20,2839	6,93E + 04
5	22,8915	10,6	0,0357	21,5010	9,38E + 04
6	22,8915	9,75	0,0315	22,9321	1,55E + 05
7	22,8915	9,285	0,0271	24,5530	2,83E + 05
8	22,8915	9,0625	0,0224	26,3408	5,77E + 05
9	22,8915	9	0,0187	28,2743	1,12E + 06

Volodymyr I. Oleksyn [a][13]

Integration of Modern Standards for Design Documentation Formatting into the Educational Process and Industrial Practice for Circuit Diagrams [10]

Abstract:

The article examines the urgent issue of Ukraine's transition from the outdated ESKD system (Unified System for Design Documentation) to modern international IEC (International Electrotechnical Commission) standards in the field of design and electrotechnical documentation. This transition represents an important stage in the process of European integration and the digital transformation of technical education and industry. The study analyzes the regulatory and technical documents traditionally used in Ukraine for creating electrical diagrams, including GOST 2.102, GOST 2.701, GOST 2.702, GOST 2.710, and GOST 2.721, and identifies their modern international counterparts: SSU EN 61355–1:2022 (IEC 61355–1:2008), SSU EN 61082–1:2022 (IEC 61082–1:2014), SSU EN IEC 81346–1:2022 and SSU EN 81346–2:2022 (IEC 81346–1:2022, IEC 81346–2:2019), and SSU IEC 60617:2018 (IEC 60617:2012 DB). A systematic comparison of their provisions has been carried out, highlighting the key differences and advantages of adopting IEC standards in modern technical design. It has been established that the transition to IEC standards ensures the unification of approaches to classification, identification, and graphical representation of elements, creating a functional-structural model of the object compatible with modern CAD/CAE systems. The article emphasizes the importance of implementing these standards in engineering education to prepare future specialists for work in an international digital environment. It demonstrates that the integration of IEC standards promotes the digitalization of technical documentation, enhances transparency, and ensures international compatibility of electrotechnical projects. It is concluded that the implementation of IEC standards in national education and industrial practice is a strategic direction for the development of Ukraine's engineering culture. This will enable the creation of a unified information ecosystem for technical documentation, ensure digital integration with international systems, enhance the competitiveness of Ukrainian engineers in the global labor market, and facilitate the effective transition to digital manufacturing in line with the principles of Industry 4.0.

Keywords: electrical circuit, element, standard, documentation, IEC, State Standard of Ukraine.

Abbreviations:

DCC is Document Kind Classification Code,

IEC is International Electrotechnical Commission,

ISO is International Organization for Standardization,

SSU is State Standard of Ukraine,

USDD is Unified System for Design Documentation (ESKD),

USTD is Unified System for Technological Documentation.

Introduction

In the context of the active process of European integration, Ukraine is aligning not only its legislation but also its standards. This is confirmed by the relevant orders of state authorities (*On the package adoption…, 2022*), according to which certain SSUs based on old Soviet standards

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[a] Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Computer graphics, Kharkiv National Automobile and Highway University. Kharkiv, Ukraine.

have already been repealed, while those still in force have a limited validity period. Moreover, around 20,000 new ISO standards have been introduced. Among them are standards regulating the development of design documentation, replacing the outdated USDD/ESKD system, which can be accessed on the Budstandart portal (*Budstandart Document Service, n.d.*).

Considering the above, and in the current conditions of technological development, the integration of international standards for the preparation of design documentation into the educational process and industrial practice has become particularly relevant. In particular, in electrical engineering and automation, electrical schematic diagrams are a key element of technical communication between designers, manufacturers, and maintenance services. The implementation and use of international standards ensure the unification of graphic symbols, the structuring of functional elements, and the improvement of the accuracy of schematic interpretation. This contributes not only to enhancing the quality of future engineers' training but also to adapting Ukrainian enterprises to the requirements of the international market.

Continuing the process of integrating modern standards for the preparation of design documentation into education and industrial practice, this article focuses on creating electrical diagrams in accordance with the new requirements. The main standards and existing differences between the newly introduced and repealed regulatory documents will be examined.

Thus, the systematic implementation of modern standards for electrical schematic design into educational programmes and production processes is an important step toward technical compatibility, digitalisation, and professional mobility of specialists.

Literature Review

Within the framework of the study, a search and critical analysis of new textbooks and teaching aids published in Ukraine in recent years (*Vanin et al., 2018*; *Hlushko, 2019*; *Kovbashyn & Pik, 2023*), concerning the rules for preparing design documentation, were conducted. It was established that most of them do not take into account recent amendments to regulatory standards and remain oriented towards the use of the USDD/ESKD system.

The situation in enterprises is even more conservative. Over the past 30 years, the requirements for preparing design documentation have hardly changed, particularly in enterprises operating in the domestic market. Typically, such enterprises have their internal standards or regulations based on USDD/ESKD, USTD, and other outdated standards. This attitude is understandable, since their main priorities are indicators such as cost, quality, and competitiveness, while internal design documentation management is considered of secondary importance. Considering that the implementation of new standards or compliance of documentation with international standards is always associated with additional expenses, only those enterprises that enter new sales markets for their products are willing to take such steps.

Active work on implementing modern international standards into the educational process—and consequently into production—is being performed by Prof. O.V. Chernikov. In his publication (*2024*), he raises the pressing issue of the necessity of transitioning the educational process to new international standards. As part of this transition, new ISO-compliant templates have been developed for drawings with updated title blocks and specification sheets. Active work is also underway to create a library of fasteners according to the updated SSU standards, based on existing ISO and DIN standard libraries. It is important

to note that all these developments are not merely formal but serve as practical add-ons to Autodesk software products (AutoCAD, Inventor, Fusion), which students actively use in the educational process. Other works (*Chernikov et al., 2021*; *Chernikov et al., 2023*) describe the automation processes in Autodesk Inventor and the depiction of views on drawings according to the standards.

Based on the analysis of the publications, it can be concluded that the process of integrating modern standards for preparing design documentation into the educational process is a highly relevant task, and that work in this area has only just begun. This is especially important for educational institutions subordinated to state authorities, since at the state level the implementation of new international standards has already taken place, and compliance with them will soon become a key requirement.

Results

Main Documents Commonly Used for Creating Electrical Schematics:

- GOST 2.102–68 USDD/ESKD. Types and Completeness of Design Documents;
- GOST 2.701–84 USDD/ESKD. Schematics. Types and Categories. General Requirements for Execution;
- GOST 2.702:2013 Unified System for Design Documentation. Rules for the Execution of Electrical Schematics (GOST 2.702–2011, IDT);
- GOST 2.710–81 Letter-Numeric Designations in Electrical Schematics;
- GOST 2.721–74 USDD/ESKD. Graphical Symbols in Schematics. General-Purpose Designations.

This list is not exhaustive and can be extended, but it provides a general idea of the key aspects. Considering that some of the listed standards have already lost validity in Ukraine and others will soon become obsolete, a reasonable question arises: which standards should be used? Services such as *Budstandart* do not provide direct recommendations on which standards to transition to, most likely because there are no direct equivalents in terms of document content.

Given the process of European integration, it becomes clear which international standards should be implemented and applied. One such example is the recent adoption of European approaches to defining power-quality parameters, in particular, the transition to a nominal voltage of 230/400 V (*European voltage and new standards…, n.d.*). Issues related to standardisation in the field of electrical, electronic and related technologies are managed by the IEC, of which Ukraine has been a member since 1993 (*International Electrotechnical Commission, n.d.*). Therefore, it is advisable to use IEC standards for developing electrical schematics.

The types, categories, and codes of design documentation familiar to us—e.g., CA (circuit diagram), LA (parts list), LCC (connection list), CC (connection diagram, wiring or installation schematic), MA (electrical installation drawing), or TST (test programme and methodology)— as proposed in GOST 2.102–68 and GOST 2.701–84, should now be classified and designated using SSU EN 61355–1:2022 *Classification and Designation of Documents for Plants, Systems and Equipment. Part 1: Rules and Classification Tables* (EN 61355–1:2008, IDT; IEC 61355–1:2008, IDT).

The essence of this standard is to define a structured document-classification system based on content and form of presentation. Its goal is to ensure unified document identification throughout the entire life cycle of technical objects. The main provisions are as follows:

- defines the concept of a "document kind" as a type characterised by the content of information and its form of presentation;
- introduces DCC enabling systematic document organisation;
- covers both technical and non-technical documents, including drawings, schematics, specifications, instructions, protocols, reports, etc.;
- applies to the preparation, exchange, management, and archiving of documentation among project participants.
- The DCC code consists of three letters with specific logical meaning:
- the first letter indicates the document group and its general type (e.g., schematic, list, installation, instruction);
- the second specifies the main sub-category within the group (e.g., principal schematic, wiring schematic, installation schematic);
- the third (optional) provides additional classification, detailing, or specific purpose (e.g., detailed, functional, test).

According to IEC 61355–1, new types and categories of certain designations are presented in comparative Table 1 (*Appendix*).

Thus, the transition from obsolete USDD/ESKD standards (GOST 2.102–68, GOST 2.701–84) to the international standard SSU EN 61355–1:2022 (IEC 61355–1) enables the structuring of design-documentation classification under unified rules. The use of DCC codes provides unified document identification regardless of industry, promotes digital data integration, simplifies information exchange between departments, and enhances compatibility with modern CAD/CAE systems.

The SSU GOST 2.702:2013 standard regulating the rules for electrical-schematic preparation can be replaced by SSU EN 61082–1:2022 *Preparation of Documents Used in Electrotechnology. Part 1: Rules* (EN 61082–1:2015, IDT; IEC 61082–1:2014, IDT). Both documents pursue similar goals—regulating the drafting of electrotechnical documentation, particularly schematics—but they are not fully equivalent, and direct substitution requires adaptation.

The main differences primarily involve the use of corresponding standards that affect the overall layout. It is worth noting that IEC 61082–1 has a more flexible adaptation system—from sheet-format sizes to element notation and placement—facilitates address-based schematic creation, and represents a digitally oriented standard ensuring scalability and international compatibility, especially in digital environments.

Hence, replacing SSU GOST 2.702:2013 with SSU EN 61082–1:2022 is a step toward a modern, digitally oriented system for preparing electrotechnical documentation. IEC 61082–1 provides flexibility in schematic design, supports international interoperability, and meets the requirements of computer-aided design, whereas the outdated GOST standard retains limitations inherent to paper formats and obsolete methodologies.

The GOST 2.710–81 standard, which governs alphanumeric designations in electrical schematics, should be replaced by SSU EN IEC 81346–1:2022 *Industrial Systems, Installations, Equipment and Industrial Products—Structuring Principles and Reference Designations. Part 1: Basic Rules* (EN IEC 81346–1:2022, IDT; IEC 81346–1:2022, IDT) and SSU EN 81346–2:2022 *Industrial Systems, Installations, Equipment and Industrial Products—Structuring Principles and Reference Designations. Part 2: Classification of Objects and Codes for Classes* (EN 81346–2:2019, IDT; IEC 81346–2:2019, IDT).

When examining the first part of the standard using simple schematic examples, at first glance, the structure of compound alphanumeric designations appears nearly identical. However, in more complex, structured schematics, the USDD/ESKD standard fails to define a clear identification structure, coding format, or inter-level relationships, resulting in enterprise-specific interpretations.

In contrast, IEC 81346–1 follows a functional-structural approach at all levels, offering a clear methodology and syntax for combining levels within a unified code, transforming them into a universal, digitally readable identification model. This allows integration of schematics, structures, databases, and documents into a single system.

The second part of the standard, dealing with the classification of objects and class codes, presents more differences. The primary distinction lies in the classification of designations: in USDD/ESKD, these are element-type groups where letters form part of the symbolic designation (e.g., K—contactor, SB—button, FU—fuse). In IEC 81346–2, these are classes and subclasses where the first letter is a class code defining the element's function within a system (K—switching device, Q—circuit breaker, F—protective device), and the second letter specifies type or principle of operation within the base class (KM—power contactor, QF—load circuit breaker, FU—fuse). A third letter or digit may be added for deeper detailing, allowing classification of specific device families or serial numbering within a product.

Certain designations, such as C (capacitor), R (resistor), L (inductance coil), M (motor), and several others, coincide, while others differ slightly. Such similarity and grouping are logical since GOST 2.710–81 was originally based on IEC recommendations of the 1960s–70s. Over time, the IEC standard evolved substantially with scientific and technological progress, while GOST 2.710–81 remained a closed system.

Occasionally, electrical schematics feature other non-IEC designations, e.g., CB (circuit breaker) or TB (terminal block), which are English-language functional abbreviations borrowed from North American standards. According to IEC, their respective designations are QF and XT.

Thus, replacing GOST 2.710–81 with SSU EN IEC 81346–1:2022 and SSU EN 81346–2:2022 ensures a shift from the outdated alphanumeric-designation system to a modern functional-structural object-identification model. IEC 81346 standards establish clear coding rules reflecting functional, locational, and product interrelations, enabling detailed class and subclass specification and ensuring unification, scalability, and digital compatibility with international design systems.

Regarding the graphical symbols in electrical schematics—standardised by GOST 2.721–74 USDD/ESKD *Graphical Symbols in Schematics. General-Purpose Symbols* and related standards (number range 721–769 of USDD/ESKD) covering graphical symbols for groups of electrical

devices from motors, switching and protection equipment to semiconductors and communication devices—it is advisable to use IEC 60617:2018 *Graphical Symbols for Diagrams* (IEC 60617:2012 DB, IDT).

This standard is one of the fundamental documents for electrotechnical design, defining a unified system of graphical symbols used in electrical, electronic, automation, and telecommunication diagrams. It includes 10 main groups covering all types of electrical elements—from basic symbols to telecommunication systems. The standard currently contains about 1,900 symbols (compared to about 600 in USDD/ESKD) and is continuously updated. Each symbol has its Sxxxxx code, description, reference to IEC 81346 (class of element), and an SVG graphic file. The standard is available in the electronic database IEC 60617 DB (*Graphical Symbols for Diagrams, n.d.*). The main groups of the standard are presented in Table 2 (*Appendix*), each subdivided by device type and subgroup.

Hence, the transition from GOST 2.721–74 to SSU IEC 60617:2018 ensures the use of a globally unified system of graphical symbols encompassing all types of electrical, electronic, and telecommunication elements. IEC 60617 contains over 1,900 current symbols, supports digital formats, and aligns with IEC 81346, making it a foundation for modern schematic design within CAD/CAE environments and ensuring international documentation compatibility.

It is also worth noting that the aforementioned standards are implemented in engineering platforms such as EPLAN, AutoCAD Electrical, SEE Electrical, and SolidWorks Electrical. Therefore, using these programmes enables the creation of electrical schematics in compliance with the international IEC standard and other regional regulations.

Discussion

The integration of international IEC standards into the system of preparing electrical engineering documentation is not only a demand of the time but also a key prerequisite for enhancing the competitiveness of national production. An analysis of the presented documents shows that the transition from the USDD/ESKD (GOST) system to the IEC 61082, IEC 61355, IEC 81346, and IEC 60617 series of standards does not imply a mechanical replacement of drafting rules, but rather a transformation in the very philosophy of technical documentation development.

From the perspective of the educational process, such integration requires a revision of curricula. Students should not merely learn drawing rules but should master systems thinking, where a schematic is not a static illustration but an integral part of a product's information model.

Ultimately, the transition to IEC standards not only modernises design documentation but also paves the way for the complete digitalisation of design processes, unification of data exchange between enterprises, and international interoperability. However, the process requires methodological support, official translation and adaptation of terminology, as well as the training of specialists capable of working simultaneously within the IEC, ISO, and USDD/ESKD environments.

Conclusion

The analysis of the evolution of design documentation standards has shown that the USDD system, represented by GOST 2.701, 2.702, 2.710 and others, no longer meets the requirements of digital and international engineering. The international IEC standards—specifically series IEC 61082, IEC 61355, IEC 81346 and IEC 60617—offer a modern, structurally and functionally coherent system for describing technical objects. This system is oriented toward digital design, automation, and product lifecycle management, where:

- IEC 61082–1 provides digitally oriented rules for the preparation of electrical diagrams, enables scaling and automated generation of addressing systems, which makes it adaptable to modern CAD/CAE platforms;

- IEC 61355–1 introduces a DCC system that allows for the integration of design, technological, and operational documentation into a single information base;

- IEC 81346–1 and IEC 81346–2 define the principles of object identification and classification according to functional, positional, and product-related aspects, forming the basis for a universal object model suitable for machine processing;

- IEC 60617 provides a globally unified system of graphical symbols for diagrams that covers modern elements of electronics, automation, and telecommunications, with dynamic updates via the IEC 60617 DB database.

The transition to international IEC standards requires a comprehensive approach—adapting terminology, developing methodological recommendations for educational institutions, updating engineering curricula, and implementing engineering platforms compatible with IEC standards.

Thus, the implementation of IEC standards in national education and production practices represents a strategically important step toward creating a unified information engineering ecosystem that meets contemporary international requirements, supports the principles of digital manufacturing, and opens opportunities for Ukraine's integration into the global technical space.

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Appendix

Table 1. Comparison of document designations according to the standard USDD/ESKD and IEC
61355-1

Designation according to USDD/ESKD		Designation according to IEC 61355-1	
Code	Name in Ukrainian	Name in English	DCC Code
E3	Схема електрична принципова	Circuit diagram	CA
E4	Схема електрична з'єднань	Connection diagram	CC
ПЕ3	Перелік елементів	Parts list	LA
ТБ33	Таблиця з'єднань	Connection list	LCC
ПМ	Програма і методика перевірки	Test specification / procedure	TST
МЕ	Електромонтажний кресленик	Mounting / installation drawing	MA

Table 2. List of the main groups of element designations according to the standard IEC 60617:2012

Group Code	Name	Ukrainian Translation	Examples of Symbols
01	Basic and general symbols	Основні та загальні графічні символи	Lines, points, intersections, grounding, polarity, arrows, etc.
02	Conductors and connecting devices	Провідники та з'єднувальні елементи	Conductors, terminals, connectors, jack plugs
03	Semiconductors and electron tubes	Semiconductors and electron tubes	Diodes, transistors, thyristors, tubes
04	Passive components	Пасивні елементи	Resistors, capacitors, coils, filters
05	Production and conversion of electrical energy	Генерування та перетворення електроенергії	Sources, generators, batteries, converters
06	Switching and protective devices	Комутаційні та захисні пристрої	Switches, relays, contactors, fuses, circuit breakers

07	Measuring instruments, lamps and signalling devices	Вимірювальні прилади, лампи, сигнальні пристрої	Ammeters, voltmeters, indicators, lighting
08	Transmission, conversion and control of signals	Передавання, перетворення та керування сигналами	Amplifiers, logic elements, signal filters
09	Telecommunication, transmission and processing systems	Телекомунікаційні та обчислювальні системи	Telephony, network circuits, microprocessors
10	Miscellaneous symbols	Різні (спеціальні) символи	Symbols without category or with combined functions

Pavlo F. Budanov [a][14]

Digital Twin as the Basis of the Automated Monitoring System for the Technological Process of a Power Unit at a Power Plant [17]

Abstract:
The relevance of the research topic is determined by several important factors that are key to the modern energy sector: real-time monitoring of technological parameters of a power unit, which is critical for maintaining the reliable and uninterrupted operation of a power plant; ensuring energy security management to prevent accidents, failures, and unforeseen emergency situations for the power unit; reducing operational costs, which allows increasing the economic efficiency of power plant operations in the context of rising energy resource prices. The relevance of the research topic is defined by the need to implement digital technologies to improve the efficiency, safety, and economic viability of power unit operations at power plants. The digital twin is an integrated tool for automated monitoring and management of technological processes in a power unit, which can be integrated with various control systems, sensor data, information systems, and cyber-physical systems, creating a unified digital ecosystem for power unit management. This ensures a high level of automation, reducing human error and enhancing the efficiency of power unit operations. The object of the study is the processes of automated monitoring and management of technological processes in a power unit using a digital twin. It is shown that the digital twin of a power unit is a virtual model that reproduces the physical state and behavior of a real power unit in real-time. It combines mathematical models, control algorithms, data from sensors, and automated control systems to ensure an accurate reflection of all key energy production processes. The main functions of the digital twin are highlighted: real-time monitoring of technological parameters; optimization of technological equipment operation modes and energy consumption; diagnosis of deviations and forecasting of emergency situations; decision support at the level of automated process control systems and management systems; integration with cyber-physical systems to ensure the connection between technical and economic indicators.

Keywords: digital twin, power unit, technological process, principles and functions of the digital twin.

Introduction

Modern nuclear and thermal power plants operate under complex conditions that require a high level of control and management of technological processes. Traditional methods of monitoring, control, and diagnostics of power units, based on manual data collection and processing, do not always allow for the timely detection of deviations, prediction of emergency situations, and optimisation of equipment operating modes. The increasing load on energy systems, high demands for efficiency and operational safety, as well as the need for integration with the economic and production indicators of power enterprises, create an acute problem of ensuring comprehensive, automated, and predictive monitoring of power plant units.

The study problem lies in developing an integrated approach that enables real-time tracking of technological processes within a power unit, identification of potential risks, and maintenance of optimal operating conditions of the equipment without overloading operators or being limited by traditional automated process control systems. The main challenge consists in combining large volumes of sensor data, historical records, and control algorithms into a single

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[a] Candidate of Technical Sciences (Ph.D.), Associate Professor, Department of Electrical Engineering and Power Engineering, V.N. Karazin Kharkiv National University. Kharkiv, Ukraine.

digital model capable not only of representing the current state but also of forecasting the development of technological processes. The proposed solution is based on the concept of a digital twin of a power plant unit.

The object of the study is the processes of automated monitoring and control of technological processes in a power plant unit using a digital twin.

The study aims to develop a concept and methodology for employing a digital twin as the foundation of a system for automated monitoring, control, and diagnostics of a power unit's technological process. This system should ensure a highly accurate representation of the physical state of equipment, predict emergency situations, and optimise operating regimes.

To achieve this purpose, the following study objectives have been defined:

- analysis of the current state of the digital twin concept in relation to technological processes of energy enterprises;
- development of a structure for the digital twin of a power unit, including physical process models, mathematical control models, informational and analytical blocks, as well as an integration layer for interaction with digital systems;
- determination of the functional capabilities of the digital twin of a power plant unit;
- utilisation of the digital twin for an interactive simulator designed for operational personnel training.

The implementation of these tasks ensures a comprehensive approach to improving the reliability, safety, and economic efficiency of power unit operation, forming the basis for the further development of predictive analytics and intelligent control systems in energy enterprises.

Literature Review

Today, both domestic and international scientific publications feature studies addressing the practical use of digital twins to improve existing automated control systems for technological processes at energy enterprises. In the study of Polishchuk and Stolbov (*2024*), the feasibility of applying digital twins in combination with machine learning algorithms to enhance the efficiency of biofuel combustion processes in boiler installations was demonstrated experimentally and analytically. The use of digital simulation enables flexible optimisation of combustion parameters in real time, contributing to resource savings and emission reductions. The practical value of the study lies in demonstrating the potential for adaptive control; however, the results are tied to a specific technical base, and the limited data sample constrains their representativeness.

Dombrovska (*2023*) conducted an in-depth review of the economic aspects of digitalisation in renewable energy. The research traces the relationship between innovative technologies and the economic efficiency of the sector, highlighting the need for new business models. The strength of this work lies in the systematic presentation, yet the absence of concrete economic calculations and quantitative examples reduces its practical relevance.

In the scientific paper of Merzhynskyi et al. (*2025*), global trends in the digitalisation of the energy sector are analysed in detail. Special emphasis is placed on the scalability of solutions based on big data, cloud computing, and artificial intelligence systems. The study is significant for understanding the prospects for transnational integration of digital solutions in energy.

However, the material is descriptive and does not sufficiently address regulatory and personnel barriers, which significantly constrain the practical implementation of the proposed approaches. The authors of study (*Orobchuk et al., 2025*) conducted a comparative analysis of modern digital twin platforms, identifying their advantages and disadvantages in terms of scalability, compatibility, and standardisation. The practical significance of the study lies in the development of criteria for assessing software solutions, which may be useful for developers and enterprises. Nevertheless, rapid progress in digital technology leads to the swift obsolescence of the obtained results.

The study of Nazarenko et al. (*2024*) presents a methodology for using digital substations in the educational process through real-time simulators. The importance of the research is defined by the implementation of practice-oriented technologies in the training of future engineers. The positive aspect lies in demonstrating the integration of digital technologies into the learning process; however, the issues of scalability and financial accessibility of the equipment remain unresolved. The work of Holotsukova and Lamonov (*2024*) illustrates practical aspects of implementing digital twins, supported by examples of real engineering solutions. A substantial advantage is the focus on applied recommendations for production and management. At the same time, the authors did not sufficiently address issues of cybersecurity, data flow management, and network resilience, which are crucial in large-scale systems.

The study of Klimenko (*2025*) explores the role of digital platforms in ensuring sustainable development, particularly in the formation of local energy markets. The authors adopted an interdisciplinary approach, combining technical and socio-economic analyses. However, there are almost no examples of full-scale implementation of these technologies in industrial practice, which limits the study's practical value. The paper of Shchehlov and Morozova (*2022*) examines the challenges and opportunities of integrating digital enterprises and digital twins. An important contribution is the identification of barriers—technological, organisational, and financial—that hinder implementation. Yet the proposed solutions are largely theoretical and require validation through practical case studies. The publication of Shapurov (*2023b*) systematises methods for creating digital twins for fault-tolerant systems. The author presented a classification of approaches and developed a basic framework for analysis. Clear systematisation is a major achievement of the study, but the optimisation aspects for resource-constrained devices are only superficially described, which complicates practical application. Storoshchuk et al. (*2025*) summarise the use of digital twins in industry and logistics. A significant advantage is the analysis of existing standards, forming a foundation for technological unification. However, the recommendations are general in nature and do not consider sectoral specifics, which limits their applied value.

The study of Shapurov (*2023a*) analyses the application of Industry 4.0 technologies in change management at energy enterprises. The authors emphasise the practical orientation of the proposed approaches. However, the research lacks long-term data to assess the sustainability of organisational transformations. The publication of Myskovets et al. (*2025*) confirms the findings of previous studies, particularly Storoshchuk et al. (*2025*), reiterating the importance of standards in industry. The novelty of the research is minimal, reducing its scientific significance. The paper of Alam and El Saddik (*2017*) presents an example of developing digital twins of production stations and testing the logic of programmable logic controllers. Its value lies in

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demonstrating the practical implementation of digital models in an educational environment. However, the results are difficult to generalise to other hardware–software complexes.

Loboda and Starovit (*2023*) once again analysed digital twin platforms, similarly to Orobchuk et al. (*2025*), but refined the evaluation criteria. This enhances the scientific precision of the study, yet the rapid pace of technological development necessitates constant data updates. The publication of Semenchuk (*2024*) proposes a digital twin model for managing the processes of the new safe confinement at the Chernobyl Nuclear Power Plant. This is an important example of applying digital solutions to critical infrastructure facilities. However, a lack of full validation under real operational conditions limits the reliability of the conclusions. The study of Lapychak (*2024*) describes the use of digital twins in logistics for supply chain management. The practical significance is confirmed by the development of a specific model, though the absence of quantitative efficiency indicators reduces the objectivity of the evaluation. The authors of paper (*Ostrovska et al., 2024*) analyse the impact of digitalisation on product standardisation and certification, exploring the potential use of blockchain and artificial intelligence. A notable achievement is the emphasis on transparency and harmonisation of processes. Yet the regulatory aspects are presented superficially, without an in-depth analysis of specific cases.

The study of Minchev et al. (*2025*) demonstrates the creation of digital twins based on cloud platforms. The scientific novelty is manifested in the practical demonstration of a prototype, relevant for industrial applications. However, there is no thorough assessment of economic efficiency and security risks. The study of Polishchuk et al. (*2024*) improves the diesel fuel combustion model for a digital twin of a marine engine. The authors show the applicability of digital technologies to high-load objects, though the lack of long-term testing under real operating conditions limits the practical value of the results.

The article of Semenyshen et al. (*2024*) focuses on microclimate modelling in buildings using digital twins and machine learning. The application of modern technologies is a strength of the work, yet the efficiency of the results requires confirmation through real experiments. In the study of Yepifanova (*2025*), the development of a digital twin of a robotic manipulator is justified to optimise trajectories and reduce energy consumption. An important contribution is the mathematical foundation of the design, although the results are not verified at the hardware level, limiting the applicability of the model.

Thus, an analysis of scientific publications shows that digital twins are increasingly applied in energy, industry, transport, construction, and logistics. The main advantages include improving the efficiency of technological processes, optimising resources, predicting emergency situations, and using digital twins for personnel training. At the same time, several limitations have been identified: most studies are applied in nature but restricted to narrow cases or specific equipment; insufficient attention is paid to cybersecurity, standardisation, and regulatory integration; and there is a lack of large-scale empirical validation and quantitative assessment of economic effects. This highlights the need for further development of universal methodologies for building digital twins, their integration with information and control systems, and the confirmation of their effectiveness through extensive practical implementation.

Development of the Structure of a Digital Twin of a Power Plant Unit

A digital twin of a power plant unit is a virtual model that reproduces the physical state and behaviour of the real power unit in real time. It integrates mathematical models, control algorithms, and data from the unit's sensors to provide an accurate representation of all key energy-production processes. Moreover, the digital twin of the power unit is a cyber-physical system that connects the real object (the power plant unit) with its mathematical model and the information environment of the plant's technological process. This integration enables continuous monitoring, analysis, and optimisation of the unit's operation, thereby improving reliability and economic efficiency.

The digital twin of the power plant unit is designed for:
- real-time monitoring (process parameter control with visualisation);
- diagnostics and forecasting (detection of deviations from the normal mode, prediction of emergency situations);
- control optimisation (selection of optimal operating modes to minimise emissions and fuel consumption);
- staff training (use of the digital twin as a simulator for operators);
- virtual experimentation (testing new control algorithms without risk to the equipment).

Main components of the digital twin of the power plant unit (*Figure 1*):

1. Physical and mathematical models:
- dynamic model of the turbine rotor (reflects mechanical vibrations, moment of inertia, and rotational stability);
- thermal model (energy balances in the boiler, steam pipelines, and condenser);
- hydraulic model (movement of the heat carrier, pressure losses, phase transitions);
- electrical model of the generator—electricity production.

2. Control models of the power unit:
- include regulators and optimisation algorithms;
- ensure maintenance of temperature, pressure, steam level, and turbine load;
- use data from sensors and adjust the operation of actuators (valves, pumps, fuel regulators).

3. Data acquisition and sensor system:
- temperature and pressure sensors, flow meters, vibration control systems, etc.;
- data are read through the power unit's automation systems in real time.

4. Information models:
- automated control system of the power unit's technological process;
- integration into the information environment;
- data are transmitted to a digital platform for modelling and forecasting;
- digital technologies are applied to detect dynamics in the variation of technological parameters and possible deviations.

Thus, as a result of the implementation of a digital twin of the power plant unit, a powerful tool is created for enhancing operational management, promptly detecting deviations in the

performance of technological equipment, and predicting potential emergencies. This makes it possible to reduce economic losses from unscheduled shutdowns, minimise accident risks, and maintain high operational efficiency of the power unit under variable loads.

Functional Capabilities of the Digital Twin of a Power Plant Unit

An analysis of the functional capabilities of the digital twin of a power plant unit has been conducted (*Table 1*). The digital twin provides multi-level monitoring, control, and diagnostics of key operational parameters of the power unit in real time.

The use of a digital twin enables the collection of current data and its intelligent analysis. Comparison of actual values of temperature, pressure, steam and water flow rates, vibration levels, and electrical characteristics with the calculated values of reference models allows for timely detection of hidden deviations and diagnosis of faults. An important feature of the system is its ability to identify even minimal deviations that do not yet have a critical impact on operation but may potentially lead to serious failures in the future.

Equipment Condition Forecasting Function. Based on historical data accumulated in the knowledge base, the digital twin analyses material degradation processes, the dynamics of component wear, and patterns of failure. Using machine learning and predictive analytics methods, the digital twin generates forecasts of the remaining service life of turbine, boiler, condenser, and pipeline components, among others. This enables maintenance to be carried out not on a calendar basis, but according to the actual technical condition, which significantly reduces repair costs and increases the overall reliability of the power unit's operation.

Operating Modes Optimisation Function. The digital twin provides the ability to create and analyse alternative operating scenarios for the power unit. In particular, it enables the simulation of operations under various loads, during partial shutdowns, or when fuel quality or environmental conditions change. This makes it possible to determine the most economically feasible operating modes that minimise fuel consumption, reduce harmful emissions, and simultaneously ensure the safe operation of equipment. Optimisation of modes also enhances the flexibility of the power unit to operate under variable energy market conditions.

Personnel Training Function. The digital twin can serve as an interactive training platform for operational and technical personnel. The creation of digital simulators based on it allows the imitation of working processes, emergency, and pre-emergency situations without risk to real technological equipment. This significantly improves personnel training quality, allows the development and testing of emergency response algorithms, and promotes the acquisition of practical skills in a safe environment.

Safety Enhancement Function. One of the key functions of the digital twin is the modelling and analysis of emergency and pre-emergency scenarios. The system allows the assessment of potential consequences of deviations in the operation of technological equipment, identification of critical points, and verification of the effectiveness of emergency response plans.

Thus, the digital twin makes it possible to test new technologies and control methods without risk to real infrastructure. This creates an additional level of safety, reduces the likelihood of human error, and contributes to the formation of a culture of preventive safety. Altogether, these functional capabilities transform the digital twin of the power plant unit into

a universal management tool that integrates monitoring, forecasting, optimisation, training, and safety within a single system.

Use of a Digital Twin for an Interactive Simulator for Operational Personnel

Based on the functions considered, the use of a digital twin for an interactive simulator for operational personnel is proposed, designed for work at an automated workstation of a nuclear power plant unit operator (*Figure 2*).

The interface of the interactive simulator for operational personnel of a nuclear power plant with a nuclear reactor has been examined. It represents a complex simulation model of a digital twin that imitates the operating modes of the power unit (*Figure 3*). The digital simulator has been developed for comprehensive training of power plant operators in managing the power unit under various operating conditions—from normal operation to complex emergency situations. The simulator interface is implemented as a professional control panel with real physical parameters, bringing the training conditions as close as possible to the real operation of a power plant.

On the left side of the interface is an extended parameter panel that displays the key technological indicators of the power unit in real time. The monitoring system includes reactor power at 1000 MW, pressure in the primary circuit at 160.5 bar, coolant temperature at +320.2°C, and water level in the steam generator at 85%. Each parameter is accompanied by detailed ranges of normal values and features a three-level colour-coded status indication system: green indicates a normal system state, yellow denotes a pre-emergency condition with parameter deviations, and red signifies an emergency state requiring immediate intervention.

On the right side of the interface, there is an extended monitoring system including four dynamic graphs. These graphs display the values of the main parameters for the last 30 seconds, allowing the operator to analyse the dynamics of changes in technological indicators. The control panel contains specialised operator action buttons grouped by functional purpose. The equipment status display system includes nine main components of the power unit: the nuclear reactor, turbine, generator, cooling system, PG–1000 steam generator, transformer, condenser, main circulation pump, and sprinkler system. The event log maintains a detailed record of all operator actions and emergency situations with second-by-second accuracy.

The simulator includes an extended system of training scenarios covering all aspects of power plant operation. Among them are the basic normal operation scenario, specialised scenarios for turbine failure, rapid pressure drop, cooling system failure, power grid instability, as well as complex combined scenarios of integrated accidents and emergency reactor shutdowns. Each scenario is accompanied by a detailed technical description and operator action recommendations.

For the instructor, advanced control functions of the training process are provided. The instructor can activate eight types of malfunctions, including turbine vibration, pressure drop, coolant overheating, cooling failure, fuel assembly problems, grid instability, reactivity anomalies, and radiation increase. The system allows sending personalised messages to the operator, selecting from pre-configured training scenarios, monitoring operator performance in real time, and conducting error analysis.

The operator has access to a wide range of control functions. They can regulate key technological parameters, perform emergency procedures of varying complexity, stabilise the system using manual and automatic modes, activate backup systems, and conduct equipment diagnostics. The system provides for both standard operational procedures and emergency response actions.

The technical features of the simulator include realistic real-time simulation with data updates every second. The physical model of parameter behaviour takes into account real technological processes of a nuclear reactor. The operator performance assessment system calculates stability and efficiency indicators based on the analysis of parameter deviations. Automatic alerts about critical conditions are generated based on a comprehensive analysis of technological indicators. Interactive graphs provide scaling functions and detailed analysis of dynamic changes.

The modelling is highly realistic and considers complex interrelations between parameters. For instance, a pressure drop in the primary circuit automatically leads to a decrease in reactor power, while a cooling system failure causes a progressive increase in coolant temperature. The model accounts for the impact of malfunctions on adjacent systems, the response time of technological equipment to control inputs, and the physical limitations of technological parameters.

Thus, this simulator is a fully functional digital twin of a power unit, enabling realistic training without any risk to actual equipment. It fully complies with the modern concept of digital twins in the energy sector, ensuring not only the reproduction of technological processes but also the practice of rare and emergency situations. This represents an essential component of the preparation of highly qualified operational personnel for the nuclear energy industry. The system allows the development of practical response skills to abnormal situations, enhances operational thinking, and provides a deep understanding of the technological processes of a nuclear power unit.

Discussion

The study problem concerns the development and implementation of a digital twin as an integrated system for automated monitoring, control, and diagnostics of power unit technological processes, which includes the synthesis of physical, mathematical, and informational models using machine learning algorithms to predict complex technical processes. The digital twin must ensure high real-time accuracy by integrating diverse processes while simultaneously optimising the operational modes of the power unit. This requires further research into methods of integrating these models into a unified automated system capable of effectively responding to changes in both external and internal parameters.

The study problem lies in how to integrate physical models of power unit technological processes, mathematical control algorithms, and machine learning algorithms into a unified digital twin system capable of predicting possible emergency situations, optimising operating modes, and ensuring real-time monitoring of technological parameters without overloading operators.

To address this research problem, it is necessary to:

1. Develop and improve physical models for simulating the dynamics of power unit processes (turbine rotor dynamics, thermal and hydraulic balance, phase transitions, etc.) with high precision.
2. Create mathematical control models that include optimal control and regulation algorithms to ensure the stable operation of the power unit under variable operating loads.
3. Integrate machine learning algorithms to create predictive models capable of accurately forecasting failures and emergency situations based on real-time data.
4. Develop mechanisms for integrating sensor systems and automated systems into a unified platform for a closed "model–reality" loop.
   Future research and development directions for this technology should include:

- applying approaches to integrating physical, mathematical, and informational models that are most effective in ensuring high accuracy and responsiveness of prediction in the power unit's digital twin;
- integrating physical models of thermal and hydraulic processes with machine learning algorithms;
- identifying optimal methods for synchronising sensor data with mathematical models in real time;
- maintaining a balance between modelling accuracy and system efficiency without overloading computational resources;
- employing methods to reduce computational costs when simulating complex physical processes;
- adapting models for real-time operation under high loads and changing conditions.

Thus, these issues contribute to a deeper understanding of the technological and scientific challenges associated with the development and implementation of digital twins in the energy sector and will help to identify directions for further research and advancement of this technology.

Conclusion

The results of implementing a digital twin of a power plant unit have been examined, which include:

1. Improved Fuel Efficiency and Reduced Energy Losses
   The digital twin enables comprehensive modelling of fuel and energy processes. As a result, operational personnel can optimise fuel consumption, ensuring maximum calorific efficiency with minimal emissions. In addition, energy losses during transmission and conversion are reduced by identifying "bottlenecks" in equipment performance. The use of predictive models facilitates timely adjustment of operating modes, which allows for the reduction of specific fuel consumption per unit of electricity generated.
2. Extended Intervals between Overhauls through Wear Prediction
   The application of predictive analytics algorithms makes it possible to determine the residual life of key components and mechanisms of the power unit. This means that instead of scheduled maintenance based on a calendar approach, condition-based maintenance can be implemented. As a result, the enterprise can significantly extend maintenance intervals,

reduce the number of unplanned shutdowns, and optimise spare parts costs. Wear forecasting helps schedule repairs for the most convenient periods, thereby reducing economic losses caused by downtime.

3. Reduced Risk of Emergency Situations

   The digital twin allows for the timely detection of potentially hazardous deviations and the prediction of pre-emergency conditions. Integration with online monitoring systems enables rapid response to critical changes in equipment operation. Furthermore, simulation of emergency scenarios helps test the effectiveness of existing safety protocols and prepare personnel for emergency situations. This reduces the likelihood of accidents and minimises their consequences if they occur.

4. Economic Justification of Investment in Modernisation

   The digital twin provides a unique opportunity to assess the effectiveness of new technologies or modernisation projects before their implementation in the physical environment (for example, testing various options for boiler equipment reconstruction, automation system upgrades, or the introduction of new materials). This makes it possible to minimise investment risks, justify expenditures, and select optimal techno-economic solutions. In a competitive market environment, such an advantage becomes a key factor in strategic development.

5. Formation of the Enterprise's Information Potential as a Resource for Strategic Management.

   The use of a digital twin contributes to the accumulation and structuring of large volumes of data concerning the operation of the power plant unit. This data array becomes the enterprise's information potential, which can be utilised for strategic planning, management decision-making, economic efficiency assessment, and forecasting of future needs. Such an approach enables the enterprise to maintain digital coherence and act proactively rather than reactively.

Thus, the digital twin of a power plant unit represents an engineering model of energy production processes and a strategic instrument that establishes a new level of enterprise management. Its implementation simultaneously enhances technical reliability, ensures energy security, reduces costs, and substantiates long-term investment decisions. Through the digital twin, power enterprises transition from the traditional "problem-reaction" approach to a predictive management system that aligns with contemporary demands for digitalisation, environmental responsibility, and sustainable energy development. The digital twin serves as a crucial tool integrating advanced technologies into energy processes. Both its scientific and practical applications open new digital resources for the energy sector, improving reliability, safety, and economic efficiency of power unit operation. Future prospects include further efficiency gains, cost reductions, and the creation of adaptive and intelligent management systems for optimising power enterprise performance.

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DIGITAL TWIN OF THE POWER UNIT OF THE POWER PLANT

Physical and Mathematical Models:

- dynamic model of the turbine rotor;
- thermal model;
- hydraulic model;
- electrical model of the generator.

Power Unit Control Models:

- regulators and optimization algorithms;
- sensors for monitoring temperature, pressure, and turbine load.

Data Acquisition System and Sensors:

- temperature, pressure sensors, flow meters, vibration control systems;
- the device reads data via the automated process control system in real time.

Information Models:

- automated process control system of the power unit (automated process control system);
- data to be transmitted to a digital modeling platform;
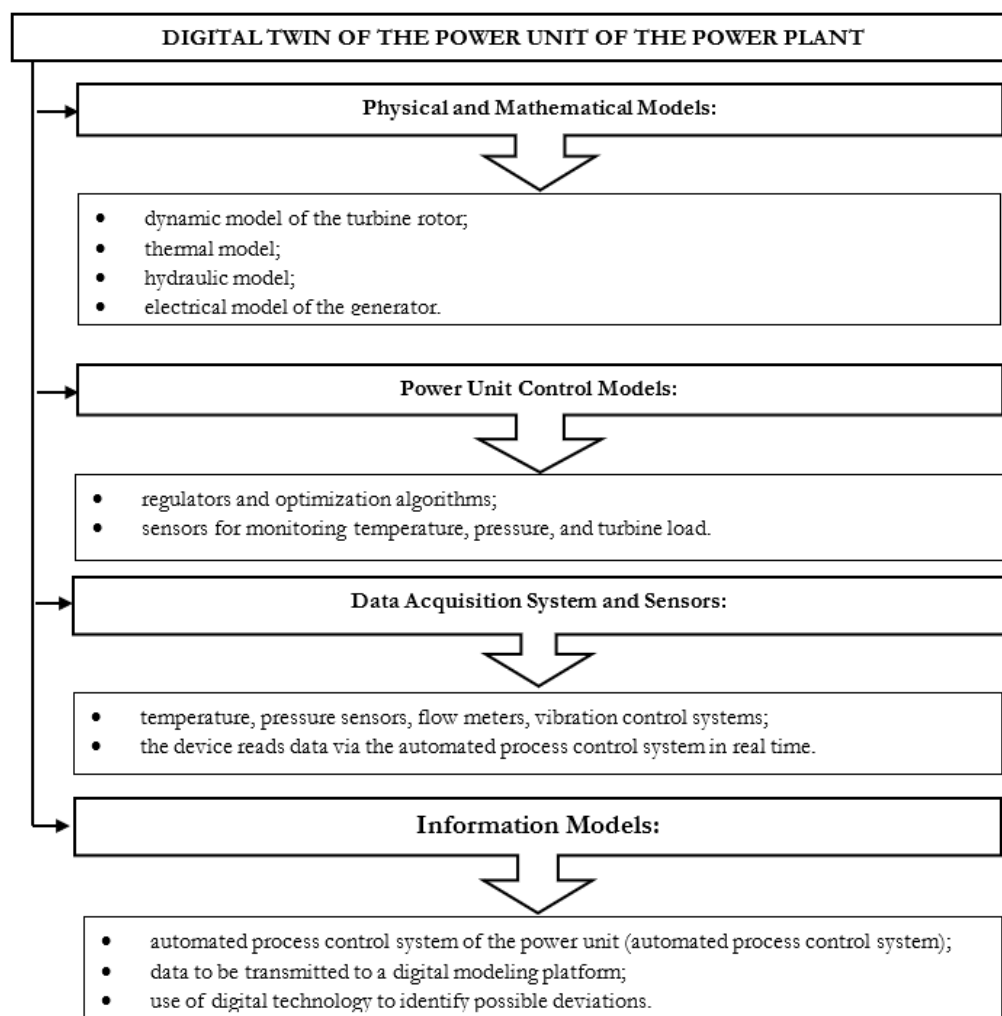- use of digital technology to identify possible deviations.

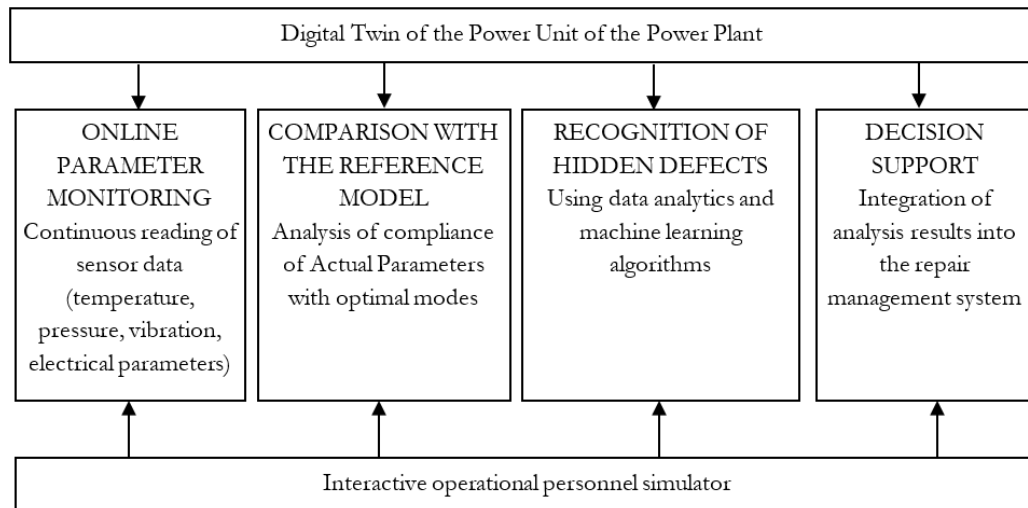Figure 1. block diagram of the Digital Twin architecture of a power plant unit

Figure 2. Scheme of Information connection between the functions of a Digital Twin and the functions of an interactive operational personnel simulator
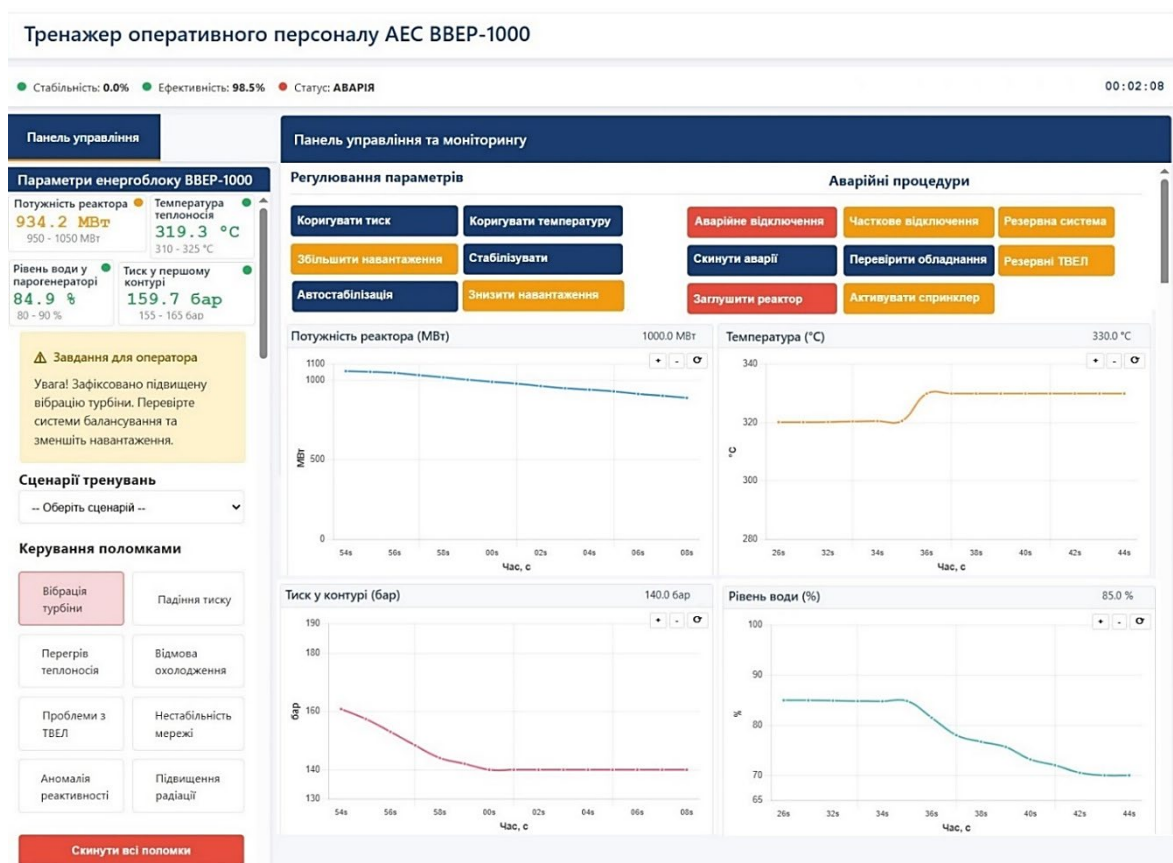

Figure 3. Digital Twin interface (simulator) for operator training (In Ukr.)

Table 1. Functionality of the Digital Twin of the power unit of the power plant

No.	Functional Feature	Implementations	Expected Effect
1	Monitoring and diagnostics	• continuous monitoring of boiler temperature and pressure; • comparison of the vibration characteristics of the rotor with the reference model; • automatic notification of exceeding critical parameters.	• reducing hardware downtime; • timely detection of malfunctions; • improving the reliability of work.
2	Predicting the state of equipment	• analysis of the operation history of pumps and pipelines; • using machine learning algorithms to determine the remaining turbine life; • making forecasts regarding the timing of node replacement.	• switching to maintenance based on the actual state; • optimisation of repair costs; • increasing the equipment readiness coefficient.
3	Optimisation of operating modes	• modelling the operation of a power unit under various loads; • determination of optimal fuel consumption for a given mode; • scenario analysis of emergency and repair stops.	• reduce fuel consumption; • improving economic efficiency; • flexibility of work in the context of changes in the energy market.
4	Staff training	• creation of digital simulators for automated workplace operators of automated process control systems; • simulation of emergency situations in a virtual environment; • modelling of normal and non-standard operating modes.	• professional development of personnel; • reducing the risk of human error; • faster response to emergency situations.
5	Improving security	• modelling of pre-Emergency States and consequences; • checking the effectiveness of emergency response plans; • testing of new management methods without risk to the equipment.	• reducing the likelihood of accidents; • reducing environmental and economic risks; • formation of a culture of preventive safety.

Vitaliy V. Shutyuk [a][15], *Olha V. Dushchak* [b][16]

Rational Use of Tomato Processing Waste in the Development of Sauces with Enhanced Biological Value [12]

Abstract:

The article analyses the current state and prospects for the production of new types of sauces based on tomato products, as a promising raw material for industrial processing, considering their high content of biologically active compounds and the possibility of cultivating tomatoes in all regions of Ukraine. Previous studies have demonstrated the nutritional value of tomato processing waste, namely seeds and pomace. As a result of the analysis of literary and experimental data, it was found that tomato seeds contain a wide range of biologically active substances that may be suitable for use in food technology. The article proposes the use of secondary products of tomato processing for the production of food semi-finished products. The subject of the study was tomato sauces enriched with the semi-finished product "Tomato Seed Paste". The object of the study was structural–mechanical and organoleptic properties of tomato sauces developed with the addition of "Tomato Seed Paste". The study aimed to determine the influence of the developed semi-finished product "Tomato Seed Paste" on the quality indicators of tomato sauces when developing a comprehensive tomato processing technology. Samples of tomato sauces with the addition of the developed semi-finished product "Tomato Seed Paste" were selected as the objects of further study. The study confirmed the feasibility of industrial processing of tomato seeds. The structural and mechanical properties of tomato sauces with the addition of a semi-finished product based on tomato seeds were analyzed. It was also found that the addition of tomato seed paste in quantities of 8% increases the initial viscosity by 1.7 times and the yield stress by 2.75 times. Increasing the amount of added tomato seed paste to 11% significantly alters the structural and mechanical properties of the final product: its viscosity increases by 2.46 times — from 147 Pa·s to 363 Pa·s.

Keywords: tomato products, tomato seeds, preservation, sauces, rheology, food technologies.

Introduction

The full-scale war in Ukraine has significantly affected the market for canned vegetables and fruits, particularly their production and supply. Military actions and shelling have led to the destruction of agro-industrial facilities, reduction in crop yields, and disruptions in supply chains. At the same time, the hostilities have forced many farms and food enterprises to change their production strategies, focusing on local markets and reducing their dependence on imported products.

During the war, the consumption of canned vegetables and fruits increased due to the instability of fresh food supplies, as well as constant power outages, which made it difficult to store fresh products for long periods. Canned foods became an important source of nutrients for the population. At the same time, rising prices for raw materials and production costs led to an increase in the prices of canned products, which significantly affected household budgets (*Semenda & Korman, 2024*).

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[a] Doctor of Engineering Sciences, Professor, Department of Canning Technology, National University of Food Technologies. Kyiv, Ukraine.
[b] Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Canning Technology, National University of Food Technologies. Kyiv, Ukraine.

The full-scale war also had a substantial impact on the import and export of canned vegetables and fruits. Military actions and bans on supplies from countries supporting the war led to a decrease in import volumes. At the same time, exports were also affected due to disruptions in logistical supply chains and reduced demand on the international market.

The current realities have created numerous challenges for the canned fruit and vegetable market in Ukraine, but they have also opened up new opportunities for the development of local production and innovation. The increased demand for local products and changes in production strategies have enabled many domestic enterprises to adapt to the new conditions and maintain their positions in the market (*Vitriak et al., 2025*).

Unfortunately, many agricultural enterprises and farms have ceased to exist fully or partially due to the occupation of a significant portion of territory by Russian forces. The enterprises whose areas were liberated from the Russians were looted or destroyed, while those that remain under occupation are considered temporarily inaccessible.

Currently, there is significant support for the processing industry in Ukraine: the government and foreign investors provide financial assistance to farmers, producers, and those engaged in processing plant-based raw materials. This creates favorable conditions for developing new types of canned products and for using non-traditional raw materials.

In recent years, the food industry has maintained a steady trend toward increasing the production of various types of tomato products, particularly sauces and seasonings. The aroma of sauces and their often-spicy taste stimulate appetite and, consequently, improve food digestibility. This effect of sauces is due to the presence of spices, seasonings, and other additives. Using different sauces with the same dish gives it a new flavor (*Beglița et al., 2023*).

Interest in sauce products is driven by their high consumer properties, good digestibility, and the ability to regulate the chemical composition, nutritional and biological value, and caloric content of the main dish (*Benderska et al., 2021*).

The subject of the study was tomato sauces enriched with the semi-finished product "Tomato Seed Paste".

The object of the study was structural–mechanical and organoleptic properties of tomato sauces developed with the addition of "Tomato Seed Paste".

The study aimed to determine the effect of the developed semi-finished product "Tomato Seed Paste" on the quality indicators of tomato sauces during the development of an integrated tomato-processing technology.

Study tasks, according to the purpose, were:

– develop a technological process for producing the semi-finished product "Tomato Seed Paste" from tomato processing waste;

– investigate the influence of different dosages of tomato seed paste on the rheological and structural–mechanical properties of tomato sauces;

– assess the impact of tomato seed paste on the organoleptic characteristics and overall quality of the finished sauces;

– determine the optimal concentration of tomato seed paste that ensures improved biological value without compromising the traditional texture and sensory profile of tomato sauces.

Methods and Materials

The research employed a complex methodological approach combining experimental, analytical, and statistical methods traditionally used in food technology to investigate the rheological, structural–mechanical, and organoleptic properties of tomato sauces. The study was conducted at the Department of Canning Technology, National University of Food Technologies (Kyiv, Ukraine), where the semi-finished product "Tomato Seed Paste" was developed and its effects on the properties of tomato sauces were comprehensively evaluated.

The experimental method formed the foundation of this study. Tomato sauces were prepared from tomatoes at technical and biological maturity stages using standard canning technology (*Benderska, 2019*; *Benderska & Bessarab, 2018*). The developed "Tomato Seed Paste" was obtained by drying and grinding tomato seeds, which were separated during the primary processing of tomatoes. The paste was then added to the sauce formulations in varying proportions—3%, 5%, 8%, and 11%—while the control sample contained no additive. This approach ensured systematic variation of the experimental factor and provided the basis for evaluating its influence on product characteristics.

The rheological method was applied to measure viscosity and flow characteristics, using a Reotest-2 rotational viscometer in accordance with DSTU 8017:2015 "Canned Products. Structured Fruit and Vegetable Sauces. Technical Specifications." The method involves measuring the torque generated by the fluid sample between coaxial cylinders at different rotation speeds (*Mironeasa & Codină, 2019*; *Flaiş & Oroian, 2025*). Each 100 cm³ sample was equilibrated at room temperature for 20–30 minutes before measurement. The results, expressed in Pascal seconds (Pa·s), allowed identification of non-Newtonian, pseudoplastic behaviour typical for tomato sauces (*Bosona & Gebresenbet, 2018*). Rheological curves were used to calculate the apparent viscosity and flow index, revealing the influence of tomato seed paste concentration on structural stability.

The sensory analysis method was applied to evaluate the organoleptic parameters—colour, aroma, taste, and consistency—of the experimental sauces. A trained panel of ten experts conducted profile analysis in accordance with ISO 8586:2012 guidelines. Each attribute was rated on a 5-point scale. The criteria for colour uniformity, naturalness, and intensity followed the methodology described by Benderska et al. (*2021*), while aroma and taste were assessed according to purity and balance of seasoning. The sensory results were statistically processed to determine the optimal additive concentration that preserved desirable consumer qualities.

Complementary physicochemical methods were used to determine the dry matter content, pH, and titratable acidity of the sauces following standard procedures (*Silva et al., 2023*). Moisture and dry matter were determined gravimetrically by oven drying at 105°C until constant weight, while acidity was measured by titration with 0.1 mol/L NaOH solution. The pH value was measured using a digital pH meter at 20°C. These parameters were used to correlate the influence of tomato seed paste addition with changes in the physicochemical stability and water-holding capacity of the sauces (*Kumar et al., 2021*).

The microscopic method was used to study the microstructure of tomato sauces enriched with seed paste. Samples were examined under a laboratory light microscope at 200× magnification. The micrographs revealed the distribution and size of dispersed particles, demonstrating that increasing seed paste content enhances the density of the structural network.

This observation supports the rheological findings and confirms the water-binding role of the fibrous and protein components of the seed paste (*Begliţa et al., 2023*).

The statistical method was applied to ensure the reliability of experimental results. All measurements were performed in triplicate, and the mean values with standard deviations were calculated. Statistical significance of differences between samples was evaluated using one-way analysis of variance (ANOVA) at a confidence level of $p < 0.05$. Correlation analysis was also performed to establish relationships between tomato seed paste concentration and rheological parameters such as viscosity, yield stress, and flow behaviour index (*Firrman et al., 2024*).

To provide a holistic understanding of the functional properties of tomato seed paste, the research incorporated data from previous chemical composition analyses (*Benderska et al., 2018*), confirming its richness in polyunsaturated fatty acids, proteins, and pectic substances. These findings guided the hypothesis that the seed paste could serve as a natural thickening and stabilizing agent. The experimental data obtained in this work were interpreted within the framework of food rheology and colloidal chemistry, allowing a comprehensive evaluation of the effects of plant-derived additives on sauce structure and quality.

The chosen combination of rheological, physicochemical, and sensory analysis methods ensures reproducibility and comparability of results with international studies on valorization of tomato by-products. The integration of these methods allows establishing scientifically grounded recommendations for optimizing the dosage of tomato seed paste in industrial sauce formulations, promoting sustainable waste utilization and improving the biological value of the product (*Solaberrieta et al., 2022*; *Silva et al., 2023*).

Literature Review

The literature review reveals a strong scientific and practical interest in the valorization of tomato processing by-products as sources of biologically active substances and valuable technological components. The study of Begliţa, Ungureanu-Iuga, and Mironeasa (*2023*) established the physicochemical and functional characteristics of tomato pomace powder in suspensions, demonstrating its potential as a structuring and nutritional ingredient in food formulations. Similarly, Bosona and Gebresenbet (*2018*) performed a life-cycle analysis of organic tomato production in Sweden, emphasizing the environmental benefits of utilizing tomato waste for new food products and reducing overall losses.

Benderska, Bessarab, and Shutyuk (*2018*) analysed the fatty acid composition of tomato seeds, confirming their richness in polyunsaturated fatty acids and proposing their application in food technologies. Complementary studies by Benderska and Bessarab (*2018*) explored the technological aspects of secondary tomato raw material utilization, focusing on developing cost-effective methods for incorporating seed and pomace fractions into processed foods. In a subsequent dissertation, Benderska (*2019*) advanced the technological framework for producing tomato sauces with the addition of seed paste, establishing the scientific basis for the current study. Her later research (*Benderska, 2021*) outlined the prospects for comprehensive tomato processing and underlined the importance of minimizing waste and maximizing biological value.

Further contributions were made by Benderska et al. (*2021*), who examined the biological value of tomato by-products, proving that the combination of pulp and seed components increases protein, fiber, and antioxidant contents. These findings align with global trends in

sustainable production reviewed by Silva et al. (*2023*), who highlighted the growing interest in tomato by-product applications in food systems as a step toward circular economy models.

The biomedical potential of tomato seeds was summarized by Kumar et al. (*2021*), who reviewed their bioactive compounds and health-promoting effects, confirming their role as valuable raw material for functional food development. The results of Mironeasa and Codină (*2019*) supported these conclusions by showing that substituting part of wheat flour with tomato seed flour significantly changes dough rheology and microstructure due to fiber and protein interactions. These rheological insights are crucial for predicting texture behaviour in sauce systems.

Recent studies emphasize novel valorization approaches. Solaberrieta et al. (*2022*) applied advanced extraction methods to isolate fatty acids and bioactive compounds from tomato seed by-products, while Firrman et al. (*2024*) demonstrated that tomato seed extract positively influences gut microbiota, revealing a new biomedical direction for waste valorization. The rheological and textural evaluation of sauces enriched with tomato pomace, carried out by Flaiş and Oroian (*2025*), confirmed that adding tomato residues improves consistency, viscosity, and storage stability, directly supporting the objectives of the current research.

Ukrainian and European studies also analyse the market context of tomato processing. Semenda and Korman (*2024*) examined the effects of the war on Ukraine's vegetable market, identifying challenges in raw material availability and emphasizing the need for resource-saving technologies. Vitriak, Khrebtan, and Volkova (*2025*) further detailed the evolution of the domestic canned food market, linking economic resilience with innovations in processing and waste reuse. These economic and geopolitical analyses provide an essential background for understanding the urgency of rational resource utilization in food production.

Finally, Stetsenko and Moshenska (*2015*) developed a method for producing dietary supplements based on tomato, pumpkin, and flax seeds, demonstrating the technological compatibility of multi-seed compositions in functional foods. Their approach illustrates the broader applicability of seed-based additives beyond sauces. Collectively, these sources substantiate the scientific rationale for integrating tomato seed paste into sauce technology as a sustainable, nutritionally beneficial, and economically justified solution.

Results

In the canning industry, special attention is given to increasing production volumes, optimizing the use of raw materials, and reducing losses. Processing the waste generated during the production of fruit and vegetable preserves and juices at factories can help extend the shelf life of materials and lower the cost of the final product (*Benderska & Bessarab, 2018*).

To achieve these goals, proper processing of canning industry waste in Ukraine is essential. One way to improve the utilisation of these materials is to organize the production of dried fruit and vegetable waste. This process can be performed at canning enterprises (*Benderska et al., 2021*), after which the raw material, as a semi-finished product, can be sold to various feed mills for further use.

Vegetables and fruits have a limited shelf life. Therefore, part of them spoils and is discarded for several reasons. The economics and ecology of production require reducing the amount of food waste and using it more rationally. These issues are currently being addressed

by the industrial organisation GroentenFruit Huis. Together with several other companies, it collected data on food waste for the years 2020–2022 to obtain a reliable picture of where residual streams and losses occur (*Vitriak et al., 2025*). Based on these data, Wageningen University & Research conducted monitoring of waste from five "exotic" and six greenhouse-grown fruits and vegetables.

Eleven organizations and more than 280 people took part in the study. The monitoring showed that, on average, 2.1% of produce is wasted, of which 92% is fermented, 5% is composted, and 3% is sent to landfill. The highest landfill rate is observed for exotic fruits— 3.7%. Based on the collected data, GroentenFruit Huis and the "Together Against Food Waste" Foundation are creating a map of their food waste to identify better ways to reduce it and hope that more companies will join the effort. In fact, enterprises lose up to 5.5 million tons of tomatoes annually (*Bosona & Gebresenbet, 2018*).

There are two main directions for the rational and efficient use of raw materials in production: selecting the most suitable processing technology and equipment. The goal is to minimize the generation of waste. This is the most important direction, as the main expenses of an enterprise are for the purchase of raw materials. The second direction is the organization of waste processing that is inevitably generated during production processes. The resulting waste should be used to create semi-finished products, as well as additional food or technical products (*Silva et al., 2023*).

Typically, waste after processing includes:
- products that are unsuitable for canning due to their shape, size, maturity, or other specific parameters—e.g., zucchini with a diameter over 70 mm, hook-shaped cucumbers, etc.;
- raw materials that are unsuitable for consumption for various reasons.

The most rational way to use such products is considered to be their processing.

Nutrition is the main factor in providing the human body with energy, structural elements, and functional activity. Considering the negative impact of the environment, there is an increasing need each year for the production of food products enriched with natural ingredients that can correct micronutrient deficiencies and enhance the body's resilience to adverse external conditions (*Benderska, 2021*).

The most complete natural source of biologically active substances is fruit and vegetable raw materials and their processed products. A significant segment of the food market based on these raw materials is occupied by sauces.

Sauces are products with defined structural and mechanical properties, which can be achieved by applying specific technological processing methods to plant raw materials or by using natural additives, such as structuring agents and acidifiers.

Tomato sauce is a rich source of organic acids, sugars, and vitamins. Its high nutritional value is due to the fact that tomatoes are capable not only of retaining but also enhancing their beneficial properties during thermal processing (*Kumar et al., 2021*).

Among the range of sauce products available on the Ukrainian market, most sauces contain preservatives, artificial stabilizers, and emulsifiers, which negatively affect the human body and are not recommended for daily consumption. The works of Telezhenko, Hrynchenko, Pyvovarov, Peresichnyi, Maliuk, Kravchenko, and other researchers have examined the scientific principles of using fruit and vegetable raw materials in sauce technology. However,

most studies focus on the use of structuring agents and flavor enhancers, which often require additional processing, reducing nutritional value and increasing production costs (*Solaberrieta et al., 2022*; *Stetsenko & Moshenska, 2015*).

A relevant area of study is the search for plant raw materials with high technological properties and their potential use in food production to expand the product range and improve organoleptic, structural and mechanical, and functional-technological characteristics (*Benderska, 2019*).

Particular attention is given to sauces based on vegetable products, which are an essential source of important substances such as vitamins, polyphenols, minerals, and other compounds necessary for normal human life. Tomatoes, as a primary raw material, are actively processed to form a wide range of products, with tomato sauces occupying a central place alongside ketchups.

Studies of the chemical composition of tomatoes have shown that their main components, which determine the structural properties of the finished sauces, include a significant content of polymers with water-retaining capacity: hemicelluloses, cellulose, lignin, pectic substances, and proteins. The presence of fiber provides porosity and, together with protopectin, pentosans, and protein compounds, ensures a high water-holding capacity of tomato pulp (*Mironeasa & Codină, 2019*).

To improve existing tomato processing technologies, the use of the semi-finished product "Tomato Seed Paste" has been proposed to enrich tomato sauces as an additional source of proteins, polyunsaturated fatty acids, and pectic substances. To determine the effect of the developed semi-finished product on the quality characteristics of the resulting sauces, it is proposed to evaluate the structural and mechanical properties of sauces made from tomatoes at different stages of ripeness with the addition of tomato seed paste (*Flaiş & Oroian, 2025*).

As the study aimed to determine the effect of the developed semi-finished product, "Tomato Seed Paste", on the quality characteristics of tomato sauces during the development of an integrated tomato-processing technology, at the Department of Canning Technology of the National University of Food Technologies, a technology for producing the semi-finished product "Tomato Seed Paste" was developed, and the influence of its dosage on the rheological characteristics of tomato sauces and their organoleptic properties was investigated.

Discussion

Tomato sauce is a complex physicochemical system, consisting of a liquid fraction with a suspended solid insoluble phase. Industrial production of tomato sauces typically involves a series of concentration steps to achieve the desired final organoleptic characteristics. Although in recent years new concentration methods such as reverse osmosis, freeze-thawing, and centrifugation followed by pulp concentration have been used, tomato sauces are still widely produced using vacuum evaporation units (*Bosona & Gebresenbet, 2018*).

According to the classification of rheological masses, tomato sauces belong to non-Newtonian fluids, characterized by pseudoplastic properties.

The quality of the tomato mass can vary significantly depending on factors such as the variety of tomatoes used, the mesh size of the filter, and most importantly, the temperature of preliminary processing.

Factors that determine the rheological properties of tomato sauce with the addition of tomato seed paste include the amount of tomato seed paste added, temperature, pH of the medium, and the concentrations of sodium chloride, sucrose, and spices included in the sauce. Therefore, to select optimal formulation ratios, the effect of the amount of tomato seed paste on the structural and mechanical properties of the finished sauces was investigated (*Firrman et al., 2024*).

The optimal dosage of tomato seed paste was determined by measuring the viscosity, flow properties, and organoleptic characteristics of the finished sauces. Structural and mechanical properties were determined using a Reotest-2 rotational viscometer.

A control sample was tomato sauce without the addition of tomato seed paste, with a dry matter content of 18%, in accordance with the requirements of DSTU 8017:2015 "Canned Products. Structured Fruit and Vegetable Sauces. Technical Specifications."

Tomato seed paste was added to the sauce in amounts of 3, 5, 8, and 11%, and spices and herbs were added according to the developed recipes. The sauce was then boiled down to achieve a dry matter content of 18% in the final product.

The results of the viscosity and flow measurements of the prepared sauces, cooled to a temperature of 20±2 °C, are shown in (*Figure 1*), with the initial and final values of viscosity and flow presented in the Appendix (*Table 1*).

Rheological curves show a significant increase in the effective viscosity of sauces with an increase in the concentration of tomato seed paste in the system. This can be explained by the high content of proteins, pectin, and hemicellulose in the tomato seed paste, which possess water-binding capacity.

The addition of 3% tomato seed paste increases the initial viscosity by 1.23 times compared to the control—from 147.84 Pa·s to 181.88 Pa·s. At the same time, the flow of the sauces also doubles (from 15.11 Pa to 30.32 Pa). Increasing the dosage of tomato seed paste to 5% results in an increase in initial viscosity by 1.38 times and flow by 2.26 times, while maintaining structural properties very close to those of the control sample.

When 8% tomato seed paste is added, the initial viscosity increases by 1.7 times, and the flow increases by 2.75 times.

Increasing the amount of tomato seed paste to 11% significantly alters the structural and mechanical properties of the final product: its viscosity rises 2.46 times—from 147.84 Pa·s to 363.77 Pa·s. Alongside the increase in viscosity, the flow of the sauces also increases, which can be explained by the chemical composition of the resulting sauces, namely the addition of 2–11% protein substances together with the paste and the increase in pectic substances. In addition to enriching the chemical composition of the tomato sauce through the addition of tomato seed paste, changes in the organoleptic characteristics of the final product were also observed.

Thus, it can be concluded that using tomato seed paste at levels of 3–5% in the developed sauce formulations allows the initial viscosity to increase by 1.23–1.38 times. At the same time, no significant changes in consistency were observed compared to the control—the sauce remained relatively fluid and retained its initial structural characteristics.

With 8% tomato seed paste, the initial viscosity increased 1.7 times. The sauce acquired a pleasant peppery taste without any foreign aroma. The consistency of the resulting sauce became spreadable while still retaining some flowability.

With 11% tomato seed paste, a significant increase in viscosity was observed, which made further dosing of the tomato sauce difficult. Sensory evaluation revealed a pronounced bitter taste. Therefore, the optimal amount of tomato seed paste can be considered 8%, which allows enriching the composition and biological value of the tomato sauce while maintaining the structural and organoleptic characteristics typical of classic tomato sauces.

Conclusion

In the canning industry, special attention is paid to increasing production volumes, optimizing the use of raw materials, and reducing losses. Processing the waste generated during the production of fruit and vegetable preserves and juices at factories can help extend the shelf life of materials and reduce the cost of the final product.

To achieve these goals, proper processing of canning industry waste in Ukraine is essential. One way to improve the utilization of these materials is the organization of further processing of fruit and vegetable waste. This process can be carried out at canning enterprises, after which the raw material, as a semi-finished product, can be used at various stages of production for further applications.

A relevant area of research is the search for plant raw materials with high technological properties and their potential use in food production to expand the product range and improve organoleptic, structural-mechanical, and functional-technological characteristics.

Previous studies have demonstrated the value of tomato production waste—seeds and pomace. Analysis of existing data showed that tomato seeds contain a wide range of biologically active substances suitable for use in food product technologies. To improve existing tomato processing technologies, the use of the semi-finished product "Tomato Seed Paste" was investigated to enrich tomato sauces as an additional source of proteins, polyunsaturated fatty acids, and pectic substances.

It was established that adding 8% tomato seed paste increases the initial viscosity by 1.7 times and flow by 2.75 times. Increasing the amount of tomato seed paste to 11% significantly alters the structural and mechanical properties of the final product: its viscosity rises 2.46 times—from 147.84 Pa·s to 363.77 Pa·s.

Conflict of Interest

The authors declare that there is no conflict of interest.

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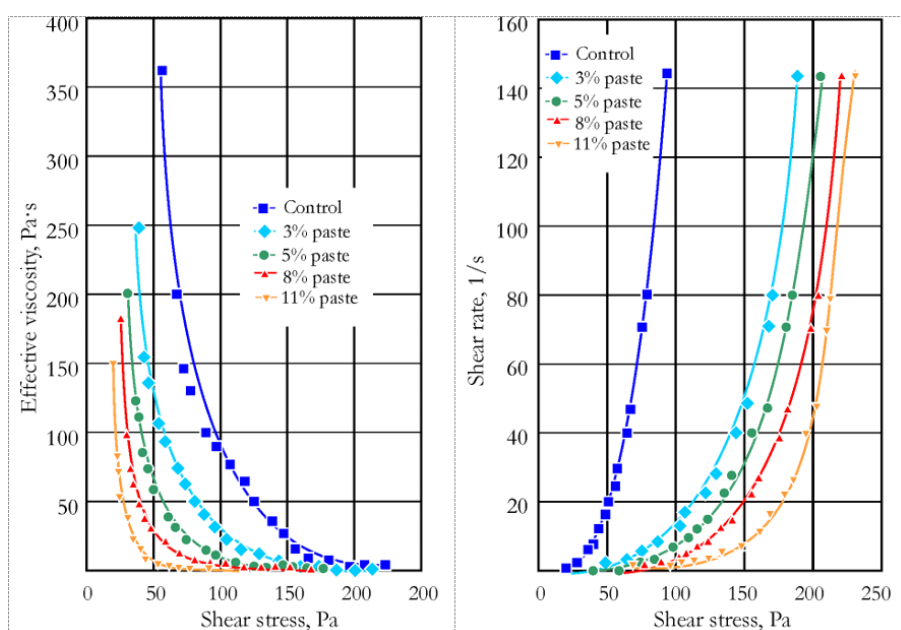
Appendix

Figure 1. Dependence of shear stress and shear rate on the effective viscosity
of tomato sauces

Table 1. Initial and final viscosity and flow properties of sauces with the addition of tomato seed paste

Sample of Sauce	Viscosity, Pa·s		Flow, Pa	
	initial	final	initial	final
Control	147.84	0.63	15.11	91.43
3%	181.88	1.30	30.32	189.5
5%	204.62	1.41	34.11	204.66
8%	250.09	1.50	41.69	219.06
11%	363.77	1.55	60.64	226.64

Liudmyla G. Bachynska [a][LZ]

The Influence of Socio-Humanitarian Sciences on Education and Creativity in the Field of Formation of the Architectural and Urban Environment [13]

Abstract:

At the end of the 20th — beginning of the 21st centuries, socio-humanitarian knowledge is significantly expanding, branching out according to social needs and helping to solve problems in architecture and urban planning. Socio-humanitarian knowledge such as political science, ideology, economics, sociology, psychology and others in the cognitive-historical process explain the specifics of the formation of a city plan, the presence of the necessary types of public buildings depending on the era, the directions of form formation and stylistics of architectural objects. The object of study is the architectural and urban planning environment. The subject of the study is the influence of socio-humanitarian knowledge on architecture and urban planning. The study aims to clarify the mechanism of influence of socio-humanitarian knowledge on architectural and urban planning objects and space. The methods used in the study are empirical observations of the development of architecture and urban planning in different political and economic conditions, the cause-and-effect relationship between socio-humanitarian knowledge and architectural and urban planning heritage. The author concludes that justification of the influence of political regimes and economic activity on the formation of society, its consciousness and on architectural and urban planning activity in different eras.

Keywords: socio-humanitarian sciences, architectural and urban planning activity, society, political regimes, economic activity, cultural and state ideology.

Introduction

Architecture as a science of creating an artificial environment for humans and their lives must meet their needs in any era, at any time. The person himself changes over time, develops, acquires skills, abilities and knowledge, thanks to scientific and technological progress, he improves the tools of labor and his own environment, using technological methods for the construction of buildings and structures. A person as such in the socio-historical process goes through various stages of his existence—periods of state formation, socio-economic and socio-political life, he tries to understand what he himself and the world around him are, and with the help of this knowledge to improve the environment. Given this, architecture cannot be just a branch of engineering that creates architectural and urban space for the needs of consumers—humans, society, and the state—here and today, serving customers. For a specialist architect who works for a person and satisfies his needs in organizing the environment, it is extremely necessary to understand what a person is, how his consciousness changes along with historical progress, how this consciousness is reflected in the cultural activity of the person himself and society, what are the dynamics of relations between an individual and society, a citizen and the state, what is at least the nearest perspective in social processes, which will entail changes in the requirements of the population for the formation of architectural and urban space.

So, knowledge of social and human sciences about man, society, the state and its politics, etc. and their influence on the formation of the consciousness of people—specialists and

a Associate Professor, Candidate of Architecture, Professor, Member of the Ukrainian Academy of Architecture, Department of Fundamentals of Architecture and Architectural Design, Faculty of Architecture, Kyiv National University of Construction and Architecture. Kyiv, Ukraine.

consumers of architectural and urban space—will determine the directions of the architect's creativity, and without them there can be no deep, full-fledged awareness of social needs.

Human life, thanks to scientific and technological progress, is constantly becoming more complicated, there is a need for additional knowledge to understand constantly updated social processes, the possibilities of using this knowledge in practice. Because of this, the number of new sciences that are born on the basis of already existing ones is increasing, they are deepening in content, responding to the latest social needs, and connections between different branches of science are emerging. The spread of the complex of socio-humanitarian disciplines in the cognitive-historical process can be explained by the increase in the areas of professional activity needed by society, the need to consider each of the areas more deeply, while having an idea of a certain industry or related industries. On the one hand, science is growing quantitatively, on the other hand, there is a danger of the spread of narrow specialization, which can be eliminated only by the method of a holistic approach to the perception of social processes. Taranenko (*2012*) notes: "Combining with power, it (science) really begins to influence the choice of certain paths of social development. This new function of science is sometimes characterized as its transformation into a social force… Science, as a worthy object of study, has now found itself under the cross-over attention of philosophy, history, sociology, economics, psychology, scientific studies, etc. In the process of its development, not only is new knowledge accumulated, but previously formed ideas about the world are also being rebuilt."

So, all socio-humanitarian sciences that are somehow connected with the formation of the architectural and urban environment should form the basis for the training of architects, and thereby raise specialists in this field from the level of an architect-engineer to a specialist who must not only take into account the influence of social processes on the creation of architectural objects, but also sees the role of architecture as a work of art in the life of the people, understands its influence on public consciousness and their own responsibility for the directions they have chosen.

Architecture has recently been increasingly considered a branch of engineering. For example, in some European countries, the curricula for Masters of Architecture do not include any humanities subjects at all, and sometimes in the programs of foreign international conferences, architecture is seen as a component of the engineering field or only in combination with computer technologies. Contacts with European countries, Ukraine's adoption of the Bologna system of university education since the early 2000s, which leads to the typification of the educational process of various universities and the knowledge gained, unfortunately, is aimed at a gradual reduction and the danger of a complete rejection of humanitarian disciplines. The efforts of Ukrainian educational institutions to restructure curricula in accordance with European standards have led to the classification of such disciplines as psychology in architecture and sociology, which are extremely necessary for architectural education, as elective. Although both disciplines help to solve important problems, for example, from the viewpoint of the psychology of visual perception of space, architectural form, color scheme, psychology of human behavior in the space of a certain organization, the arrangement of a sense of social community or, conversely, the needs of isolation, visual and functional convenience, ways of organizing psychological mood using objects and space, and solving many other problems of

the life of society with the assistance of these sciences. Does it make sense to abandon such important knowledge for an architect for the sake of shortening the curriculum?

Architecture consists of two main parts—artistic and engineering (*Figure 1*). It is a contribution of humanity to the spiritual and material culture of peoples. As an artistic component, architecture, thanks to such means as architectural form, stylistics, synthesis of arts, is a carrier of certain ideas and social or state ideology. As a work of art, it affects the emotional and sensory side of the human psyche, forming a positive or negative assessment of the state of the environment. Being a work of art, architecture forces a person to constantly be, live, and act in this environment (in this space—a work of art), which affects the consciousness of a person, shapes it. So, an architect is obliged to realize that he, as an artist, as a creator, as a person who fulfills a certain order from a consumer (a person, society or state), must be responsible for his creativity and the manifestations of its influence on a person. A kind of basis for the development of the artistic component of architecture is the understanding of the political and economic system, on which the existence of a social system under democratic conditions of government or state ideology in countries with a totalitarian regime depends, which is manifested in various artistic methods of reflection. So, is it appropriate to remove from the curricula of training architects' humanitarian disciplines that will explain to students the essence of these disciplines and their influence on public consciousness, which will provide an understanding of the responsibility of a specialist architect to society? The second component of architecture is a complex of various engineering sciences that help to implement architectural projects, must take into account the latest achievements in construction technologies, building materials and structures, ensuring the reliability and strength of the structural framework of the structure, for which knowledge of geology is necessary, especially in difficult soil conditions. Geology, which studies the earth's shell, its subsoil, soils and their composition and thereby helps construction, also belongs to the humanities.

The object of the study considered in this article is the architectural and urban environment.

The subject of the study is the influence of socio-humanitarian knowledge on the formation of architectural objects.

The scientific study aims to clarify the complex of socio-humanitarian knowledge that influences the formation of architectural and urban planning objects in any historical period, to show the mechanism of their influence, and to classify socio-humanitarian disciplines from the viewpoint of their interaction with the theoretical and practical activities of the architect.

The objectives of the study are:

- get acquainted with the socio-humanitarian sciences and establish among them the knowledge that will help the architect determine the ways of creating architectural and urban planning objects appropriate to the time and various conditions; to find out what issues in the creative process they are related to, to demonstrate the connection between political and economic activity, social consciousness and directions of cultural activity in architecture;
- show with the help of a diagram the influence of ideology on the formation of the nomenclature of public buildings of the urban planning ensemble as the main object of the city center, on the form, silhouette and style in the architecture of public buildings, the planning of the urban planning ensemble, etc.;

–   provide examples of the latest transformations in the use of socio-humanitarian knowledge in architecture (using the work of Timokhin and Shebek (*2025*) as an example).

Methods

The methodological framework of the study combines general scientific and specialised approaches aimed at revealing the multifaceted interaction between socio-humanitarian knowledge and the architectural and urban environment. The research relies primarily on empirical observation, comparative analysis, and the identification of cause-and-effect relationships between social processes and the evolution of architectural creativity.

At the general level, the study employs the principles of historicism, systemic analysis, and dialectical reasoning, which allow interpreting architectural phenomena within the broader context of human social and cultural development. The principle of historicism ensures the reconstruction of the evolution of architectural forms, urban structures, and aesthetic paradigms in direct dependence on the political, ideological, and economic circumstances of each epoch. Dialectical reasoning, in turn, makes it possible to trace the interdependence of material and spiritual factors in the formation of architectural and urban environments—from the utilitarian needs of society to their artistic and ideological expression.

Systemic analysis, as developed within modern socio-humanitarian methodology (*Tulenkov & Bekh, 2025*), provides the theoretical instrument for understanding architecture as a complex dynamic system that integrates artistic, engineering, social, and psychological components. This method allows identifying the structural unity of urban systems, architectural forms, and settlement networks based on the principle of hierarchy and interaction of subsystems—from housing interiors to regional urban planning.

At the specialised level, the study applies comparative-historical and socio-cultural methods. The comparative-historical approach makes it possible to identify analogies between urban planning models of different civilisations and political systems, revealing the dependence of city morphology on the dominant ideology and social order. Through the analysis of urban ensembles of states with centralized governance versus democratic systems, the researcher establishes typological differences in planning logic, the symbolism of architectural forms, and functional diversity.

The socio-cultural method provides insight into the reflection of political regimes, economic activity, and collective consciousness within architecture and town planning. It focuses on the interrelation between social ideology and the artistic image of architectural objects. By considering architecture as both an art form and a social phenomenon, this approach explains how buildings and spatial compositions convey ideological meanings and shape public consciousness.

The interdisciplinary synthesis of socio-humanitarian disciplines plays a central role in the methodological design. Political science, sociology, psychology, law, and cultural studies were integrated to explain the mechanisms of influence of human sciences on architectural creativity. Political psychology and sociology elucidate the processes of forming public opinion regarding architectural space, while legal sciences regulate the practical realisation of urban development concepts. The study also relies on insights from philosophy and aesthetics to justify the spiritual dimension of architectural creation, emphasising architecture as a medium of humanistic values.

In addition, empirical observation of architectural practice and historical evidence provided the factual base for the research. Direct examination of architectural objects, typological classification of urban ensembles, and review of documentary sources allowed the author to determine the dynamic relationship between socio-political transformations and architectural stylistics. The use of system-structural and system-functional analysis contributed to understanding the mechanism of transformation of architectural space in response to social changes, technological progress, and the evolution of human needs.

Thus, the methodological framework integrates analytical, comparative, empirical, and systemic procedures that ensure a holistic perception of architecture as a manifestation of socio-humanitarian knowledge. The study's methodological synthesis allows revealing architecture not merely as an engineering discipline but as an integral cultural phenomenon, whose evolution reflects the spiritual, political, and psychological development of society itself.

Literature Review

The theoretical foundation of this research is rooted in the interdisciplinary synthesis of socio-humanitarian and architectural studies. Earlier works emphasised the dependence of architecture on economic and political structures, yet modern scholarship expands this connection to include ideology, psychology, and cultural consciousness as key determinants of architectural creativity.

Classical theories of urban formation, such as those presented by Hrushka (*1963*) in *Development of Town Planning*, demonstrated that architectural and urban forms are historically conditioned by material production, economic activity, and the political organisation of society. Hrushka's Marxist dialectical framework laid the groundwork for later studies linking socio-economic development to spatial morphology. Complementary to this, Hrushevsky (*1991*) traced the evolution of Ukrainian urban and cultural identity, showing how historical statehood and national consciousness shaped settlement patterns and architectural symbolism.

The integration of philosophical and cultural approaches to architecture is represented by Bibler (*2018*), who explored culture as a "dialogue of cultures", underscoring the mutual influence between humanistic thought and material creation. This concept resonates with modern interpretations of architecture as a communicative system reflecting social dialogue.

Socio-psychological dimensions were deepened through the works of Rubinstein (*1999*) and Gubko (*2004*), whose studies of human consciousness and the psychology of the Ukrainian nation provide the foundation for understanding the perception of architectural space and its emotional impact on individuals. These insights explain how aesthetic and compositional choices in design affect human well-being and collective identity.

Otreshko (*2013*) extended the discussion by analysing ideology as an integral part of state formation, linking political thought, moral values, and artistic expression. His conclusion that ideology acts as a "cementing spiritual foundation" of society supports the present study's argument that architecture functions as a visualisation of political and cultural ideology.

Empirical and theoretical perspectives on urban development are further supported by Bunin and Savarenskaya (*1979*), whose multi-volume *History of Town Planning Art* catalogued stylistic and structural transformations across epochs. Their typological classification of

architectural forms under various governance systems provides an essential basis for comparative analysis in this paper.

The socio-humanitarian expansion of architectural research is also evident in the works of Taranenko (*2012*), who emphasised the "human dimension" of modern socio-humanitarian knowledge. His concept of science as a social force directly aligns with the author's attempt to integrate humanistic disciplines into architectural education and professional practice. Similarly, Batryn (*2024*) discussed the diversification of socio-humanitarian sciences as a response to the global complexity of human activity, a process that also affects architectural methodology.

A significant methodological milestone is represented by Tulenkov and Bekh (*2025*), whose elaboration of system analysis provides a universal framework for interdisciplinary research. Applied to architecture, this approach allows for understanding the systemic unity between artistic form, function, and social purpose. It underpins the study's attempt to link the micro- and macro-levels of spatial organisation—from interior design to the settlement network.

The recent monograph by Timokhin and Shebek (*2025*), *Constellation of Architectural and Urban Heritage of Ukraine*, illustrates the current scientific paradigm in architectural research. By employing integrative methods combining history, geography, synergetics, cultural studies, and even fractal geometry, the authors demonstrate the potential of cross-disciplinary analysis in architectural theory. Their research validates the idea that architecture must actively incorporate knowledge from both scientific and non-scientific domains to understand and harmonise human environments.

Finally, Plokhii (*2022*) contributes to the broader cultural context by interpreting Ukrainian history as a continuous negotiation between geography, identity, and cultural resilience. His insights are crucial for explaining the specific socio-cultural determinants that influence Ukrainian architectural creativity today.

Together, these sources constitute a coherent body of literature that frames architecture as a socio-humanitarian phenomenon. They collectively confirm that the evolution of architectural and urban environments is inseparable from the dynamics of political regimes, collective consciousness, and cultural ideology. The reviewed works provide both theoretical justification and empirical evidence for the author's thesis that architecture embodies the unity of humanistic knowledge and material creation—a synthesis that must remain central in architectural education and practice.

Results

Empirical research in the study of the history of architecture and the history of urban planning culture shows us the diversity of urban planning, the specificity of types of public buildings, the variability of stylistic trends, etc. Moreover, between the trends in the architectural and urban planning practice of countries with common political regimes and common methods of management, one can see the unity of the principles of forming urban space and the similarity of architectural forms, and this allows us to conclude that it is necessary to look for the reasons for such similarities in social processes. At the beginning of the author's research in this direction, the work of the Slovak academician Hrushka *Development of Urban Planning* (*1963*) served as a reference point in the world of scientific literature on the topic of considering socio-humanitarian scientific knowledge and architectural and urban planning practice as a single

holistic complex that explains and justifies the content of human, country and people's life in general and especially in the field of architecture and urban planning. Hrushka wrote: "Every branch of science… should be based on knowledge of the development of the main interrelations and dependencies of science on nature and economic conditions… This means that all phenomena should be considered not in isolation, but in connection with the historical conditions that cause and shape any phenomenon…" (*1963, p. 13*) And further: "The emergence, changes and development of society, its ideas, theories, political views, the form of states and their structure, the settlement and form of settlements, cities, the organization of nature, flow from the conditions of the material life of developing society." (*Hrushka, 1963, p. 14*) This capital work was first published in 1959, the second Russian-language edition took place in 1963, it is clear that at that time the author in his scientific searches was based on the theory of Marxism-Leninism, and this determined the focus on dialectics and the socio-economic activity of humanity as the main basic factor, as the reason that conditioned its development and activity in other areas. According to the study of the development of the architectural and urban planning industry in the historical process, Hrushka determined the factors influencing this industry from the point of view of their priority regardless of the socio-economic formation, starting from the primitive communal system. Economic activity forms economic relations between people in the production process. Recognition of economic activity as basic led to the division of society by types of employment of the population, professional characteristics that society needs at a certain time. Thus, a society with a certain structure characteristic of the era is created. Already when the first states appeared in the history of mankind, a significant influence on the development of urban planning was exerted by political regimes planning the development of the economy. Nature in human life also plays an important role. Socio-economic activity takes place in certain natural and climatic conditions. Man, master's nature, adapts to living conditions and adapts it to his needs, in ancient times he receives building materials from nature, from which he creates primary settlements and builds cities. As a reflection of economic activity and convenient natural conditions for living, there was a population increase.

Hrushka's research was very different from the theoretical works of the mid-twentieth century in the field of architecture, which mostly considered architecture only as such, ignoring the person himself, his psychology, the peculiarities of his social status and the needs of life. A person in the theory of architecture existed only as a subject with certain physical parameters that had to be taken into account in ergonomics. So, under the influence of the work of E. Hrushka, the author of the article had the idea to analyze the socio-humanitarian sciences and their connection with the theory and practice of the architectural and urban planning industry. Work in this direction opened up the opportunity to see social life in general in the historical process and the architectural environment as an extremely important part of this life, in which it takes place, which forms it and provides opportunities to obtain a level of comfort that meets human needs and create conditions for successful activity. The results of these studies are presented in more than two dozen articles, two of which are given in this publication as an example (*Bachynska, 2016*; *Bachynska, 2017*). Substantiation of the connection between the socio-humanitarian sciences and the architectural and urban planning industry allowed us to set the goal of establishing the mechanism of influence of humanitarian knowledge on the creation of

the environment. And first it was necessary to continue the consideration of the factors that influenced the formation of urban planning culture. With the development of society, the driving force for further progress and improvement of the architectural and urban space is human activity and the historical events caused by it (conquest of territories or coexistence, exchange of experience). Historical science, especially our domestic one, provides us with facts of considering the history of Ukraine on the basis of its statehood (*Hrushevsky, 1991*), and not as a class struggle, the creation of a cultural and social space on its territory, which was facilitated by the movement of peoples along the borders of our country and "led to the formation of a unique set of cultural features that formed the foundations of modern Ukrainian self-consciousness." (*Plokhii, 2022, p. 24*) Also, the further development of the architectural and urban space was ensured by the promotion of scientific and technological progress, the political and social ideology prevalent in the state, a different social consciousness and corresponding cultural activity, the degree of religiosity, etc. It can be argued that all processes occurring in the modern world, in one way or another, influence the formation of the urban and non-urban environment created by humans.

During the times of the primitive communal system, primitive human actions for obtaining food in the form of gathering fruits and roots, fishing, hunting, and over time the first attempts at agriculture and animal husbandry can be attributed to the germs of economic activity. As a result of joint work, relations and the division of responsibilities between members of the genus arose, which were the first slightest signs of the birth of economic relations and the future society. The improvement of the tools of agriculture led to the accumulation of an additional product, which allowed to feed those who began to perform other functions. The appearance of elders, guards, and artisans in the Neolithic village is an important sign of further social development, in which types of activity determined belonging to certain professions, and economic relations between people and professional division demonstrate to us a close connection between the first and the second, where society by professional status will be determined by the economy. The need for a perfect organization of social life leads to the birth of the state and its leadership (*Bibler, 2018, p. 190*). The history of mankind during the period of agrarian and even transition to industrial society has left us with evidence of the then existing *principle of settlement of citizens in the city plan depending on social and property status, that is, the principle of the structure of society was clearly reflected in the planning of the city.* This is what became the source of the search for connections between socio-humanitarian knowledge and urban planning and architecture!

Further empirical research, comparing urban planning in states with a centralized system of government and individual manifestations of democratization, regardless of socio-economic formation, showed incredible differences in urban planning. Thus, the first type of states was characterized by an extraordinary orderliness of planning, even starting from the outline of the plan, most often the city was square in plan, with square or rectangular blocks, there was always an orientation of the city plan to the cardinal points, settlement was differentiated according to the social or property status of the inhabitants, there was a mandatory axial symmetry in the formation of the city center or urban ensemble, which necessarily occupied the territory of the geometric center, cities had one main function, the main buildings in the cities were either palaces or temple complexes. Some countries with centralized power were also characterized by

canonical planning schemes, the presence of treatises in which the principles of local government organization and urban planning were simultaneously considered in unity, and modules were used in the construction that helped to implement its typification (*Bunin & Savarenskaya, 1979*). Of course, under such conditions, the ideology of the ruling elite was reflected in the main object, such as the urban ensemble (*Figure 3*). The second type of state with elements of social democratization lacked all of the above, despite the fact that order existed, for example, in Ancient Greece, cities of the classical period had a quarter system with development according to the "golden ratio" along with a free outline of cities, the principles of development of city centers were characteristic: "perception of buildings at an angle" and "picturesque filling of the viewer's horizon", public buildings were intended mainly for residents—libraries, theaters, stadiums, meeting rooms, etc. In our state of the times of Rus-Ukraine, there was an orientation in the organization of both the city center and any estate onto the so-called "red" (beautiful) porch. Cities of this direction of power were multifunctional, unique in planning. All similar actions to decorate the city center were distinguished by diversity. Thus, the history of urban planning clearly notes *the dependence on the political regime* urban planning and the formation of buildings, the influence of ideology on architecture and the synthesis of arts, necessary to enhance the effect of the "appeal" of architecture and artistic means to a person, to the viewer who is in the space of the city.

Modern socio-humanitarian sciences, which, in connection with social processes and achievements of the present, are growing due to the multitude of tasks that require urgent solutions. Since the middle of the twentieth century, systemic research in various scientific fields has begun to spread, including the person himself, treated by science as a biopsychosocial system that is constantly in contact with the environment, natural and mental environment. Since a person is a system, his needs are systemic, and of course, he demanded consistency in the organization of space for his life. Knowledge of universal science Systemic research, which allows for scientific research in any field, regarding any objects and phenomena, has helped to understand various architectural and urban planning objects, establish the unity of the laws of their construction, regardless of the theoretical distribution of these objects in individual fields, and understand, using the system-structural and system-functional types of systems analysis, the essence of the formation of architectural space, its dependence on temporal changes and the renewal of functions and the corresponding changes in the structure of architectural objects that have occurred recently and lead to multifunctionality and a complex-universal figurative solution to replace the typological purity and clearly defined imagery in the architecture of the last century. Figure 2 (*Appendix*) shows one of the examples obtained through system analysis. This is a single object series that covers interior design, residential apartments and houses, urban planning, regional planning and the system of settlements. All components of this system called *Housing*, which belonged to different areas in the design and solution of professional problems and required specialists of different specializations, were created on the basis of a single spatial-communication structure, where each component increases spatially, territorially, based on the growth of the collective of residents or representatives of the population using it, the change, increase and complication of life tasks and needs.

Recently, more and more socio-humanitarian disciplines are beginning to be developed in terms of content to meet the needs of individual specialties for a deeper and broader

understanding of the basic foundations of professional training. The author offers to make a brief overview of some socio-humanitarian disciplines that are associated with the need to understand the specifics of the directions of the formation of architectural and urban space. The first group of sciences includes those that are fundamental, which provide basic knowledge, explain the objective laws of the surrounding world (*Batryn, 2024, p. 260*). This is philosophy, economics, political science as such, and their various combinations, variations of combinations, needed by modern society, when the methods of one science are used to study the problems of another, for example, political psychology, political geography, political anthropology, etc. Political science is a branch of knowledge that studies the political life of society, subjects of political activity, the representation of power and types of government systems, and many other aspects. But architectural science is interested in political regimes, on which the ideology of the state depends, which determines the directions of socio-cultural and architectural-urban planning activities. By the way, the branches born of political science can also be useful for architecture. Thus, political psychology can become one of the aspects in the formation of public opinion in the activities of communities regarding changes in the use and establishment of new functions of public spaces, political geography will help in solving territorial problems that directly relate to urban planning, regional planning and the system of settlements, political anthropology (ethno-political studies) is useful when studying the history of architecture, especially its early stages.

The second group of sciences that are in contact with architecture includes those that directly take on the solution of architectural problems, these are law, sociology (*Pichi, 2009*), psychology (*Rubinstein, 1999*), including the specifics of the psychology of the Ukrainian people, which is determined by historical social processes (*Gubko, 2004*). Architecture as a work of art, thanks to its form and style formation, is able to talk about social life, the type of political system, the ideology of the state (*Otreshko, 2013*) and state policy towards society. V. Otreshko believed that "ideology is an integral part of the spiritual life of society, an important element of social consciousness. It is about the relationship of consciousness with social psychology, politics, law, morality, philosophy, science, religion, etc. In fact, we can say that ideology, together with law, morality, and the system of values accepted in society, is the cementing spiritual foundation of its existence and the defining guiding moment of state formation." (*Otreshko, 2013*)

Thus, the interaction of the political regime, state policy and political economy determines the state's order for the professional sphere, in a certain sense, the state's "dictation" regarding the socio-demographic structure is manifested, which is reflected in the planning of any urban development objects. Sociology not only studies society, its changes and needs (*Pichi, 2009*), but also provides survey materials that help architecture establish norms and standards for design, the level and needs of types of services, under market conditions, volumes for housing of various categories and other indicators are established. Legal sciences in architectural and urban development activities are extremely important, they establish legal norms, construction legislation. The list of socio-humanitarian sciences that directly help architectural and urban development activities to solve specific issues is large—these are medicine, human ecology, ethnology, religious studies, economical geography, geology, art history and others. Each of them contributes to creating an environment for the life of consumers-customers—humans, society, and the state; these sciences can be classified as applied.

Discussion

In addition, it is possible to single out a separate group of sciences that closely interact with the theory of architecture and the foundations of creativity—art history, aesthetics, graphic design, history of culture, design, architecture, urban planning, composition, etc.

An extremely important event in the field of architectural theory was the birth of the monograph *Constellation of the Architectural and Urban Heritage of Ukraine* by the doctors of architecture of the KNUBA, professors Timokhin and Shebek, a major scientific work, the scientific research of which is based on a combination of a deep theoretical base and long-term field surveys that took place during the authors' trips throughout Ukraine, photo fixation, sketches, picturesque and graphic works of monuments of architecture, culture and modern architecture, which provided a vivid picture of the features of the specifics of the architectural and urban space of the regions of our country. The scientific conclusions were also tested and confirmed in the final certification works of the masters-scientists of the Faculty of Architecture. The scientific work involved "integrative methods of researching regional cultures, which combine the achievements of history and cultural studies, geography and geology, astrology and eniology, urban synergetics and the theory of harmonization of the architectural environment, socionics and sacred mythopoetics, landscape science and fractal geometry. Having common features, they are united under the guidance of the methodological principles of critical regionalism and physiognomy of cultures, which serve as a guide in complex architectural and urban planning studies." (*Timokhin & Shebek, 2025, p. 263*) Compared to the complex of socio-humanitarian sciences mentioned in the article, which exist as scientific knowledge in themselves and, forming a worldview and social consciousness, influence varieties of cultural activity, can be useful for architectural science and practice, this unique work is distinguished by the fact that in it scientists involve a wide range of knowledge, both scientific and non-scientific, for analysis, architectural research takes an active position, it does not analyze the possibility of applying other sciences, it dictates what exactly should take part in scientific research in architecture and urban planning. I think that such a position, such an approach, like the first swallow, will open the way for the further development of architectural science, which will take its leading place among other sciences about the environment where man lives and acts.

Conclusion

1. Close contact was established between socio-humanitarian sciences and professional architectural and urban planning activities during the second half of the 20th century.
2. The change in the scientific paradigm in the scientific world led to the extraordinary spread and branching of socio-humanitarian sciences, some of which increasingly explain processes in the history of cultural activity, and specifically in the history of architecture and urban planning.
3. The tendency to attribute architecture to engineering, which is observed in European universities and is copied by Ukrainian educational activities for the sake of the desire to get closer to the European Union, is absolutely wrong, because it limits the knowledge of Ukrainian specialists.

4. Knowledge of socio-humanitarian sciences allows us to find explanations for any phenomena in architecture and urban planning, provides opportunities to consciously choose the planning, structure, style of architectural objects and, understanding the essence of social processes, predict directions in architecture and urban planning for the future.

5. The latest scientific work *Constellation of Architectural and Urban Heritage of Ukraine* (*Timokhin & Shebek, 2025*) once again demonstrated a change in the scientific paradigm in scientific research in the architectural and urban planning field, when architecture is not involved in contacts with socio-humanitarian sciences, but shows an active stance on the choice of scientific and non-scientific knowledge that is necessary for scientific research in architecture and urban planning.

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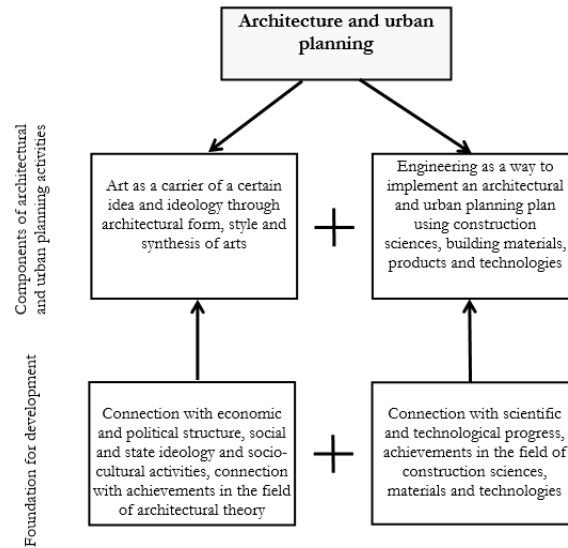
Appendix

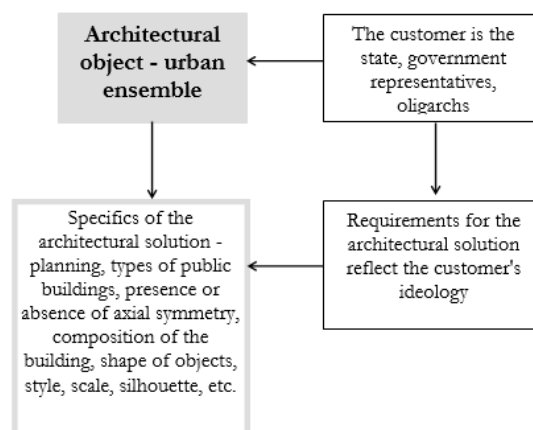Figure 1. Components of architecture and urban planning

Figure 2. Reflection of ideology (needs of the authorities in the formation of the architecture of the urban planning ensemble
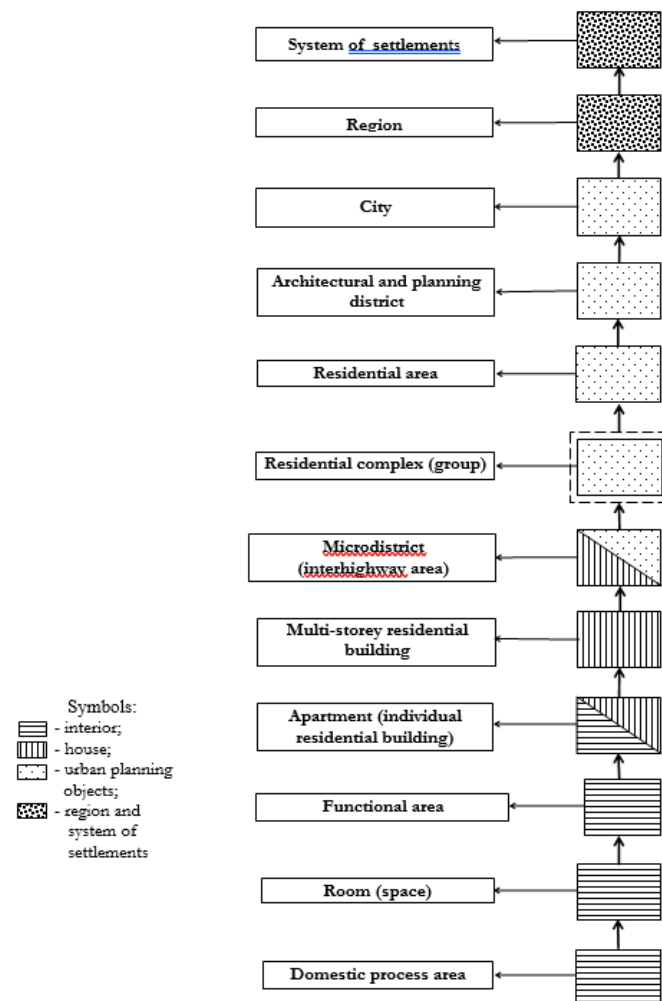
Figure 3. One example of using the research system is an object series in architecture and urban planning

Authors:

[1] *Oleksiy V. Myronyuk*, Doctor of Engineering Sciences, Associate Professor, Department Head, Chemical Technology of Composite Materials Department, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.
https://orcid.org/0000-0003-0499-9491

[2] *Oleksiy O. Sikorsky*, Candidate of Engineering Sciences (Ph.D.), Senior Lecturer, Chemical Technology of Composite Materials Department, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.
https://orcid.org/0000-0002-3730-2016

[3] *Kateryna Yu. Redko*, Candidate of Economic Sciences (Ph.D.), Associate Professor, Senior Researcher, G. M. Dobrov Institute for Scientific and Technological Potential and Science History Studies. Kyiv, Ukraine.
https://orcid.org/0000-0003-2609-3471

[4] *Oleksandr V. Kharlan*, Candidate of Sciences in Architecture (Ph.D.), Associate Professor, Department of Design and Reconstruction of the Architectural Environment, Faculty of Architecture, Ukrainian State University of Science and Technology, Educational and Scientific Institute "Pridneprovska State Academy of Civil Engineering and Architecture". Dnipro, Ukraine.
https://orcid.org/0000-0003-1473-6417

[5] *Yevhen A. Vilgin*, Doctor of Public Administration, Associate Professor of the Department of Public Administration and economic policy, Simon Kuznets Kharkiv National University of Economics. Kharkiv, Ukraine.
https://orcid.org/0000-0003-3607-2711

[6] *Lyudmila Y. Avedyan*, Ph.D. in Economics, Associate Professor Department of Public Administration, Public Administration and Economic Policy, Simon Kuznets Kharkiv National University of Economics. Kharkiv, Ukraine.
https://orcid.org/0000-0002-4636-6898

[7] *Hanna B. Breslavska*, Candidate of Pedagogical Sciences (Ph.D.), Senior Lecturer, Department of Primary Education, Admiral Makarov National University of Shipbuilding. Mykolaiv, Ukraine.
https://orcid.org/0000-0002-6144-4890

[8] *Liubov V. Stehnitska*, Candidate of Philological Sciences (Ph.D.), Associate Professor, Department of Foreign Languages, Bukovinian State Medical University. Chernivtsi, Ukraine.
https://orcid.org/0000-0001-7005-4563

[9] *Myroslava P. Kukhta*, Doctor of Sociological Sciences, Associate Professor, Department of Sociology, Faculty of Sociology and Law, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". Kyiv, Ukraine.
https://orcid.org/0000-0003-4663-9670

[10] *Dmitro L. Hasilin*, Ph.D. Student, Department of Information Technology Security, National University "Lviv Polytechnic". Lviv, Ukraine.
https://orcid.org/0009-0000-4636-7666

[11] *Ihor M. Zhuravel*, Doctor of Engineering Sciences, Senior Researcher, Department Head, Department of Information Technology Security, National University "Lviv Polytechnic". Lviv, Ukraine.
https://orcid.org/0000-0003-1114-0124

[12] *Lyudmyla V. Haponova*, Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department Head, Department of Computer Graphics, Kharkiv National Automobile and Highway University. Kharkiv, Ukraine.
https://orcid.org/0000-0002-6038-2624

[13] *Volodymyr I. Oleksyn*, Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Computer graphics, Kharkiv National Automobile and Highway University. Kharkiv, Ukraine.
https://orcid.org/0000-0002-3223-8561

[14] *Pavlo F. Budanov*, Candidate of Technical Sciences (Ph.D.), Associate Professor, Department of Electrical Engineering and Power Engineering, V.N. Karazin Kharkiv National University. Kharkiv, Ukraine.
https://orcid.org/0000-0002-1542-9390

[15] *Vitaliy V. Shutyuk*, Doctor of Engineering Sciences, Professor, Department of Canning Technology, National University of Food Technologies. Kyiv, Ukraine.
https://orcid.org/0000-0002-6480-5890

[16] *Olha V. Dushchak*, Candidate of Engineering Sciences (Ph.D.), Associate Professor, Department of Canning Technology, National University of Food Technologies. Kyiv, Ukraine.
https://orcid.org/0000-0002-9811-3286

[17] *Liudmyla G. Bachynska*, Associate Professor, Candidate of Architecture, Professor, Member of the Ukrainian Academy of Architecture, Department of Fundamentals of Architecture and Architectural Design, Faculty of Architecture, Kyiv National University of Construction and Architecture. Kyiv, Ukraine.
https://orcid.org/0000-0002-6942-5627

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