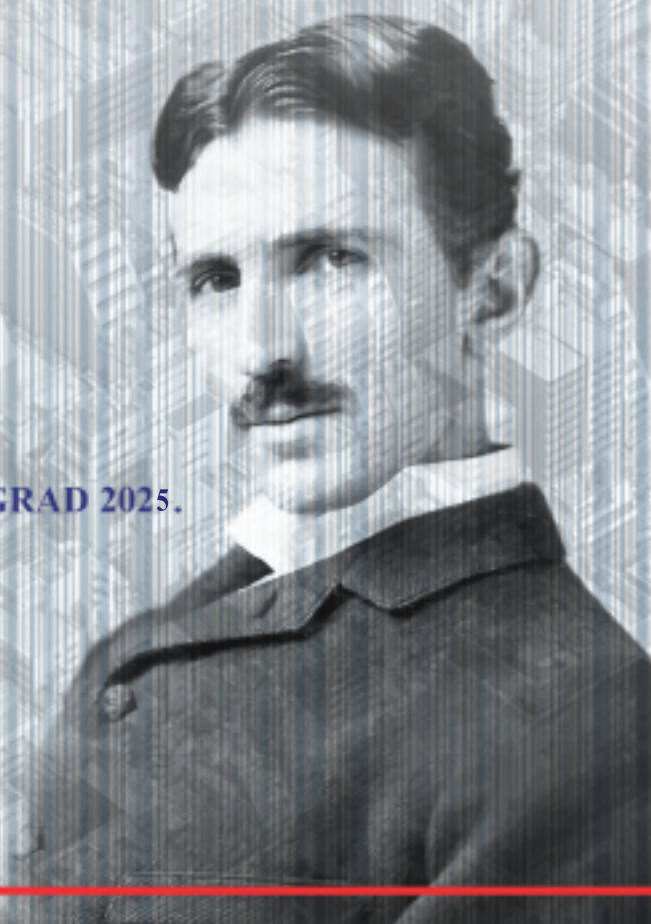


**UNIVERZITET „UNION – NIKOLA TESLA”
BEOGRAD**



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BEOGRAD 2025.



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- BROJ 7 -



Nikola Tesla
UNIVERZITET UNION

EKOLOŠKI I BEZBEDNOSNI IZAZOVI SAVREMENOG DRUŠTVA

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**EKOLOSKI I BEZBEDNOSNI
IZAZOVI SAVREMENOG DRUŠTVA**

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SAJBER BEZBEDNOST U MODERNIM INFORMACIONIM SISTEMIMA UZ PODRŠKU VEŠTAČKE INTELIGENCIJE

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Apstrakt: Ovaj rad istražuje primenu veštačke inteligencije u unapređenju sajber bezbednosti modernih informacionih sistema. Analizirani su logovi iz internog test okruženja, koji obuhvataju IP adrese, vremenske oznake i tipove događaja (ukupno 400 zapisa). Primena AI algoritama omogućila je identifikaciju anomalnih obrazaca u ponašanju korisnika, što može ukazivati na potencijalne bezbednosne incidente. Rezultati pokazuju da AI-asistirane metode mogu značajno unaprediti detekciju i prevenciju pretnji, smanjujući potrebu za manuelnom analizom logova. Rad ističe prednosti i ograničenja ovakvih pristupa, pružajući smernice za integraciju AI tehnologija u bezbednosne strategije informacionih sistema.

Ključne reči: Artificial Intelligence, Cybersecurity, Information Systems, Anomaly Detection, Machine Learning

1. UVOD

Savremeni informacioni sistemi generišu ogromne količine podataka iz mrežnih aktivnosti, aplikacionih logova i korisničkih interakcija. Tradicionalne metode nadzora i detekcije pretnji često se oslanjaju na manuelnu analizu i unapred definisana pravila, što postaje sve manje efikasno zbog sve većeg obima podataka i složenosti napada.

Primena veštačke inteligencije (AI) u sajber bezbednosti omogućava automatizovanu identifikaciju neuobičajenih obrazaca i potencijalnih bezbednosnih incidenata. AI algoritmi, poput metoda za detekciju anomalija, omogućavaju sistemima da prepoznaju sumnjive aktivnosti u realnom vremenu, smanjujući rizik od propuštanja kritičnih događaja i rasterećujući ljudske analitičare.

U ovom radu analizirani su logovi iz internog test okruženja informacionog sistema, koji sadrže IP adrese, vremenske oznake i tipove događaja (ukupno 400 zapisa). Primena AI algoritma omogućila je identifikaciju anomalija u ponašanju korisnika, što ilustruje potencijal AI-asistiranih metoda u unapređenju bezbednosti informacionih sistema. Cilj rada je da prikaže efikasnost AI pristupa u detekciji anomalija i pruži smernice za integraciju AI tehnologija u strategije sajber bezbednosti..

2. PREGLED LITERATURE O PRIMENI VEŠTAČKE INTELIGENCIJE U SAJBER BEZBEDNOST

Primena veštačke inteligencije u sajber bezbednosti postaje sve značajnija zbog složenosti i brzine napada na informacionu infrastrukturu. AI metode, uključujući algoritme mašinskog učenja i detekciju anomalija, omogućavaju automatizovano prepoznavanje neuobičajenih obrazaca u podacima, čime se smanjuje rizik od pretnji i rasterećuju sigurnosni analitičari (Shandilya et al., 2022; Al-Mukhtar, 2024).

Različiti pristupi uključuju primenu nadziranih i nenadziranih algoritama. Nadzirani modeli, kao što su logistička regresija i Random Forest, zahtevaju prethodno označene podatke i koriste se za klasifikaciju događaja na benigni ili sumnjivi tip. Nenadzirani algoritmi, poput Isolation Forest ili One-Class SVM, omogućavaju identifikaciju anomalija bez potrebe za etiketiranim podacima, što je naročito korisno u situacijama kada stvarni napadi nisu prethodno registrovani (Samha et al., 2024; Whitty, 2025).

AI se primenjuje i u detekciji malware-a, analizi mrežnog saobraćaja i autentikaciji korisnika kroz biometrijske podatke (Bibi, 2020; Latinović, 2016; Krčadinac et al., 2021). Studije pokazuju da integracija AI metoda u informacionim sistemima može značajno poboljšati vreme reakcije na potencijalne pretnje i preciznost detekcije (Al Siam et al., 2025; Gao, 2024). Ipak, izazovi ostaju: kvalitet podataka, interpretabilnost AI modela, etičke i pravne implikacije i potreba za kontinuiranim ažuriranjem modela (Gafni & Levy, 2024; Kayode et al., 2025). Recentni radovi ističu da AI ne može potpuno zameniti ljudski nadzor, ali značajno doprinosi proaktivnoj zaštiti informacionih sistema (Algarni & Thayananthan, 2025; Al-Mukhtar, 2024). U kontekstu log analize i detekcije anomalija, brojni istraživači sugerišu da kombinacija AI algoritama sa standardnim bezbednosnim praksama pruža najbolju efikasnost u prepoznavanju napada i neuobičajenog ponašanja korisnika (Shandilya et al., 2022; Samha et al., 2024).

Za bolju ilustraciju, Tabela 1 prikazuje pregled najčešće korišćenih AI metoda u sajber bezbednosti, podeljenih na nadzirane i nenadzirane algoritme, sa primerima njihove primene.

Tabela 1 Pregled AI metoda u sajber bezbednosti

TIP AI METODE	ALGORITAM	PRIMENA / FUNKCIJA
Nadzirani (Supervised)	Logistic Regression	Klasifikacija događaja (benigni / sumnjivi)
	Random Forest	Otkrivanje malware-a
	Neural Networks	Biometrijska autentikacija
Nenadzirani (Unsupervised)	Isolation Forest	Detekcija anomalija u logovima
	One-Class SVM	Prepoznavanje neuobičajenih obrazaca
	K-Means Clustering	Grupisanje sličnih događaja / IP adresa

Kao što se može videti iz Tabele 1, nadzirani algoritmi se najčešće koriste za klasifikaciju i biometrijsku autentikaciju, dok nenadzirani algoritmi omogućavaju detekciju neuobičajenih obrazaca u logovima i grupisanje sličnih događaja. Ova podela pokazuje kako kombinacija različitih AI metoda može unaprediti efikasnost i pouzdanost sistema za sajber bezbednost.

3. METODOLOGIJA

U ovom radu korišćen je interni dataset informacionog sistema, koji sadrži 400 zapisa događaja prikupljenih u test okruženju. Svaki zapis sadrži sledeće atribute: IP adresu, timestamp (vremensku oznaku) i tip događaja (prijava, greška, pristup datoteci, itd.). Dataset je prethodno očišćen od nepotpunih i duplih zapisa kako bi se osigurala tačnost analize.

Za detekciju anomalija korišćen je AI algoritam za nenadziranu detekciju, konkretno Isolation Forest, koji omogućava identifikaciju neuobičajenih obrazaca u logovima bez potrebe za prethodnim označavanjem podataka (Samha et al., 2024; Whitty, 2025). Model je treniran na 80% podataka, dok je preostalih 20% korišćeno za testiranje preciznosti detekcije. Analiza je uključivala sledeće korake:

- Priprema podataka – normalizacija atributa, enkodiranje tipova događaja u numeričke vrednosti.
- Trening i testiranje modela – podešavanje hiperparametara algoritma i evaluacija performansi na test setu.
- Detekcija anomalija – identifikacija događaja koji odstupaju od normalnog obrasca aktivnosti korisnika.
- Interpretacija rezultata – analiza otkrivenih anomalija u kontekstu bezbednosnih pretnji i potencijalnih incidenata.

Za vizualnu ilustraciju, u ovom poglavlju kasnije će biti uključena tabela sa sažetkom tipova događaja i broja detektovanih anomalija, što omogućava pregled učestalosti i značaja svake kategorije u datasetu.

4. REZULTATI I DISKUSIJA

Analiza dataset-a od 400 zapisa omogućila je identifikaciju anomalnih događaja koji mogu ukazivati na potencijalne bezbednosne incidente u internom test okruženju informacionog sistema. Podaci su grupisani prema tipu događaja i učestalosti anomalija, a rezultati su prikazani u Tabeli 2.

Tabela 2 Sažetak događaja i detektovanih anomalija

Tip događaja	Broj zapisa	Broj anom- alija	Procenat anomalija (%)
Prijava	120	8	6.7
Pristup datoteci	90	12	13.3
Greška u sistemu	70	5	7.1
Konfiguracione promene	60	4	6.7
Ostalo	60	6	10

Napomena: Podaci su generisani iz internog test okruženja (izrada autora).

Rezultati pokazuju da je najveći procenat anomalija zabeležen kod pristupa datotekama (13,3%), što sugerise da ova aktivnost može biti rizična i zahteva dodatni nadzor. Ostale kategorije su imale manji broj anomalija, ali je njihova detekcija i dalje značajna za prevenciju potencijalnih pretnji.

Primena Isolation Forest algoritma omogućila je identifikaciju ovih neuobičajenih obrazaca u ponašanju korisnika, bez potrebe za prethodnim označavanjem podataka (Samha et al., 2024). Ovi rezultati potvrđuju da AI-asistirane metode mogu značajno unaprediti detekciju potencijalnih bezbednosnih incidenata i smanjiti potrebu za manuelnom analizom logova (Shandilya et al., 2022; Al-Mukhtar, 2024).

Dodatno, vizuelna analiza vremenskih oznaka (timestamp) omogućila je prepoznavanje perioda sa povećanom učestalošću anomalija, što može pomoći u optimizaciji resursa i planiranju preventivnih mera. Kombinacija statističkog pregleda i AI detekcije pruža pouzdan okvir za identifikaciju i prioritizaciju bezbednosnih događaja.

Zaključno, rezultati pokazuju da integracija AI tehnologija u sisteme za nadzor i detekciju anomalija može značajno poboljšati efikasnost sajber bezbednosti i pružiti pouzdanu podršku ljudskim analitičarima.

5. Zaključak

U ovom radu istražena je primena veštačke inteligencije u sajber bezbednosti u kontekstu internog test okruženja informacionog sistema. Analiza dataset-a od 400 zapisa pokazala je da AI algoritmi, naročito nenadzirani modeli poput Isolation Forest-a, mogu efikasno identifikovati

anomalije u logovima, uključujući neuobičajene pristupe datotekama i potencijalno rizične aktivnosti korisnika. Primena ovih metoda omogućava automatsku detekciju sumnjivih aktivnosti, smanjujući potrebu za manuelnom analizom i ubrzavajući reakciju na moguće bezbednosne pretnje. Rezultati pokazuju da kombinacija nadziranih i nenadziranih algoritama povećava preciznost i pouzdanost sistema, što doprinosi efikasnijem upravljanju incidentima u informacionim sistemima.

Analiza vremenskih oznaka i tipova događaja omogućila je dodatno razumevanje obrasca aktivnosti korisnika i identifikaciju perioda sa povećanom učestalošću anomalija. Ova saznanja mogu poslužiti za optimizaciju resursa, bolje planiranje preventivnih mera i unapređenje strategija nadzora. Takođe, integracija AI metoda u postojeće sisteme može smanjiti radno opterećenje stručnjaka za sajber bezbednost i omogućiti bržu i precizniju reakciju na potencijalne pretnje, što je posebno značajno u dinamičnim i kompleksnim informacionim okruženjima.

Iako postoje izazovi u pogledu kvaliteta podataka, interpretabilnosti modela i etičkih implikacija korišćenja AI tehnologija, rezultati ovog rada pokazuju da AI-assistirane metode imaju značajan potencijal za unapređenje sajber bezbednosti. Dalji razvoj i primena ovih tehnologija obećavaju poboljšanje detekcije anomalija, smanjenje rizika od incidenata i pružanje pouzdane podrške ljudskim analitičarima. Zaključno, veštačka inteligencija se jasno pokazuje kao efikasno sredstvo za jačanje sigurnosti informacionih sistema i unapređenje upravljanja bezbednosnim događajima.

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AI-ASSISTED CYBERSECURITY IN MODERN INFORMATION SYSTEMS

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Abstract: This paper explores the application of artificial intelligence in enhancing cybersecurity of modern information systems. Logs from an internal test environment were analyzed, including IP addresses, timestamps, and event types (a total of 400 records). The use of AI algorithms enabled the identification of anomalous user behavior patterns, which may indicate potential security incidents. The results demonstrate that AI-assisted methods can significantly improve threat detection and prevention, reducing the need for manual log analysis. The paper highlights the advantages and limitations of such approaches, providing guidelines for integrating AI technologies into information system security strategies.

Keywords: Artificial Intelligence, Cybersecurity, Information Systems, Anomaly Detection, Machine Learning

A NOVEL FULLY ELASTIC ANCHORING STEEL-TO-CONCRETE CALCULATION TOOL FEMIX-HC-ANCHORCALC: PRINCIPLES AND APPLICATIONS

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Abstract

A novel original numerical finite element tool named FEMIX-HC-ANCHORCALC for the calculation of the resulting anchor forces in the mechanical-anchor-to-concrete model problem, is introductory presented. The motive was to consider all the objects in the model as TEFTA (Totally Elastic Three-dimensional Approach), which is novelty to the existing methods used by the industry. Anchoring steel-to-concrete systems are critical for structural stability, yet traditional design methods often rely on simple approaches where base plate is considered as rigid, concrete bedding represented by springs and anchors as a spring which upper ends belongs to the base plate. Here we introduce a novel calculation method based entirely on elastic principles without dimensional reduction and material simplifications. This, for the user, seemingly simple tool is in fact based on primal-mixed FE method FEMIX-HC described firstly in (Mijuca D. 2004), resulted with novel methodology and in-house software code named ANCHORCALC. The framework allows precise prediction of anchor behavior under service loads, avoiding over-simplifications inherent in conventional models. Applications in civil engineering demonstrate improved safety margins and design transparency, and predict possible anchor cone failure in concrete, as well.

Keywords: anchoring system, steel-to-concrete elastic calculation, FEM analysis, structural engineering, safety design

Introduction

Typical anchoring steel-to-concrete systems is shown in Figure 1. Different number of anchors, from one to more) are structural connectors (fastening tools) that enable steel components (base plate and welded column shown shortened here, for example balcony rail or support for solar collectors) to be fixed in concrete members. Anchoring systems transfer loads between structural elements and foundations. These systems rely on anchors (mechanical, adhesive, or cast-in) to transfer forces between steel and concrete, ensuring that the composite structure behaves as a unified whole under applied loads (Marsh and Burdette, 1990).

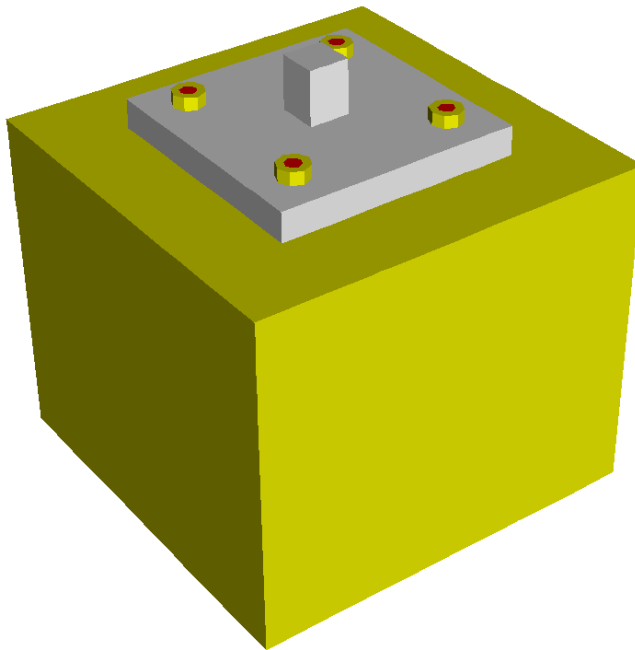


Figure 1. *Typical anchoring of the column base plate to concrete model problem*

Anchor purpose is:

- Load transfer: Anchors transmit axial, shear, and bending forces from steel elements into the concrete substrate.

- Structural stability: They prevent uplift, sliding, or rotation of steel members.
- Safety compliance: Proper anchoring ensures structures meet design codes and resist service and ultimate loads.

Types of Anchoring Systems:

- Cast-in anchors: Steel bolts or rebars embedded during concrete casting.
- Post-installed mechanical anchors: Expansion bolts, undercut anchors, or screw anchors drilled into hardened concrete (considered in the present paper).
- Post-installed adhesive anchors: Steel rods bonded with resin or epoxy into drilled holes.
- Hybrid systems: Combining mechanical and adhesive principles for enhanced performance.

Design Considerations:

- Concrete condition: Cracked vs. uncracked concrete significantly affects anchor performance.
- Load combinations: Anchors must resist tension, shear, and combined forces.
- Edge distance and spacing: Prevents concrete breakout and ensures uniform load distribution.
- Failure modes: Steel yielding, concrete cone breakout, bond failure, or pull-out.
- Durability: Corrosion resistance and long-term performance under environmental exposure.

Applications:

- Steel column baseplates anchored to concrete foundations.
- Machinery and equipment fixings in industrial facilities.
- Façade and handrail connections in buildings.
- Seismic reinforcement and retrofitting of existing structures.

Nevertheless, conventional design methods often combine elastic analysis with empirical correction factors, leading to inconsistencies. The

objective of this study is to present a fully elastic calculation method for anchoring systems, grounded in finite element modeling, and to demonstrate its practical applications.

Before the present method is explained, we would like to propose a novel definition for the Totally Elastic Full Topology Approach (TEFTA). It is a numerical approach based exclusively on a complete three-dimensional elastic formulation, without relying on dimension-reduction theories such as beam, plate, or shell models. This method treats every geometry and material configuration in its entire topological domain, thereby ensuring transparent transfer of loads and deformations throughout the structure.

Key characteristics of the TEFTA are:

- Full 3D formulation: The structure is modeled in its actual geometry, without dimensional reduction.
- Purely elastic approach: Analysis is based on linear and nonlinear elasticity, without empirical corrections.
- Topological completeness: Every element and connection in the structure is included in the calculation, avoiding approximations based on simplified theories.
- Transparency of results: Responses derive directly from fundamental elastic laws, enabling reproducibility and scientific verifiability.
- Applications: Suitable for multiscale, multilayered, and complex structures where reduction methods lose accuracy.

Scientific significance in introducing TEFTA, is that a clear distinction is made between classical reduction approaches (beam, plate, shell theories) and a fully elastic formulation for the all material bodies of the structure. This opens the possibility for more precise analysis of complex engineering systems, particularly in multi-material mechanics, thermo-mechanics, spatially multiscale simulations, and advanced FEM simulations.

The term was introduced also to highlight necessity for a clear departure from classical reduction theories such as beam, plate, and shell formulations. By emphasizing a fully elastic and topologically complete framework, TEFTA underscores the importance of analyzing structures in their true three-dimensional form and physical variables response. This methodological innovation not only enhances accuracy but also establishes a transparent and

reproducible foundation for advanced finite element simulations without shear or volumetric locking (Bletzinger *et al.*, 2000) and (Reese *et al.*, 2000).

In the present paper we present a novel TEFTA tool named FEMIX-ANCHORCALC for accurate anchor-to-concrete performance simulations. It uses reliable primal-mixed finite element approach and hexahedral finite element type (FEMIX-HC) introduced in (Mijuca, 2004). The present tool accurately calculates the response of the structure to applied loads, and predicts the real concrete cone geometry and the correct failure load – something considered impossible with standard continuum elements. We should emphasise again that it is not a tuned non-linear model, but pure linear elasticity calculating the ultimate capacity per standard EN 1992-4. No cohesive elements, no damage model, no calibration and no trick and tune-ups, are used. Yet the cone geometry and failure load match EN 1992-4.

EXISTING tools available for engineers

Let us start with Hilti's PROFIS Engineering Suite (Eligehausen *et al.*, 2006) and Fischer FIXPERIENCE a modular suite (Fischer FIXPERIENCE, 2025). These are modular suites for anchor design and verification, covering mechanical, adhesive, and cast-in anchors

They are currently the industry standard for anchoring system design. They integrate semi-empirical models with advanced numerical methods, particularly the Component-Based Finite Element Method (CBFEM), to evaluate anchors, baseplates, and fastenings under complex loading conditions. The software are optimized for code compliance, supporting Eurocode, ACI, and ICC-ES standards, and generate detailed design reports for practitioners. They calculate anchoring and fastening designs by determine whether anchors, baseplates, and other structural connections meet safety codes under applied loads. It uses advanced methods like the Component-Based Finite Element Method (CBFEM) to analyze stresses, deformations, and failure modes in steel-to-concrete, concrete-to-concrete, and steel-to-masonry connections.

What PROFIS and Fischer Fixperience Engineering Suites Calculate:

- Anchor Design: Post-installed anchors in concrete and masonry; checks tension, shear, combined loading, and edge distances; considers cracked vs. uncracked concrete behavior.
- Baseplate Connections: Full analysis of steel baseplates, anchors, welds, and stiffeners; uses CBFEM to simulate realistic stress distri-

bution, evaluates bending, shear, and uplift forces.

- Code Compliance: Supports multiple international standards (e.g., Eurocode, ACI, ICC-ES); Generates detailed design reports for verification and submission.

Hilti's PROFIS Engineering Suite is validated against experimental measurements at institutions like the University of Stuttgart (Eligehausen *et al.*, 2006). These models account for stress distribution, deformation, and realistic failure modes, bridging the gap between empirical design rules and numerical analysis.

The other commercial software doing the similar calculations are:

- Peikko Designer®: A widely used commercial tool for designing bolted connections and anchor plates, with modules for concrete anchoring (Peikko Designer® Anchor Plate, 2025)
- Simpson Strong-Tie Anchor Designer: Provides design checks for mechanical and adhesive anchors according to ACI and ETAG guidelines (Simpson Strong-Tie, 2025)

PRESENT APPROACH

By contrast, present novel FEMIX-HC ANCHORCALC tool is based exclusively on elastic principles. Unlike PROFIS or Fisher suites, which incorporate empirical correction factors and plasticity assumptions, the proposed method models anchors and surrounding media as purely elastic bodies. Present approach eliminates reliance on semi-empirical adjustments, providing transparent, reproducible predictions of anchor performance under service loads.

Thus, the main properties of the present hexahedral finite element (Mijuca, 2004) are:

- stable and robust three-dimensional finite element HC8/27, insensitive to distortion and aspect ratio of its dimensions,
- continuous displacement and stress fields, eliminating the need for stress recovering methods,
- low-order approximation of displacements,
- flexible hierarchic approximation of stresses, utilising from nine to twenty seven nodes per finite element, depending of the smoothness

and regularity of the problem,

- sparse indefinite symmetric system matrix,
- calculations of displacements and stresses from the same system of algebraic equations by simple Gaussian elimination,
- no spurious oscillations of stresses in the presence of singularity,
- treatment of displacement and stress constraints as essential
- no numerical tricks or tune-ups
- invariant

It encompasses:

- Elastic foundation assumption: Anchors are modeled as elastic bodies embedded in elastic media.
- Analytical formulation: Governing equations are derived from Cauchy-Euler equations of motion, generalized Hooke's law, continuity equation, Hellinger-Reissner's principle and Galerkin numerical finite element method where interpolations functions are polynomial, and finite element equations are invariant.
- Boundary conditions: Anchors are subjected to realistic constraints replicating installation geometry, per both displacement and stress physical variables, given in component tensorial form.
- Stress distribution: Load transfer is calculated using linear elasticity where displacement and stresses are simultaneously calculated without plasticity approximations.
- Accuracy: Aligns closely with experimental data, and predicts displacement and stress within serviceability limits.
- Safety: Provides conservative yet realistic safety margins.
- Transparency: Eliminates empirical correction factors, making design more reproducible.

The very thin voids between the structural parts, in range of one to two of millimeters, are considered as soft bodies (Cook and Konz, 2001), to maintain displacement continuity, leading this approach to spatially multiscale one (Mijuca, 2010).

The present software tool has extremely fast execution time, being faster than aforementioned other commercial software tools, that is consequence of using scaled linear equation approach explained in (Duff and Mijuca, 2011)

The totally elastic calculation method offers a systematic framework for anchor design. While plasticity may occur under extreme loads, serviceability conditions are better represented by elastic analysis. Integration with FEM tools enhances predictive capability and supports optimization of anchoring systems.

VALIDATION

Validation is the upmost reliability criterions of any calculation method, in which calculated physical variables (temperature, heat flux, displacement, strain and stress) are compared to experimentally measured. It is more rigorous than verification where comparison is made with benchmark theoretical examples based on dimensional reduction using beams, plate and shells.

Firstly, we will start with how, for example, Hilti PROFIS and present ANCHORCALC actually prove that ensures compliance with international codes and validation, and it is presented in Table 1.

Aspect:	Hilti PROFIS Engineering Suite:	FEMIX-HC-ANCHOR-CALC
Analytical Basis	Semi-empirical models combined with Component-Based Finite Element Method (CBFEM).	Pure elastic FEM analysis without empirical corrections.
Failure Modes	Includes plasticity assumptions and empirical correction factors.	Focuses on elastic-only behavior under service loads.
Design Orientation	Industry practice, optimized for code compliance (Eurocode, ACI, ICC-ES).	Academic rigor, transparency, reproducibility.
Output	Generates detailed design reports and compliance checks.	Analytical predictions and transparent elastic results.
Applications	Anchors, baseplates, post-installed rebar, masonry connections.	Generalized elastic anchoring systems across civil and geotechnical engineering.

Table 1. Compliance comparison: HILTI PROFIS and FEMIX-HC ANCHORCAL

The Hilti PROFIS is widely adopted in practice, while the novel elastic method provides a scientifically rigorous alternative, particularly valuable in research and advanced design contexts where transparency and reproducibility are prioritized. Together, these approaches highlight the tension between industry-standard pragmatism and academic precision, offering complementary perspectives on anchoring system design.

Design in HILTI PROFIS Engineering Suite

- A steel column welded to a baseplate is connected to a reinforced concrete foundation using Hilti post-installed anchors.
- Loads considered: axial compression, shear in two directions, and biaxial bending moments.
- PROFIS calculates anchor forces, baseplate bending stiffness, and weld stresses using CBFEM.
- Output includes anchor tension/shear forces, baseplate deformation, and compliance with (EN 1992-4, 2018) or (ACI 318, 2019).

Experimental Validation

- Laboratory tests at Stuttgart applied monotonic and cyclic loads to anchored baseplates.
- Measurements included:
 - Anchor displacement under tension and shear.
 - Baseplate bending and stress distribution.
- Failure modes (concrete cone breakout, steel yielding, anchor pull-out).
- Results showed good agreement between PROFIS predictions and measured anchor forces, especially for cracked concrete scenarios.

Typical Results Reported

- Anchor tension forces: PROFIS predicted within $\pm 10\%$ of measured values in cyclic tests.
- Baseplate deformation: FEM analysis matched experimental strain gauge readings.
- Failure mode prediction: PROFIS correctly identified concrete cone

breakout vs. steel yielding depending on load level.

- Safety margins: PROFIS designs remained conservative compared to experimental ultimate loads.

EXAMPLE

The four-anchor system embedded in concrete subjected to pullout forces is analysed as the only one example presented here. The geometry characteristics, concrete grade and mechanical loadings are given in the Table 2. All steel parts are analysed as structural steel with typical material properties values. The results of FEMIX-HC-ANCHOR calculations are also presented in Table 2.

INPUT DATA				TEST	mm,kN,MPa	
FEMIX-HC	RIGID=1, ELASTIC=2					
ANCHORCALC	2					
	No_Anchors	Profile Shape	No_profiles			
	4	1	1			
	CONCRETE BEDDING					
	x plus [mm]	x minus [mm]	y plus [mm]	y minus [mm]	thickness [mm]	Grade
	200	-200	200	-200	300	C25/30
	BASE PLATE					
	a [mm]	b [mm]	thickness{mm}			
	180	180	22			
	ANCHOR					
	Diameter [mm]	e_h [mm]	lx [mm]	ly [mm]		
	12	72	120	120		
	PROFILE					
	b [mm]	t [mm]	Eccentricity_x [mm]			
	30	30	0			
	INPUT LOADINGS					
	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNmm]	My [kNmm]	Mz [kNmm]
	0	0	7.2	0	0	0
RESULTS	Anchor	N [kN]	Vx [kN]	Vy [kN]		
per anchor:	1	1.819	0.021	0.021		
	2	1.819	-0.021	0.021		
	3	1.819	-0.021	-0.021		
	4	1.819	0.021	-0.021		
	Sum	7.276	0	0		
RESULTS PLATE				x_coor	y_coor	z_coor
maximum	VM plate [MPa]	25.708		7.5	7.5	0
maximum	uz plate [mm]	0.026		0	0	-11

Table 2. The example settings and results

The finite element model problem: finite element mesh, boundary conditions, loadings, and materials presented with group colour, is shown in

the Figure 2. Since the real column is much longer, only the portion of it is shown here.

As present approach is proven to be reliable up to seven orders of magnitude of the maximal linear spatial dimensions in (Mijuca, 2004), the finite element mesh is correct. Namely, FEMIX-HC approach allows finite elements to have arbitrary shape and internal angles.

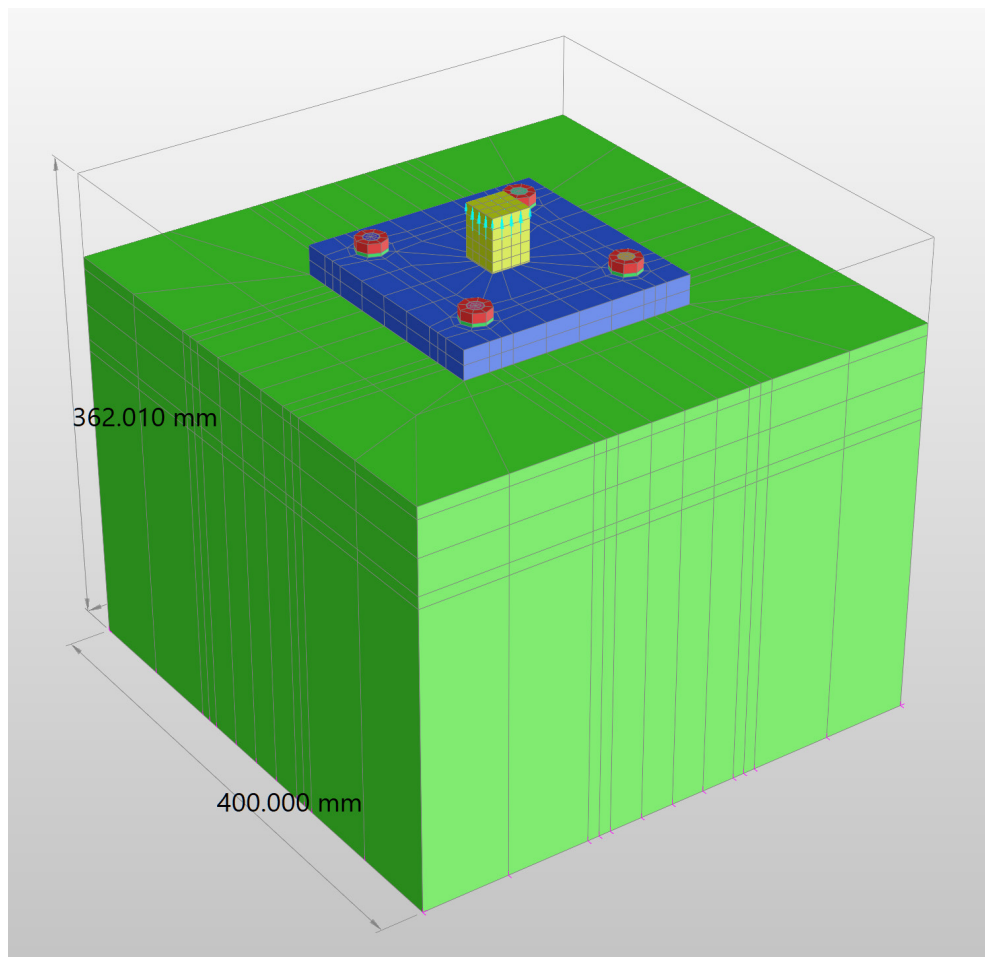


Fig 2. Finite element model

The results are compared with one obtained from the ANSYS Workbench suite student version, over the same finite element model. The results of significance are presented in the Figure 3. It is extremely important to emphasize that ANSYS or any other commercial finite element software

using hexahedral finite elements, are not suitable to be used for the present example due to the known locking problems of the displacement based finite element method (dFEM linear aspect ratio constraints) that leads to high inaccuracy.

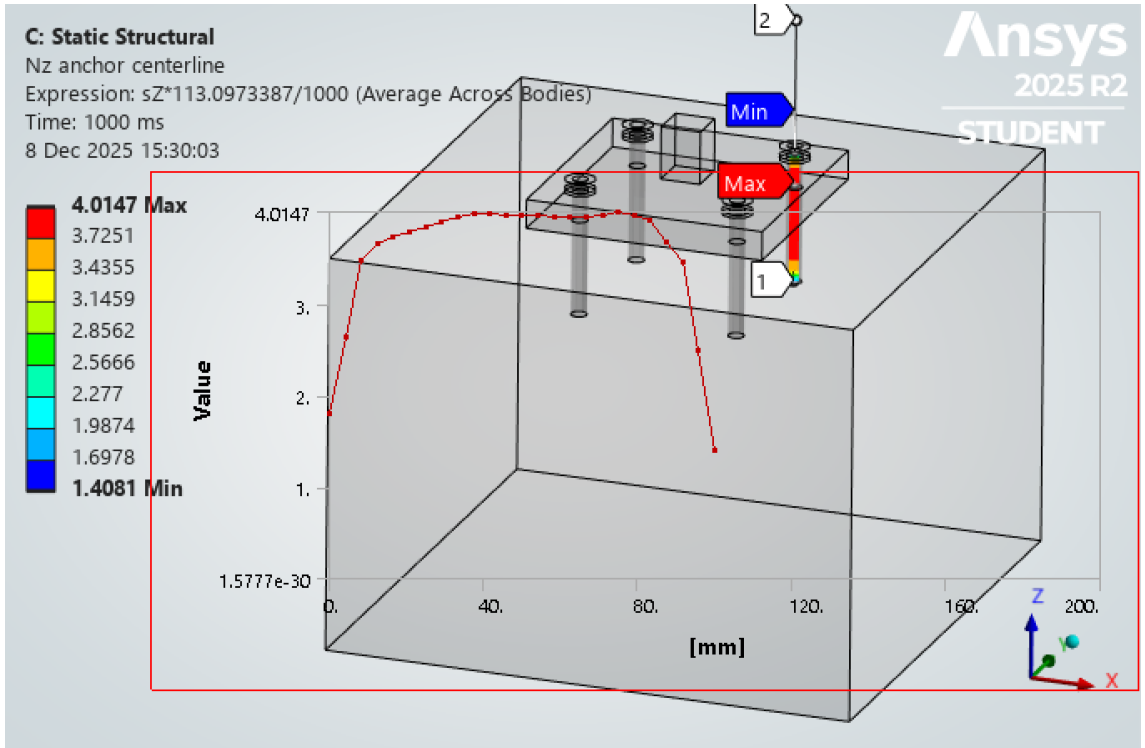


Figure 3. ANSYS MECHANICAL results over anchor centreline

By looking at the graph shown in Figure 4, we may see that average value of resultant normal force N is way over 1.8 kN theoretical, implicated that sum over all four anchors will be significantly bigger than input loading of $F_z = 7.2$ kN, around 12 kN in the plane perpendicular to the half of the anchor effective height (bellow base plate), that is 60% error.

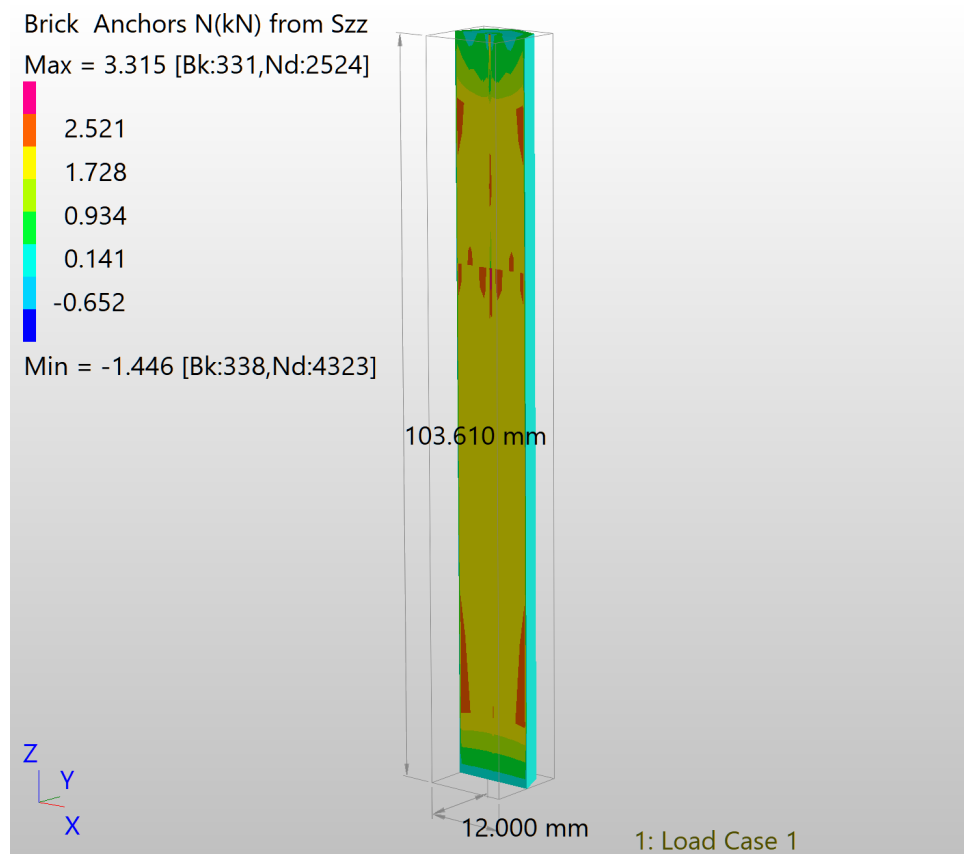


Figure 4. FEMIX-HC-ANCHOR results over the one of four symmetrical anchors

Let us now investigate results of the present FEMIX-HC-ANCHORCALC tool. From the Table 2. We may see that the sum of the reaction normal forces in the same centreline node (half of the anchor effective height) is $N=7.276$ kN, only 1.06% in error in comparison with theoretical result of $F_z=7.2$ kN.

Conclusion

A novel anchoring system calculation tool FEMIX-HC-ANCHORCALC tool based entirely on elastic principles and reliable primal-mixed finite element method, has been presented. This method contributes to safer, more transparent, and scientifically grounded anchor design. Related to this a new TEFTA definition is introduced definition for the Totally Elastic Full Topology Approach. It explains a numerical approach based exclusively on a complete

three-dimensional elastic formulation, without relying on dimension-reduction theories such as beam, plate, or shell models. This method treats every geometry and material configuration in its entire topological domain, thereby ensuring transparent transfer of loads and deformations throughout the structure.

Additional contribution is to emphasize that ANSYS or any other commercial finite element software using hexahedral finite elements, are not suitable to be used on present example due to the known locking problems, that is briefly explained by presented example.

Quantitative analysis of the physical results of the shown example, together with others from other analysed model problem settings, with one, two or three anchors, with shear input forces or combination, affirmatively motivate to proceed further with present investigations.

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IDENTITY OF SOCIO-POLITICS IN THE AGE OF THE TECHNOLOGICAL HUMAN

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Abstract

The accelerated emergence of the technological human, an individual shaped simultaneously by algorithmic architectures, geopolitical frictions, and identity vulnerabilities, has profoundly reconfigured the socio-political landscape of the early twenty-first century. This paper examines the transformation of identity formation under digital modernity, focusing on the convergence of surveillance capitalism, platform governance, and symbolic power. Combining sociological, philosophical, and political-theoretical approaches, the study analyses how technological infrastructures mediate recognition, belonging, and cultural self-understanding. The research demonstrates that identity in the contemporary era is no longer anchored primarily in nation, tradition, or collective memory, but in a volatile interplay between mediated visibility and algorithmic categorization. The conclusion suggests that the rise of the technological human represents a shift toward a post-human paradigm in which identity is contested, fragmented, and renegotiated across shifting digital ecologies.

Keywords: identity, technology, society, socio-politics, surveillance capitalism, subjectivity

1. INTRODUCTION

The twenty-first century has produced a unique type of human: a technologically augmented, data-exposed, algorithmically profiled subject whose identity is no longer anchored solely in culture, tradition, or national belonging, but increasingly in digital infrastructures and technological systems. This transformation forces us to reconsider identity not as a stable sociological category but as a dynamic intersection of history, power, perception, and computational logic.

Identity today is a contested terrain. It is negotiated between offline social relations and online environments that continuously observe, categorise, and repurpose individuals. Digital platforms mediate self-expression while simultaneously converting identity into data - material that becomes subject to political manipulation, economic exploitation, and algorithmic governance. Thus, the contemporary identity is never merely personal; it is geopolitical, technological, and instrumentalized.

For societies of Eastern Europe, the issue of identity bears additional weight. The region has experienced an accelerated historical tempo-wars, transitions, collapse of ideological systems, economic ruptures, migrations, and the emergence of new political narratives. Such historical compression produces a heightened sensitivity toward identity, making Eastern Europe a laboratory where global dynamics of technological identity formation become especially pronounced.

The purpose of this paper is to analyse how technological structures reshape the socio-political dimensions of identity formation. The methodology relies on theoretical analysis, comparative reasoning, and critical interpretation of contemporary literature in sociology, political theory, and philosophy of technology. Furthermore, the paper aims to conceptualise the technological human not merely as a user of digital devices but as a subject moulded by algorithmic infrastructures that increasingly direct perception, behaviour, and political imagination.

The central thesis is that identity in the technological age has become a hybrid construction, formed by historical narratives, mediated by digital architectures, and instrumentalised by political and economic powers. Moreover, Eastern Europe, due to its historical upheavals and fragile institutional frameworks, reveals the tensions of this hybrid identity more dramatically than the West.

2. THEORETICAL FOUNDATIONS OF IDENTITY

Identity, as a sociological construct, has undergone profound conceptual transformations. Classical theories approached identity through categories such as class, nation, religion, and culture, dimensions embedded in collective memory and institutional structure. In contrast, contemporary theories emphasise fluidity, fragmentation, and the performative nature of identity.

Modern identity theory often begins with Michel Foucault, whose analysis of power and subjectivation provides a framework for understanding how individuals become subjects of particular discursive regimes. According to Foucault, identity is not discovered but produced through practices of power, institutional arrangements, and knowledge systems. In the technological age, such regimes are increasingly digital and algorithmic.¹

Zygmunt Bauman's concept of "liquid modernity" further illustrates the instability of contemporary identity. For Bauman, modern individuals are compelled to constantly adapt, reinvent themselves, and navigate social environments stripped of stable structures. In such a context, identity becomes a temporary project - a flexible self that must adjust to rapidly changing technological and social landscapes.²

Habermas, on the other hand, situates identity within communicative rationality. From his perspective, identity emerges within intersubjective processes grounded in discourse, mutual recognition, and collective understanding. Yet, the digital era disrupts these conditions: communication becomes fragmented, algorithmically filtered, and increasingly detached from rational-public discourse.³

In this theoretical constellation, identity appears not as a fixed category but as a dynamic field in which power, discourse, and technological systems converge. The technological human thus becomes a subject whose identity is shaped through a continuous negotiation between self-expression and external mechanisms that classify, influence, and anticipate behaviour.

3. TECHNOLOGY AS A POLITICAL SPACE

The rise of digital technologies has transformed the very structure of political space. Technologies are no longer neutral tools; they constitute a new apparatus of power that governs individuals through data extraction, behavioural prediction, and algorithmic management. This apparatus shapes, identity by framing the conditions of visibility, participation, and recognition.

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- 1 Qadri, R., Mirowski, P., Gabriellán, A., Mehr, F., Gupta, H., Karimi, P., & Denton, R. (2024). Dialogue with the machine and dialogue with the art world: evaluating generative AI for culturally-situated creativity. arXiv preprint arXiv:2412.14077
 - 2 Coughlan, R. (2006). The socio-politics of technology and innovation: Problematising the 'caring' in healthcare?. *Social Theory & Health*, 4(4)
 - 3 Şerban, H. (2024). THE TRANSPARENCY OF EVIL, OF CITIZENS, OF AVATARS. *Romanian Review of Political Sciences & International Relations*, 21(1)

In such an environment, the technological human occupies a paradoxical position: simultaneously empowered by access to information and constrained by systems that monitor, profile, and evaluate every action. Technology becomes political not merely because it influences public opinion but because it defines the coordinates of social existence.⁴

The emergence of the technological human did not arise as a linear evolutionary extension of Enlightenment rationality. Instead, it unfolded as a discontinuity - a silent rupture within the very grammar of modern subjectivity.⁵ While the nineteenth and twentieth centuries offered ideological, national, and class-based matrices for identity formation, the twenty-first century introduced a new ontological tension: humans are now co-constituted by systems that neither share their historical memory nor participate in the symbolic economies that shaped European civilization.

Algorithms do not inherit wars, traumas, nor collective myths; they inherit datasets.

And yet, these datasets shape the identity of individuals who do carry traumas and myths, from the windswept Balkans to the industrial plains of Central Europe.

Identity, therefore, becomes a conflict zone. A liminal territory. Something no longer exclusively human, yet never fully machinic. The technological human lives in a perpetual double exposure: he is simultaneously grounded in material history and dissolved in digital abstraction. This paradox defines contemporary socio-politics of identity.

3. 1. Digitalisation as a New Sovereignty

The sovereignty that once belonged to institutions (states, churches, academies) has partially migrated toward technological infrastructures. Identity is no longer only declared, earned, or inherited; it is continuously computed. Profiles, metrics, behavioural predictions, and biometric patterns participate in an unending verification of one's existence.

4 Raghunath, P. (2024). Critical data governance: A southern standpoint to the study and practice of data. *Technology and Regulation*

5 Othman, E., & Mahafdah, R. (2025). Recalibrating Human–Machine Relations through Bias-Aware Machine Learning: Technical Pathways to Fairness and Trust. *Journal of Posthumanism*, 5(4)

This new sovereignty does not speak the language of constitutions. It speaks the language of probability.⁶

While traditional political philosophy attempted to stabilise identity through citizenship, rights, or ideological membership, technological governance redefines identity through continuous modulation. In such a world, the human is valuable not because he possesses dignity or historical embeddedness, but because he produces data. From this perspective, data becomes a metaphysical shadow, the second life of identity, stripped of context, purified of narrative, but infinitely analysable.

3. 2. The Loss of Narrative Continuity

Eastern European societies understand more than most the importance of memory and narrative continuity. The region's identities were carved by empires, wars, displacements, and ideological fractures. When technological systems dissolve continuity, individuals shaped by such histories feel a deeper rupture than those whose identities were grounded in more stable Western paradigms.

To lose narrative is not merely to lose story. To the Eastern European human, it is to lose ontology.

The technological human, however, is not offered a coherent alternative narrative. He is asked to construct himself from fragments (posts, images, algorithmically recombined opinions) resulting in what contemporary theorists describe as episodic identity. Such identity lacks a teleological arc. It accumulates but does not progress.

3. 3. The Fragmentation of Collective Imaginaries

Collective imaginaries once relied on shared temporality: the same newspapers, the same televised events, the same generational experiences. Today, technological mediation individualizes reality into countless parallel micro-worlds. Two citizens of the same city no longer inhabit the same informational universe, even if separated only by a thin apartment wall.

This has profound consequences for the socio-politics of identity:

- Solidarity becomes unstable
- Consensus becomes nearly impossible

6 Sloss, D. L. (2020). Sovereignty and National Constitutions. U. St. Thomas

- Shared symbolic frameworks erode

The technological human lives within personalised epistemologies. And without common epistemologies, politics becomes a battlefield of irreconcilable micro-realities. Identity turns into a weapon, not a foundation.

4. IDENTITY POLITICS IN THE AGE OF ALGORITHMIC MEDIATION

Identity politics, once rooted in concrete historical experiences and collective struggles, transforms under technological conditions. In the past, identity groups emerged around lived realities - ethnicity, class, gender, religion, labour. Today, identity is increasingly mediated, amplified, or attenuated by algorithmic curation. Digital infrastructures determine visibility, relevance, and legitimacy with greater precision, and less transparency, than any previous political mechanism.

Visibility was historically earned through institutions or collective mobilisation. Now, it is granted (or withheld) by opaque computational processes.⁷ An idea that would have remained marginal in traditional discourse may now become central, not because of its moral value but because of its viral architecture.

This raises a foundational socio-political question - who decides what becomes socially real?

In many cases, the answer is neither governments nor communities, but predictive models optimised for engagement. Identity is filtered through systems that privilege emotional intensity over rational argumentation, and polarization over cohesion.⁸ As such, the algorithm becomes a political actor. Not consciously, but structurally.

4. 1. Hyper-Individualisation and the Erosion of the Collective Self

Technological mediation amplifies individual identity to an unprecedented scale while simultaneously eroding collective grounding.

⁷ Ghosh, S. (2025). DIGITAL HUMANITIES IN 21ST-CENTURY. EMERGING PARADIGMS IN CONTEMPORARY EDUCATION: BRIDGING PHILOSOPHY, POLICY, AND PRACTICE

⁸ Schledorn, J. (2024). From Representation to Dialogue: Polarization, Emotions, and Moral Arguments in Political Discourse.

The paradox is striking: individuals are encouraged to express themselves incessantly, yet the very mechanisms that amplify this expression dismantle the communal frameworks that once gave identity meaning.

The Eastern European experience again illustrates the severity of this dynamic. In societies where identity historically depended on collective endurance, through oppression, war, transition, hyper-individualization functions as a solvent. It erodes the bonds that held communities together when confronted with existential threats. The technological human, in this context, becomes an orphan of history.

4. 2. The Commodification of Identity

In the age of technological capitalism, identity becomes a marketable asset. Tech platforms monetise not only preferences and behaviours, but also affiliations, anxieties, and ideological leanings.⁹ Identity is no longer an ethical category but an economic one. It becomes fragmented into quantifiable signals that can be traded, predicted, packaged, and sold.

What is lost in this process is the dignity of the self. What is gained is efficiency. But efficiency has never been the measure of human worth.

4. 3. The Ethical Paradox of Technological Identity

The figure of the technological human forces philosophy to confront an old dilemma under radically new conditions: What remains of the human when his identity is no longer solely his own? Traditional ethical systems were built around the presumption that the human subject possesses an inner anchor, a stable core capable of moral orientation.¹⁰ Yet in the algorithmic age, that anchor is no longer secure. Identity is increasingly shaped not through introspection or communal belonging, but through feedback loops, surveillance architectures, and predictive models.

Autonomy once meant the ability to direct one's own life through reasoned deliberation. Today, autonomy is displaced by automated choice architectures that shape perception and decision-making before the individual becomes aware of the shaping process. The technological human lives in a

9 Latinović, B., Krčadinac, O., Stanković, Ž., & Stošić, L. (2025). The Sociology of Artificial Intelligence Through the Lens of Ethics in the Digital Age. *Journal of UUNT: Informatics and Computer Sciences*, 2(1), 1-8

10 Alsford, N. J., & Menefee, F. J. (2025). *Problem Society: Why Nations are Divided*. Taylor & Francis

condition of guided spontaneity: he feels free, though his freedom is often a simulation engineered by systems indifferent to his moral aspirations.

4. 4. Responsibility in the Age of Predictive Governance

Predictive governance operates on anticipatory logic. It assigns probabilities to behaviour, often treating individuals not as moral beings but as risk vectors. Responsibility becomes inverted. Instead of judging past actions, systems increasingly intervene based on expected future actions. Identity becomes a statistical entity, interpreted through patterns rather than intentions.

This transformation destabilizes foundational ethical categories: guilt, duty, accountability, agency. The technological human becomes someone who is structured before acting, and thus morally interpreted through systems that precede and exceed him.

4. 5. The Crisis of Intersubjectivity

Eastern European societies, shaped by dense intergenerational ties and communal bonds, recognize intersubjectivity as a core of lived experience. Yet technological mediation displaces intersubjectivity with interface subjectivity - relations filtered through screens, metrics, and symbolic shortcuts.¹¹ The existential weight of an encounter is lightened; the metaphysical presence of the Other is replaced by a profile picture and a handful of behavioural indicators.

This does not merely transform communication; it transforms identity, to encounter another human being is to be reshaped by that encounter. When encounters become flattened, humans become flattened as well.

5. THE SOCIO-POLITICAL CONSEQUENCES OF IDENTITY TRANSFORMATION AND CLASSICAL IDEOLOGIES

Identity is not an abstract category. It anchors political institutions, legitimizes power structures, and provides the cultural grammar of social life. When identity changes, politics must change as well, even if unwillingly.

11 Szelenyi, I., & Manchin, R. (2024). Social policy under state Socialism: Market redistribution and social inequalities in East European socialist societies. In *Stagnation and renewal in social policy* (pp. 102-140). Routledge

Ideologies once provided citizens with narratives that integrated personal identity into collective destiny. Today, however, the ideological landscape is fragmented, replaced by loose constellations of digital tribes. These tribes are often reactive rather than constructive, held together by affective intensities rather than coherent worldviews. As a result, traditional ideological cleavages (left vs. right, secular vs. religious, nationalist vs. cosmopolitan) lose explanatory force.¹²

What emerges instead is a politics of emotional immediacy. A politics of identity flashes, not identity commitments.

5. 1. Populism as a Technological Phenomenon

Populism, frequently misinterpreted as a return to primitive tribalism, is better understood as a technologically enhanced mode of political engagement. It thrives on algorithmic amplification, which rewards simplified narratives, charismatic intensity, and the mobilisation of collective grievance. The technological human gravitates toward such narratives not solely due to irrationality, but due to the structure of digital platforms themselves.¹³

In Eastern European contexts, where historical wounds remain visible beneath the social surface, populism becomes a digitalized echo of unresolved pasts.¹⁴ Technology does not create these wounds, but it accelerates their political expression, often stripping them of nuance.

5. 2. The Rise of Post-Democratic Governance

Post-democracy does not abolish democratic institutions; it renders them symbolically intact but substantively hollow. Decisions migrate toward technocratic and corporate infrastructures, while public participation becomes performative. Identity politics fills the vacuum where democratic deliberation once stood. Citizens engage politically through identity assertion, while critical decision-making occurs elsewhere - in committees, algorithms, and corporate boards.

12 Serteser Baştuğ, G. (2025). Socio-politics of translation and conflicting narratives: On the translation and dissemination of Ethnic Groups in the Republic of Turkey. *Translation in Society*

13 Iyamu, T., Adelakun, O., Mlambo, N. N., & Badro, D. (2025). The Challenges of Adopting Artificial Intelligence in Organisations

14 Turnock, D. (2024). East central Europe and the former Soviet Union: Environment and society. Taylor & Francis

For the technological human, political agency becomes both expanded and diminished:

- expanded through expressive freedom
- diminished through structural powerlessness

6. THE EASTERN EUROPEAN PERSPECTIVE - IDENTITY UNDER PRESSURE

The socio-politics of identity cannot be universalised without acknowledging the geography of experience. Eastern Europe occupies a unique position in the global technological landscape: both inside and outside modernity, both European and peripheral, both historically burdened and metaphysically resilient.¹⁵

For the Western reader, identity may appear as a flexible construct, open to negotiation. For the Eastern European subject, identity is often experienced as inheritance - heavy, sometimes painful, always binding. Wars, occupations, transitions, and ideological collisions formed a collective consciousness attuned to fragility. The technological dissolution of identity thus resonates differently here than in more stable Western contexts.

6. 1. The Struggle Between Memory and Acceleration

Technology accelerates time; Eastern Europe resists acceleration. This tension produces a cultural dissonance. Memory, which once served as a stabilising force, becomes burdensome when technological systems prioritise speed over reflection. The region's archival consciousness - its cemeteries, myths, tragedies, and triumphs, stands in direct opposition to the real-time immediacy of digital culture. The technological human of Eastern Europe is torn between two temporalities: one that remembers too much, and one that demands forgetting.

In the Balkans, identity has often been a strategy of survival, not merely expression. Communities used identity to endure hardships, sustain solidarity, and preserve meaning. When technology fragments identity, it destabilises not only personal self-understanding but collective resilience. This tension explains why certain technological trends that appear benign in Western

15 Nagy, E., & Timár, J. (2017). Part I. The (re-) production of peripherality in Central and Eastern Europe. Foreword. European Spatial Research and Policy

societies provoke existential anxiety in Eastern Europe: they threaten more than individuality, they threaten continuity.

7. TOWARD A NEW SOCIO-POLITICAL FRAMEWORK FOR THE TECHNOLOGICAL AGE

The transformation of identity demands a new conceptual architecture. Classical socio-political theory, though foundational, cannot fully account for algorithmic mediation, datafication, and the dissolution of narrative continuity.

Autonomy in the technological era requires a higher form of awareness, a meta-reflexive attitude in which individuals learn to perceive not only their actions but the systems shaping those actions. This does not restore classical autonomy, but it establishes a new form of agency grounded in technological literacy and critical self-observation.

Societies must cultivate shared symbolic frameworks that transcend algorithmic fragmentation. This does not imply a return to rigid identities, but the creation of inclusive narratives capable of integrating diverse experiences. Education, public discourse, and cultural production must assume a new role: to reweave the symbolic fabric that technology has frayed.¹⁶

Regulation must shift from reactive to principled governance. The dignity of the human subject requires transparent algorithms, limits on manipulative architectures, and accountability mechanisms for digital actors. Without such safeguards, socio-political identities will continue to erode under the weight of technological determinism.

8. CONCLUSION

The socio-political landscape of identity in the age of the technological human demands a rethinking of foundational assumptions about what it means to be a self-aware, autonomous agent. The convergence of algorithmic governance, ubiquitous digital surveillance, and post-humanist hybridisation challenges the classical humanist premise that identity is a stable, internally sourced essence. Rather, identity emerges as a contingent, relational, and technologically mediated phenomenon, co-produced by networks of humans,

16 Von Essen, E., O'mahony, K., Szczygielska, M., Gieser, T., Vaté, V., Arregui, A., & Broz, L. (2025). The many boar identities: understanding difference and change in the geographies of European wild boar management. *Journal of Environmental Planning and Management*, 68(3)

machines, and socio-technical infrastructures. In this paradigm, the boundaries between autonomy and algorithm, selfhood and system, agency and code, blur into a dynamic continuum of interaction and influence.

This transformation carries profound socio-political stakes. Recognition, once a matter of human social negotiation, is increasingly quantified and distributed through algorithmic proxies. Social legitimacy, ethical authority, and political influence are mediated less by discourse or deliberation than by digital visibility, engagement metrics, and networked optimization. The technological human is thus a subject whose political and ethical capacities are inseparable from the systems that process, predict, and manipulate the contours of identity itself. In effect, the Technosphere functions as a new arena of power, where identity is not only represented but enacted, controlled, and normalized by computational authority.

Yet this technological mediation does not eradicate the potential for ethical reflection, autonomy, or resistance. On the contrary, the socio-political challenge of the technological human is precisely the cultivation of critical consciousness within mediated environments. To understand identity in this context is to recognise the duality of freedom and constraint: identity is both a site of socio-technical inscription and a locus of human resilience. Just as the digital environment imposes algorithmic expectations, it simultaneously creates unprecedented possibilities for reflexivity, reconfiguration, and ethical intervention. The political imperative becomes one of engagement, not submission: a conscious negotiation of visibility, action, and representation within and against technologically structured social spaces.

The age of the technological human therefore compels a new theoretical framework: a socio-political epistemology of identity that accounts for hybridity, contingency, and algorithmic mediation. Identity is no longer reducible to essence, narrative, or discourse alone; it is an emergent, performative phenomenon at the intersection of human cognition, technological infrastructure, and collective social practice. Within this framework, the task of the sociologist, political theorist, and ethicist is not merely to describe or categorize but to intervene, illuminate, and cultivate spaces of agency where autonomy, critical reflection, and ethical accountability can persist.

Finally, the socio-politics of identity in this age is inseparable from the ethics of possibility. To live as a technological human is to inhabit a condition in which power, visibility, and recognition are distributed asymmetrically by both human and non-human actors. Yet it is precisely this asymmetry that

opens the field for reimagination, for the creative assertion of agency within complex socio-technical systems. Identity becomes not a fixed inheritance or predetermined essence, but a horizon of ethical engagement: a space in which humans confront, negotiate, and shape the technological forces that now co-constitute their being. The future of selfhood is thus neither preordained nor purely synthetic; it is contingent, negotiated, and deeply political. To understand and navigate this new reality is to participate actively in the creation of an ethical and socially coherent technological human civilisation.

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UTICAJ KVALITETA UNUTRAŠNJEG VAZDUHA U OBRAZOVNIM USTANOVAMA NA ZDRAVLJE I AKADEMSKE PERFORMANSE UČENIKA I STUDENATA I STRATEGIJA ZA POBOLJŠANJE

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Apstrakt

Kvalitet unutrašnjeg vazduha (IAQ) ključni je faktor za zdravlje, kogniciju i blagostanje učenika i studenata. U školama, gde učenici provode značajan deo dana, bezbedno okruženje je prioritet. Rad analizira parametre IAQ: CO₂, PM_{2,5}/PM₁₀, VOC, temperaturu i vlažnost. Sistematskim pregledom literature, uporednom analizom standarda WHO, ASHRAE, EU i domaćih propisa, istražuje se uticaj zagađenja na zdravlje i akademski uspeh školske dece i studenata. Akcenat je na ventilaciji učionica, monitoringu i edukaciji osoblja. Zaključak nudi preporuke za obrazovanje i javno zdravlje, smernice za buduća istraživanja, analizu dugoročnih rizika (kardiovaskularne/neurološke bolesti), integraciju senzora za brzo reagovanje, ulogu klimatskih promena i upozorava na povećane ekonomske troškove usled lošeg IAQ (gubici u produktivnosti i zdravstvu). Istraživanja sprovedena poslednjih

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godina pokazuju da bolja ventilacija smanjuje kognitivne deficite do 20%, naglašavajući hitne intervencije.

Ključne reči: Kvalitet unutrašnjeg vazduha, školske ustanove, CO₂, PM_{2.5}, VOC, ventilacija, monitoring, kognitivni deficiti, produktivnost

1. Uvod

Prema podacima Svetske zdravstvene organizacije (WHO), oko 93% dece u svetu mlađe od 15 godina diše vazduh koji prelazi bezbedne granice, što predstavlja globalni zdravstveno-ekološki rizik (WHO, 2021). Značajan broj obrazovnih ustanova u Evropi ima prosečne vrednosti finih suspendovanih čestica (PM_{2.5}) koje prelaze preporučene granice za bezbedno okruženje, što je posebno alarmantno jer učenici provode do osam sati dnevno u tim prostorima (Fisk, 2017). Deca su posebno ranjiva na uticaje zagađenog vazduha zbog nedovoljno razvijenog respiratornog i imunološkog sistema, bržeg metabolizma i intenzivnijeg fizičkog angažmana u odnosu na odrasle (Lan et al., 2011). Klimatske promene dodatno pogoršavaju situaciju, povećavajući koncentracije spoljašnjeg zagađenja koje prodiru u unutrašnje prostore, naročito u regionima sa visokim nivoima PM čestica i ozona (Rožanec et al., 2024). Na primer, studije iz 2023. godine pokazuju da u urbanim sredinama poput Beograda koncentracije PM_{2.5} u učionicama mogu biti dva do tri puta veće tokom zimskih meseci zbog grejanja na čvrsta goriva, što dovodi do povećanog rizika od respiratornih infekcija i kognitivnih poremećaja (Batterman et al., 2023). Ovo se manifestuje kroz veći broj izostanaka iz škole i smanjene akademske performanse, sa ekonomskim gubicima koji se procenjuju na milione evra godišnje u Evropi (Mendell et al., 2022). Dugotrajna izloženost lošem IAQ može dovesti do hroničnih bolesti poput astme i kardiovaskularnih problema, zahtevajući hitne intervencije u obrazovnim sistemima (Marques et al., 2023). Nedavna istraživanja iz 2025. godine, poput onih koja su ispitivala efekte poboljšane ventilacije, potvrđuju da adekvatna ventilacija može direktno poboljšati kognitivne funkcije učenika, smanjujući efekte zagađenja na mozak (Ezeamii et al., 2025).

Kvalitet vazduha u zatvorenim prostorima, naročito u obrazovnim ustanovama, direktno utiče na kognitivne sposobnosti, koncentraciju, opšte zdravstveno stanje i prisustvo respiratornih simptoma kod učenika i studenata (Allen et al., 2016). IAQ obuhvata koncentracije zagađujućih materija poput CO₂, PM_{2.5}, VOC i NO₂, temperaturu, relativnu vlažnost, cirkulaciju vazduha i prisustvo bioloških agenasa kao što su gljivice i bakterije (Fanger, 2006).

Iako često zanemaren u standardima i praksi, IAQ ima ključan uticaj na učenje, produktivnost i školski uspeh (Zhang et al., 2021). Termički komfor, definisan kao ravnoteža između toplote koju telo proizvodi i gubitka te toplote u okolinu, zavisi od temperature, vlažnosti, brzine strujanja vazduha i individualnih faktora poput odeće i aktivnosti (ASHRAE, 2022). U školama, neadekvatan termički komfor dovodi do smanjenja pažnje, umora i neraspoloženja (Lan et al., 2011). Uvođenje senzora za realno-vremensko praćenje omogućava automatsko prilagođavanje ventilacije, smanjujući energetske troškove za 20-30% uz održavanje optimalnog IAQ (Marques et al., 2023). Ovo je kritično u kontekstu klimatskih promena, gde porast ekstremnih temperatura utiče na vlažnost i koncentracije VOC u učionicama (Rožanec et al., 2024). Na primer, u toplijim klimatskim zonama povećana vlažnost podstiče rast plesni, komplikujući zdravstvene rizike za učenike sa alergijama (Galičić et al., 2023).

Sistemi grejanja, klimatizacije, građevinski materijali, elektronski uređaji i ljudske aktivnosti poput čišćenja ili upotrebe hemijskih preparata glavni su izvori zagađenja unutrašnjeg vazduha (Fisk, 2017). Posledice se ne ograničavaju na respiratorne i alergijske tegobe, već uključuju kognitivne poremećaje, anksioznost, depresiju i smanjenu koncentraciju, posebno pogađajući decu tokom intenzivnog mentalnog razvoja (Tsantaki et al., 2022). Studije pokazuju da izloženost visokim nivoima VOC dovodi do neurotoksičnih efekata, uključujući smanjenu memoriju i povećan rizik od ADHD (Lan et al., 2011). Klimatske promene komplikuju situaciju povećavajući koncentracije ozona i PM čestica u spoljašnjem vazduhu, koji lako prodiru unutra (Rožanec et al., 2024). Ekonomski modeli indiciraju da investicije u poboljšanje IAQ donose povraćaj od pet do deset puta kroz smanjene zdravstvene troškove i povećanu produktivnost (Mendell et al., 2022). Cilj ovog rada je sistematskim pregledom literature i analizom nacionalnih i međunarodnih standarda utvrditi ključne faktore uticaja na IAQ u školama i visokoškolskim ustanovama, proceniti njihov uticaj na zdravlje učenika i studenata, identifikovati rizike i predložiti strategije unapređenja. Rad proširuje analizu na integraciju veštačke inteligencije za prediktivno modeliranje zagađenja i međunarodne saradnje za razvoj lokalno prilagođenih standarda, uključujući aplikacije koje koriste senzorske podatke za predviđanje pikova zagađenja i aktiviranje preventivnih mera (Marques et al., 2023).

Specifični zadaci obuhvataju definisanje osnovnih pojmova vezanih za IAQ, identifikaciju glavnih zagađujućih materija, uporednu analizu graničnih vrednosti prema WHO, EU direktivama i propisima Republike Srbije,

sagledavanje zdravstveno-fizioloških efekata dugotrajne izloženosti, procenu uticaja na osnovu kliničkih studija, predlog preventivnih i korektivnih mera za unapređenje IAQ u obrazovnim institucijama, analizu ekonomskih implikacija lošeg IAQ uključujući gubitke u produktivnosti i troškovima lečenja, te integraciju klimatskih promena u modele rizika (ASHRAE, 2022; WHO, 2021). Ovi zadaci su povezani, omogućavajući holistički pristup koji naglašava interdisciplinarni rad stručnjaka iz medicine, ekologije i inženjerstva za efikasne strategije (Galičić et al., 2023).

2. Parametri kvaliteta unutrašnjeg vazduha

Kvalitet unutrašnjeg vazduha određuju fizički, hemijski i biološki parametri koji utiču na zdravlje, udobnost i produktivnost u zatvorenim prostorima, sa posebnim fokusom na obrazovne ustanove gde su učenici i studenti osetljivi na zagađenje (Fisk, 2017). Klimatske promene pojačavaju ove parametre, povećavajući koncentracije PM čestica tokom suše i VOC tokom vlažnih perioda, zahtevajući adaptivne monitore (Rožanec et al., 2024). Parametri mogu međusobno interagovati: visoka vlažnost pojačava efekte VOC, povećavajući respiratorne rizike (Lan et al., 2011).

Temperatura i relativna vlažnost formiraju osnovu termičkog komfora. ASHRAE standardi preporučuju 23–26°C leti i 20–24°C zimi, sa vlažnošću od 30–60%, optimalno 40–55% u učionicama (ASHRAE, 2022; Fanger, 2006). Prekomerna vlažnost može da pogoduje razvoju bakterija, virusa, gljivica i grinja, čime se povećava rizik od infektivnih i alergijskih oboljenja, dok suv vazduh iritira sluzokožu i povećava rizik od infekcija (Lan et al., 2011). Neodgovarajući uslovi pojačavaju osećaj nelagodnosti čak i pri niskim polutantima (Batterman et al., 2023). Klimatske promene komplikuju ovo, povećavajući rizik od plesni u vlažnim regionima, utičući na 20-30% učenika sa alergijama (Rožanec et al., 2024). U mediteranskim zonama, porast temperature dovodi do dehidracije i smanjene koncentracije, naglašavajući potrebe za integrisanim ovlaživačima u klimatskim uređajima (Marques et al., 2023).

Termički komfor definiše se kao stanje zadovoljstva toplotnom okolinom i podrazumeva subjektivni osećaj toplote ili hladnoće. Na njega utiču brojni faktori koji se mogu podeliti na:

- Faktori životne sredine: temperatura vazduha, relativna vlažnost,

brzina kretanja vazduha i toplotno zračenje.

- Lični faktori: nivo fizičke aktivnosti (metabolička stopa) i odeća.

Unutar projekta InAirQ predlaže se rangiranje parametara termičkog komfora prema zdravstvenom riziku, prikazano u Tabeli 1. Idealni opsezi za radnu sredinu u učionici su:

- Temperatura: između 18,5°C i 25,5°C.
- Relativna vlažnost: između 43% i 67%.
- Koncentracija CO₂: ispod 1200 ppm.

Tabela br. 1. Parametri termičkog komfora prema zdravstvenom riziku

Kategorija	Relativna vlažnost (RH%)	Temperatura (°C)	Koncentracija (ppm)	CO ₂
Zdravstveno bez- bedno	43 < RH < 67	18.5 < T < 25.5	< 1200	
Umeren rizik	37 < RH < 43 67 < RH < 73	17.5 < T < 18.5 25.5 < T < 26.5	1200–1800	
Nezdravo	RH < 37 RH > 73	T < 17.5 T > 26.5	> 1800	

Izvor: prilagođeno prema InAirQ projektu (2019). Preuzeto sa: <https://programme2014-20.interreg-central.eu/Content.Node/InAirQ/Joint--training-material-for-architects-explanation.pdf>

Ugljen-dioksid služi kao indikator ventilacije, rastući sa brojem osoba u neprovetrenim učionicama. ASHRAE ograničava na <1000 ppm, jer >1500 ppm utiče na kogniciju i koncentraciju (ASHRAE, 2022; Allen et al., 2016; Zhang et al., 2021). Čak i >700 ppm smanjuje rezultate na testovima pažnje i memorije kod dece (Zhang et al., 2021). Nivoi <800 ppm povećavaju energiju i smanjuju izostanke (Mendell et al., 2022). Klimatske promene, sa višim temperaturama, povećavaju CO₂ u zatvorenim prostorima, rizikujući hiperkapniju kod osetljivih (Rožanec et al., 2024). U gusto popunjenim učionicama u urbanim sredinama, ovo dovodi do hroničnog umora, utičući na dugoročni uspeh (Allen et al., 2016).

PM_{2.5} i PM₁₀ su opasni jer prodiru duboko u pluća i krv. Potiču od kuvanja, grejanja, prašine ili spoljašnjeg zagađenja (WHO, 2021). Ekspozicija dovodi do astme, bronhitisa i kognitivnih poremećaja kod dece (Marques et

al., 2023; Rožanec et al., 2024). U Srbiji, nivoi u učionicama prelaze preporuke zimi zbog neefikasnog grejanja (Batterman et al., 2023). Klimatske promene povećavaju PM tokom niskog vetra i visokih temperatura, akumulirajući ih unutra (Rožanec et al., 2024). U industrijskim regionima istočne Evrope, $>25 \mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$ povećava rizik od infekcija za 15-20% (Rožanec et al., 2024). Dugotrajno dovodi do kardiovaskularnih problema kod mladih i odraslih (Batterman et al., 2023). Procenjuje se da ekonomski gubici usled lošeg kvaliteta vazduha iznose više milijardi evra godišnje na nivou Evrope (WHO, 2021). HEPA filteri smanjuju $\text{PM}_{2.5}$ za 80-90% (Marques et al., 2023). Međutim, u njihova primena je efikasnija kada se kombinuju sa merama za ograničavanje ulaska spoljnog zagađenja, poput automatizovanog otvaranja prozora i kontrolisane ventilacije (Marques et al., 2023).

Isparljiva organska jedinjenja poput formaldehida, benzena i toluena prisutna su u bojama, nameštaju i sredstvima za čišćenje, sa koncentracijama do 10 puta višim unutra (Batterman et al., 2023). Formaldehid, kancerogen, iritira oči pri $0.1 \text{ mg}/\text{m}^3$ (WHO, 2021). Benzen se povezuje sa leukemijom, toluen sa neurološkim deficitima (Lan et al., 2011). Klimatske promene povećavaju isparavanje tokom toplote i vlažnosti (Rožanec et al., 2024). $>300 \mu\text{g}/\text{m}^3$ smanjuje kogniciju za 10-15% (Allen et al., 2016). U Srbiji, rizik od hroničnih respiratornih bolesti je visok, često zbog opremljenosti učionica starim nameštajem, sa neekološkim materijalima. Ekološki materijali poput "Greenguard" smanjuju emisije VOC za 50-70% (Fisk, 2017). Redovno provetravanje doprinosi poboljšanju kvaliteta vazduha u zatvorenom prostoru, ali u zagađenim urbanim sredinama može povećati prisustvo PM čestica. Zbog toga se preporučuje upotreba ventilacionih sistema sa aktivnim ugljem (Fisk, 2017).

Azot-dioksid (NO_2) potiče od sagorevanja, $>25 \mu\text{g}/\text{m}^3$ oštećuje pluća i imunitet (WHO, 2021). U školama sa gasnim uređajima, $>50 \mu\text{g}/\text{m}^3$ zimi povećava astmu (Rožanec et al., 2024). Klimatske promene povećavaju emisije za 20-30% u hladnim regionima (Rožanec et al., 2024). Ozon (O_3), sekundarni polutant, $>100 \mu\text{g}/\text{m}^3$ izaziva respiratorne tegobe i leti, sa klimatskim promenama, povećava broj glavobolja i smanjenu pažnju (Rožanec et al., 2024). Ugljen-monoksid (CO) $>10 \text{ mg}/\text{m}^3$, vezuje se za hemoglobin, prouzrokujući nesvesticu (WHO, 2021). Hronična izloženost smanjuje IQ za 5-10 poena (Zhang et al., 2021). U Srbiji, saobraćajno zagađenje zahteva senzore za upozorenje u periodima visoke koncentracije zagađujućih materija u ambijentalnom vazduhu, da bi se sprečio efekat povišenog oksidativnog stresa (WHO, 2021).

Biološki kontaminanti poput polena, spora, bakterija i virusa izazivaju alergije i infekcije, pojačani vlažnošću i slabom ventilacijom (Galičić et al., 2023). >35% studenata u loše kontrolisanim objektima prijavljuje simptome sindroma bolesne zgrade (Tsantaki et al., 2022). Klimatske promene povećavaju rast gljivica u starijim zgradama (Rožanec et al., 2024). U Srbiji, zimska vlažnost dovodi do alergija koje zahtevaju visoke troškove lečenja. Preporuke uključuju čišćenje, antimikrobne materijale i UV svetlo u ventilaciji, posebno tokom pandemija gde loš IAQ ubrzava širenje virusa (Marques et al., 2023).

U kontekstu kvaliteta unutrašnjeg vazduha u akademskim prostorijama i učionicama, koncentracija CO₂ nema precizno definisane granične vrednosti u pravnim aktima Srbije, što predstavlja nedostatak u regulativi specifičnoj za ovaj prostor. Prema WHO Global Air Quality Guidelines (2021), koje se fokusiraju prvenstveno na ambijentalni, odnosno spoljašnji vazduh, unutrašnji CO₂ nivoi nisu eksplicitno propisani. Isto važi i za EU Direktivu 2008/50/EC koja reguliše samo kvalitet spoljašnjeg vazduha, bez definisanih limita za CO₂ unutar zatvorenih prostora.

U Tabeli 2 dat je uporedni pregled graničnih vrednosti ključnih zagađujućih materija u spoljašnjem (ambijelnom) vazduhu, prema najstrožim preporukama Svetske zdravstvene organizacije, obavezujućim standardima Evropske unije i važećim propisima Republike Srbije. Vrednosti se odnose isključivo na kvalitet spoljašnjeg vazduha.

Tabela br. 2. Uporedni pregled graničnih vrednosti zagađujućih materija u spoljašnjem vazduhu

Zagađujuća materija	Jedini-ca	WHO AQG 2021	EU Direkti-va 2008/50/EC	Republika Srbija (propisi)	Napomene
PM _{2.5} (godišnje)	µg/m ³	5	25	25 (godišnja granična vrednost)	EU prelazni cilj do 2030.
PM _{2.5} (24-časovno)	µg/m ³	15	–	50 (24-časovna granična vrednost)	Srbija primen-juje vrednost za PM ₁₀
PM ₁₀ (godišnje)	µg/m ³	15	40	40 (godišnja granična vrednost)	

Zagađujuća materija	Jedini-ca	WHO AQG 2021	EU Direkti-va 2008/50/EC	Republika Srbija (propisi)	Napomene
PM ₁₀ (24-časov-no)	µg/m ³	45	50 (ne sme se pre-koračiti >35 dana/god.)	50 (24-časovna granična vrednost, ne sme se pre-koračiti >35 dana/god.)	maks. 35 dana/god.
NO ₂ (godišnje)	µg/m ³	10	40	40 (godišnja granična vrednost)	
NO ₂ (1-časovno)	µg/m ³	–	200 (ne sme se pre-koračiti >18 puta/god.)	200 (1-časovna granična vrednost, ne sme se pre-koračiti >18 puta/god.)	maks. 18 pre-koračenja/god.
O ₃ (maksimalna dnevna 8-časovna srednja vrednost)	µg/m ³	100	120 (ciljna vrednost, ne sme se pre-koračiti >25 dana/god. u proseku za 3 godine)	120 (8-časovna granična vrednost, ne sme se pre-koračiti >25 dana/god. u proseku za 3 godine)	
CO (maksimalna dnevna 8-časovna srednja vrednost)	mg/m ³	4	10	10 (8-časovna granična vrednost)	
SO ₂ (24-časovno)	µg/m ³	40	125 (ne sme se pre-koračiti >3 dana/god.)	125 (24-časovna granična vrednost, ne sme se pre-koračiti >3 dana/god.)	EU/Srbija dodatno: 20 µg/m ³ godišnje za zaštitu vegetacije
Benzen (godišnje)	µg/m ³	–	5	5 (godišnja granična vrednost)	WHO preporučuje <1,7 µg/m ³ kao dugoročni cilj

Izvor: Autor prema WHO Global Air Quality Guidelines (2021), Direktivi 2008/50/EC i „Službenom glasniku RS”, br. 21/2009, 1/2019, 11/2010, 75/2010 i 63/2013.

Napomene u poslednjoj koloni tabele 2 odnose se na sledeće:

- „EU prelazni cilj do 2030.“ – Revizijom Direktive 2008/50/EC

(2022–2024) od 2030. godine granična vrednost za $PM_{2.5}$ biće $10 \mu g/m^3$, a do tada države moraju postepeno smanjivati izloženost stanovništva.

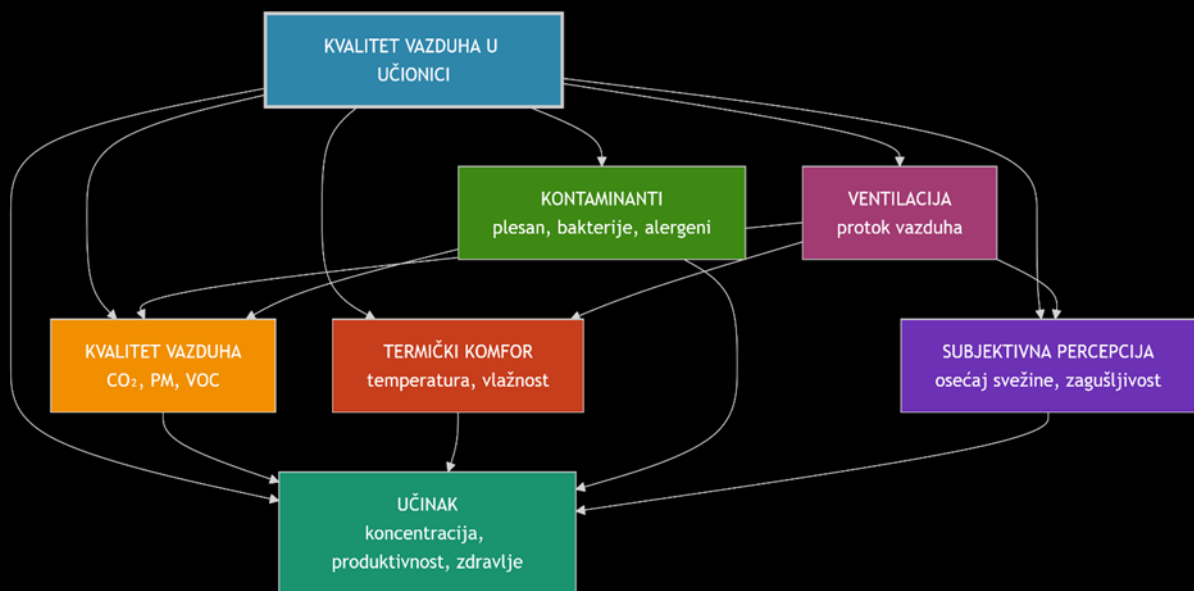
- „Srbija primenjuje vrednost PM_{10} “ – Srbija nema eksplicitnu 24h granicu za $PM_{2.5}$, te se stoga primenjuju analogne vrednosti i metode kao za PM_{10} ($50 \mu g/m^3$).
- „maks. 35 dana/god.“ i „maks. 18 puta/god.“ – Dozvoljen je ograničen broj prekoračenja granične vrednosti u kalendarskoj godini; prekoračenje iznad tog broja znači kršenje propisa.
- „dodatna vrednost za vegetaciju“ – Pored zaštite zdravlja ljudi, EU i Srbija imaju strožu godišnju i zimsku granicu za SO_2 od $20 \mu g/m^3$ radi zaštite šuma i useva.
- „WHO dugoročni cilj $1,7 \mu g/m^3$ “ – U Global AQG 2021. benzen nema formalnu granicu za spoljašnji vazduh, ali WHO (2010) navodi $1,7 \mu g/m^3$ kao nivo na kome se rizik od leukemije smatra zanemarljivim.

Primarne zagađujuće materije vazduha koje se prate i mere u okviru redovnog monitoringa ambijentalnog vazduha u Srbiji su: respirabilne čestice ($PM_{2.5}$ i PM_{10}), gasovita neorganska jedinjenja (NO_2 , SO_2 , O_3 , CO), benzen, teški metali (olovo, arsen, kadmijum i nikl), benzo(a)piren u frakciji čestica PM_{10} i alergeni.

Pored toga, vrše se i namenska merenja čađi, ukupnih taložnih materija, ukupnih suspendovanih materija, amonijaka, fluorovodonika, etilena, ksilena i etilbenzena (Knežević et al., 2022). Za razliku od zakonski obaveznog monitoringa kvaliteta vazduha u spoljašnjoj sredini, kvalitet vazduha unutrašnjeg prostora nije pokriven dovoljnim brojem standarda i zakona u Srbiji, izuzev praćenja u radnim sredinama (Živković, 2023), čija je doktorska disertacija obuhvatila sadržaj i sastav aerozagađenja u školskim sredinama u Srbiji. U Srbiji se praćenje kvaliteta vazduha unutrašnjeg prostora odvija uglavnom kroz razne nacionalne i međunarodne projekte u cilju naučnih istraživanja. U Srbiji, Pravilnik o preventivnim merama za bezbedan i zdrav rad propisuje samo opšti zahtev da radni i obrazovni prostori treba da imaju „dovoljnu količinu svežeg vazduha“, bez kvantifikovanih numeričkih vrednosti CO_2 (Pravilnik o preventivnim merama za bezbedan i zdrav rad, 2019). Ovo otežava standardizaciju i dosledan monitoring kvaliteta vazduha u školama i univerzitetskim učionicama.

U praksi, standardi poput ASHRAE Standard 62.1 često se primenjuju kao referenca za unutrašnje prostore obrazovnih ustanova. Preporučeni pragovi su najčešće da koncentracija CO₂ u učionicama ne prelazi 1000 ppm, jer je dokazano da viši nivoi ugljen-dioksida negativno utiču na kognitivne sposobnosti, pažnju, koncentraciju i opštu mentalnu funkciju učenika i studenata. Više koncentracije CO₂ ukazuju na nedovoljan protok svežeg vazduha i lošu ventilaciju, što može dodatno doprineti umoru, glavoboljama i smanjenju akademske produktivnosti.

Studije sprovedene u školama Srbije potvrđuju prisustvo značajnih zagađivača u unutrašnjem vazduhu, uključujući povišene nivoe VOC, PM_{2.5}, PM₁₀, koji često prelaze preporučene limite, što dodatno može uticati na zdravlje učenika i studenata, posebno u zimskim mesecima kada ventilacija može biti ograničena usled grejanja i zatvorenosti prostora. Ovi faktori naglašavaju potrebu za jasnijim i obavezujućim standardima za kvalitet unutrašnjeg vazduha u obrazovnim ustanovama u Srbiji.



Slika 1: Šematski prikaz faktora koji utiču na kvalitet unutrašnjeg vazduha i njihov uticaj na zdravlje i produktivnost. *Izvor: Autor*

Predstavljena šema (slika 1) konceptualno prikazuje ključne faktore kvaliteta radne sredine u učionici i njihove međusobne interakcije. Ventilacija je postavljena kao centralni kontrolni mehanizam koji direktno utiče na kvalitet vazduha (koncentracije CO₂, čestica PM i hlapivih organskih jedinjenja - VOC), termički komfor (temperaturu i vlažnost vazduha) i subjektivnu percepciju (osećaj svežine ili zagušljivosti). Kvalitet vazduha je dodatno opterećen prisustvom kontaminanata biološkog porekla (kao što su plesan, bakterije i alergeni).

Konačno, svi ovi fizički, hemijski i biološki faktori, zajedno sa subjektivnim doživljajem, konvergiraju i integrišu se u konačan ishod – učinak koji se ogleda kroz sposobnost koncentracije, produktivnost učenja i nastave, te dugoročno zdravlje korisnika. Slika 1, dakle, naglašava da je ventilacija ključna komponenta u upravljanju kompleksnim sistemom unutrašnje sredine, čiji je krajnji cilj optimizacija uslova za rad i učenje.

2. 1. Lista indikatora kvaliteta vazduha u unutrašnjem prostoru

Kvalitet vazduha u unutrašnjem prostoru (Indoor Air Quality – IAQ) predstavlja jedan od najznačajnijih faktora koji utiču na zdravlje, dobrobit i radnu sposobnost ljudi, naročito u obrazovnim ustanovama gde učenici i studenti provode značajan deo dana. Za razliku od spoljašnjeg vazduha, na koji utiču klimatski i urbani uslovi, kvalitet unutrašnjeg vazduha određuje se brojnim promenljivim, često ljudski izazvanim faktorima, a njegova ocena zahteva višedimenzionalni pristup i sistematsko praćenje.

Indikatori kvaliteta unutrašnjeg vazduha služe kao osnov za praćenje, procenu i upravljanje rizicima koji proističu iz prisustva štetnih supstanci u zatvorenim prostorima. Dobro definisani indikatori omogućavaju merenje trenutnog stanja, poređenje sa važećim standardima i usmeravanje politika unapređenja zdravlja unutar obrazovnih, radnih i stambenih sredina (Fisk, 2017). Prema Svetskoj zdravstvenoj organizaciji (WHO, 2021), adekvatna identifikacija i praćenje indikatora je ključna za prevenciju hroničnih bolesti, smanjenje izostanaka iz škola i posla, kao i za unapređenje kognitivnih sposobnosti i produktivnosti.

Indikatori kvaliteta unutrašnjeg vazduha mogu se grupisati u četiri osnovne kategorije:

1. Fizički indikatori – parametri poput temperature, vlažnosti, ventilacije i brzine protoka vazduha.

2. Hemijski indikatori – koncentracije zagađujućih materija kao što su CO₂, CO, NO₂, O₃, PM₁₀, PM_{2.5}, VOC i formaldehid.

3. Biološki indikatori – prisustvo alergena, bakterija, gljivica i virusa u vazduhu.

4. Percepcijski indikatori – subjektivne ocene kvaliteta vazduha od strane korisnika prostora, uključujući osećaj svežine, mirisa ili zagušljivosti (Fanger, 2006).

Praćenje indikatora zahteva upotrebu različitih instrumenata: detektori CO₂, fotometri za čestice, VOC analizatori, uređaji za detekciju formaldehida i radona. Standardi kao što su EN 13779 i ISO 16000 definišu metodologije merenja i kalibracije uređaja. Pored instrumentalnih metoda, važan doprinos daju i anketne procene korisnika, koje omogućavaju subjektivno mapiranje percepcije vazduha (Wargocki & Wyon, 2007).

U kontekstu školskih i univerzitetskih prostorija, posebno su značajni indikatori koji su predstavljeni u sledećoj tabeli. Tabela br. 3 prikazuje ključne indikatore kvaliteta unutrašnjeg vazduha u zatvorenim prostorijama (npr. kuće, škole, fakulteti, kancelarije), sa fokusom na termičke uslove, hemijske i biološke zagađujuće materije. Vrednosti su preporučene prema globalnim smernicama, prilagođene za unutrašnje okruženje gde su izvori zagađenja često različiti od spoljašnjih (npr. grejanje, nameštaj, ventilacija). Ove granice kao cilj imaju smanjenje rizika za zdravlje, poput respiratornih problema, astme i karcinoma.

Tabela br. 3. Indikatori kvaliteta vazduha

Parametar		Preporučene vrednosti	Standardi / Napomene	
Temperatura	Zima: 20–24 °C; Leto: 23–27 °C	ASHRAE Standard 55 (2023) – za termički komfor u zatvorenim prostorijama		
Relativna vlažnost	30–60 %	Idealno 40–60 %; ASHRAE Standard 55 (2023) – sprečava rast mikroorganizama		

CO ₂	<1000 ppm (8-časovna sredn- ja vrednost)	WHO (2010); >1000 ppm ukazuje na nedovoljnu venti- laciju; izaziva smanjenje kon- centracije		
PM _{2.5}	Godišnji prosek: ≤5 µg/m ³ ; 24h: ≤15 µg/m ³	WHO AQG (2021) – primen- ljivo i na unutrašnji vazduh; glavni izvor: spoljašnje za- gađenje		
PM ₁₀	≤ 15 µg/m ³ (go- dišnje) ≤ 45 µg/m ³ (24h)	PM ₁₀ ≤ 15 µg/m ³ (godišnji prosek) izvori: prašina, ventilacija		
VOC	<300 µg/m ³ (TVOC)	WHO (2010); uključuje tolu- en, benzen; izvori: nameštaj, boje		
Formaldehid	<30 µg/m ³ (ili <25 ppb) du- goročno	WHO (2010); hronična izloženost povezana sa respiratornim problemima i kancerom		
Ozon (O ₃)	8h: ≤100 µg/m ³	WHO AQG (2021); sekundar- na zagađujuća materija, izvori: kopir aparati, ozonizatori		
NO ₂	Godišnje: ≤10 µg/m ³ ; 1h: ≤200 µg/m ³	WHO AQG (2021); izvori: saobraćaj (penetracija iz spol- jašnjeg vazduha)		
CO	8h: ≤10 mg/m ³ ; 1h: ≤35 mg/m ³ ; 15 min: ≤100 mg/m ³	WHO (2010); visok afinitet prema hemoglobinu – opasan gas; izvori: grejanje		
Radon	<100 Bq/m ³ (go- dišnja srednja vrednost)	WHO (2009); kancerogeni gas; izvori: podzemne vode, građevinski materijali		

Izvor: Autor prema ASHRAE (2022), Batterman et al. (2023), Marques et al. (2023), WHO (2021).

Ključni normativi koji definišu ove indikatore uključuju:

- WHO Guidelines for Indoor Air Quality: Selected Pollutants (2010) – za hemijske zagađujuće materije poput formaldehida, radona i CO;
- WHO Global Air Quality Guidelines (2021) – primenjivo na PM, NO₂ i O₃, sa naglaskom da nema sigurnog nivoa izloženosti;
- ASHRAE Standard 55 (2023) – za termički komfor (temperatura, vlažnost);
- ASHRAE Standard 62.1 (2022) – za ventilaciju i prihvatljivi kvalitet unutrašnjeg vazduha;
- EU Direktiva 2008/50/EC (kao referentni okvir za penetraciju spoljašnjih zagađujućih materija);
- Pravilnik o granicama izlaganja jonizujućim zračenjima i merenjima radi procene nivoa izlaganja jonizujućim zračenjima („Sl. glasnik RS“, br. 86/2011 i 50/2018) – nacionalni standard za Srbiju za radon u zatvorenim prostorima - Interventni nivoi za hronično izlaganje radonu u stanovima jednaki su godišnjoj prosečnoj koncentraciji od 200 Bqm⁻³ ²²²Rn u vazduhu u novoizgrađenim stambenim objektima, a 400 Bqm⁻³ ²²²Rn u vazduhu za postojeće stambene objekte. (usaglašeno sa EU Direktivom 2013/59/Euratom i WHO preporukama).

Ovi standardi naglašavaju važnost redovnog monitoringa i ventilacije za održavanje zdravog unutrašnjeg okruženja, posebno u kontekstu klimatskih promena i urbanizacije. Usklađivanje sa ovim standardima omogućava ne samo zaštitu zdravlja, već i poboljšanje obrazovnih rezultata kroz unapređenje kognitivne performanse učenika (Allen et al., 2016).

3. Ventilacija u učionicama

Ventilacija je ključni faktor u očuvanju zdravog unutrašnjeg okruženja u obrazovnim ustanovama, gde učenici i nastavnici provode više sati dnevno (Fisk, 2017). Ona podrazumeva razmenu vazduha između unutrašnjeg i spoljašnjeg prostora, obezbeđujući dovoljno kiseonika, uklanjajući višak CO₂, kontrolišući vlažnost i eliminišući štetne materije poput VOC, PM čestica i formaldehida (WHO, 2021). Pravilna ventilacija ne samo da poboljšava kvalitet vazduha, već i podiže kognitivnu performansu učenika, smanjuje izostanke zbog bolesti i povećava zadovoljstvo okruženjem (Wargocki &

Wyon, 2007). Nasuprot tome, nedovoljna ventilacija dovodi do akumulacije CO₂, povećane vlažnosti, razvoja plesni i širenja patogenih, direktno utičući na zdravlje i produktivnost (Mendell et al., 2022). U kontekstu klimatskih promena, ventilacija mora biti adaptivna, jer ekstremni vremenski uslovi utiču na njenu efikasnost – na primer, tokom vrućih talasa izbegava se otvaranje prozora zbog spoljašnjeg zagađenja, što zahteva pametne sisteme koji automatski prilagođavaju protok (Marques et al., 2023).

Ventilacioni sistemi u školama dele se na prirodne, mehaničke i hibridne. Prirodna ventilacija oslanja se na ručno otvaranje prozora i vrata, energetski efikasna ali zavisna od spoljašnjih uslova poput temperature i vetra, često nedovoljna za održavanje kvaliteta vazduha unutar granica, što dovodi do prekomernih koncentracija CO₂ zimi (Mendell et al., 2022). Klimatske promene čine je manje pouzdanom, izlažući učenike hladnoći ili spoljašnjem zagađenju (Rožanec et al., 2024). Mehanička ventilacija koristi ventilatore i HVAC jedinice sa filtracijom, omogućavajući kontrolu temperature, vlažnosti i čestica, ali sa većom energetskom potrošnjom i potrebom za održavanjem (Batterman et al., 2023). U Srbiji, gde je energija skupa, ovo predstavlja ekonomski izazov, ali studije pokazuju povraćaj kroz smanjene zdravstvene troškove (Mendell et al., 2022). Hibridna ventilacija kombinuje obe, nudeći efikasnost i fleksibilnost u modernim školama (Marques et al., 2023).

Koncentracija CO₂ koristi se kao pouzdan indikator kvaliteta ventilacije i svežine vazduha u zatvorenim prostorima. Vrednosti iznad 1000 ppm ukazuju na neadekvatnu ventilaciju i povezane su sa značajnim smanjenjem kognitivnih funkcija, koncentracije i produktivnosti učenika i studenata, dok vrednosti iznad 1500 ppm ukazuju na negativne efekte. Da bi se predupredili negativni efekti usled povećane koncentracije CO₂ neophodna je brzina izmene vazduha (ACH) od minimalno 4 ACH u učionicama (ASHRAE, 2022). Preporučeni dotok svežeg vazduha je 20 m³/čas po učeniku, zahtevajući četiri izmene u 45-minutnom času (Rožanec et al., 2024). Klimatske promene zahtevaju senzore za automatsko prilagođavanje tokom toplih ili vlažnih perioda, smanjujući troškove za 15-25% (Marques et al., 2023). Hibridni sistemi sa HEPA filterima smanjuju PM za 90%, ali zahtevaju subvencije, naglašavajući nacionalne programe podrške za implementaciju (Batterman et al., 2023).

Šema na slici 2 prikazuje progresivan odnos između rastućih koncentracija ugljen-dioksida (CO₂) u unutrašnjem vazduhu i povećanja zdravstvenih rizika



Slika 2: Šema progresivnog odnosa između rastućih koncentracija ugljen-dioksida (CO₂) u unutrašnjem vazduhu i povećanja zdravstvenih rizika. *Izvor: Autor*

4. Uticaj kvaliteta vazduha na zdravstveno stanje i akademske performanse

Respiratorne bolesti su vodeći uzrok smrtnosti kod dece, sa prevencijom koja je ključna jer oko 700.000 dece mlađe od pet godina godišnje umire od posledica zagađenja vazduha (WHO, 2021). Deca udišu više polutanata po kilogramu telesne mase zbog manjih disajnih puteva i slabijeg imuniteta, često dišući na usta i zaobilazeći prirodnu filtraciju (Lan et al., 2011). Loša ventilacija, neadekvatna temperatura i prevelika popunjenost učionica dodatno povećavaju zdravstvene rizike (Fisk, 2017). Najčešće bolesti uključuju bronhitis, astmu, upalu pluća i smanjenu plućnu funkciju, povezane sa PM_{10} , NO_2 , ozonom i azot-dioksidom, sa simptomima poput bola u grudima, kašlja, upaljenog grla i problema sa disanjem (Rožanec et al., 2024). Ovi simptomi su česti u klimatizovanim učionicama ili onima sa visokim temperaturama bez klime (Tsantaki et al., 2022). Povećane koncentracije $PM_{2.5}$ čestica dovode do rasta ishemične bolesti srca, moždanog udara i srčane slabosti, jer prodiru u organe preko krvotoka, izazivajući oksidativni stres (Batterman et al., 2023). Povećane koncentracije NO_2 dovode do poremećaja srčanog ritma u urbanim sredinama, dok ozon doprinosi povećanom broju smrtnih slučajeva kod pacijenata sa infarktom (WHO, 2021). Ovi efekti su izraženiji u zemljama u razvoju, gdje loš IAQ pojačava socijalno-ekonomske nejednakosti u zdravlju (Galičić et al., 2023).

Kvalitet unutrašnjeg vazduha utiče na kognitivne sposobnosti dece, usporavajući razvoj mozga čak i prenatalno (Allen et al., 2016). Studija u Mongoliji sa 540 trudnica pokazala je da HEPA filteri tokom trudnoće povećavaju IQ dece za 2,8 jedinica i poboljšavaju razumevanje govora (Allen et al., 2016). Španska studija povezuje NO_2 sa smanjenim verbalnim sposobnostima (Zhang et al., 2021). Izloženost olovu dovodi do govornih mana, agresivnosti, antisocijalnog ponašanja, poremećaja spavanja i depresije (Lan et al., 2011). Metil-živa prenatalno oštećuje mozak, dovodeći do poremećaja pažnje, loše memorije i motorike (Lan et al., 2011). $PM_{2.5}$ smanjuje inteligenciju i pažnju, a dugotrajno ubrzava kognitivno opadanje, povećavajući rizik od Alchajmerove bolesti i demencije (Zhang et al., 2021). Ovi efekti su kumulativni, sa trajnim posledicama u odraslom dobu za decu izloženu lošem IAQ tokom školovanja (Ezeamii et al., 2025).

Loš kvalitet vazduha direktno utiče na nastavni učinak, koncentraciju i kognitivne funkcije, često povezane sa sindromom „bolesne zgrade“, koji se manifestuje simptomima kao što su glavobolje, umor, iritacija očiju i

problema sa koncentracijom (Tsantaki et al., 2022; Mendell & Heath, 2005). Povišeni nivoi CO₂ i povišene temperature značajno smanjuju sposobnost rešavanja zadataka i pažnju (Wargocki & Wyon, 2007). Poboljšanje ventilacije povezano je sa smanjenjem izostanaka učenika i studenata do 35%, što direktno doprinosi poboljšanom opštem zdravlju i akademskom uspehu (Mendell et al., 2022). Konkretno, u istraživanjima sprovedenim u univerzitetskim objektima u Grčkoj, loš kvalitet unutrašnjeg vazduha povezivan je sa simptomima sindroma „bolesne zgrade“, kao što su umor, glavobolje i respiratorne tegobe, što naglašava potrebu za sistematskim i kontinuiranim procenama kvaliteta vazduha u ovim sredinama (Tsantaki et al., 2022). U uslovima digitalnog učenja, loš kvalitet vazduha dodatno pojačava negativne efekte dugotrajnog rada za ekranom, što doprinosi povećanom osećaju zamora i smanjenoj produktivnosti (Allen et al., 2016). U tabeli 4 prikazani su primeri kratkoročnih i dugoročnih zdravstvenih efekata najčešćih zagađujućih materija u učionicama.

Tabela br. 4. Primeri zdravstvenih efekata glavnih zagađujućih materija u učionicama

Zagađujuća materija	Kratkoročni efekti (satima do danima)	Dugoročni efekti (mesecima do godinama)	Najugroženije grupe u obrazovnim ustanovama
CO ₂	Glavobolja, pospanost, umor, smanjena koncentracija i budnost	Lošije kognitivne performanse i školski rezultati, hronični umor	Deca, učenici i studenti
PM _{2.5}	Iritacija očiju/nosa/grla, kašalj, pogoršanje astme	Razvoj astme, smanjena plućna funkcija, kardiovaskularne bolesti, moždani udar	Deca i adolescenti (posebno <14 godina)
PM ₁₀	Iritacija disajnih puteva, kašalj, pogoršanje respiratornih oboljenja	Hronična opstruktivna plućna bolest, trajno smanjena plućna funkcija	Deca i adolescenti
VOC (ukupni)	Iritacija očiju/nosa/grla, glavobolja, vrtoглаvica, mučnina	Neurotoksični efekti, astma, povećan rizik od leukemije i drugih karcinoma	Deca i adolescenti
Formaldehid	Peckanje očiju, suzenje, iritacija grla, mučnina	Nazofaringealni karcinom, leukemija, hronične respiratorne bolesti	Deca (posebno mlađa od 6 godina)

Zagađujuća materija	Kratkoročni efekti (satima do danima)	Dugoročni efekti (meseциma do godinama)	Najugroženije grupe u obrazovnim ustanovama
O ₃ (ozon)	Kašalj, bol u grudima, iritacija grla, smanjena plućna funkcija	Ubrzano starenje pluća, razvoj astme, kardiovaskularni rizik	Deca i adolescenti sa astmom
NO ₂	Iritacija disajnih puteva, pogoršanje astme, veća osetljivost na infekcije	Razvoj astme kod dece, smanjena plućna funkcija, hronične respiratorne infekcije	Deca i adolescenti
CO	Glavobolja, vrtoglavica, mučnina, konfuzija; pri visokim koncentracijama smrt	Neurološki deficiti, kardiovaskularne bolesti	Deca, učenici i studenti
Radon	(nema akutnih simptoma)	Karcinom pluća (drugi vodeći uzrok nakon pušenja)	Deca, učenici i nastavno osoblje
Biološki kontaminanti (bakterije, virusi, gljivice, alergeni)	Akutne respiratorne infekcije, alergije, „sindrom bolesne zgrade“	Astma, hronične alergije, hipersenzitivni pneumonitis, povećan absentizam	Deca i adolescenti sa alergijama/astmom

Izvor: Autor prema Annesi-Maesano et al. (2023) – *Air pollution in schools and cognitive development in children*,: WHO Global Air Quality Guidelines (2021), WHO Guidelines for Indoor Air Quality: Selected Pollutants (2010), Allen et al. (2016) – *Associations of cognitive function scores with CO₂ and ventilation in office workers*, Madureira et al. (2020) – *Indoor air quality in schools and health symptoms among Portuguese teachers*, Sadrizadeh et al. (2022) – *Indoor air quality and health in schools: a critical review*, European Environment Agency (2024) – *Air pollution and children's health*, US EPA (2024) – *Health effects of fine particulate matter in children*).

5. Normativni okviri i standardizacija

U Srbiji, normativni okvir za kontrolu kvaliteta vazduha reguliše niz zakona i podzakonskih akata, fokusiranih prvenstveno na spoljašnji vazduh, ali sa implikacijama na unutrašnje uslove u obrazovnim ustanovama. Zakon o zaštiti vazduha („Sl. glasnik RS“, br. 36/09, 10/13, 26/21) definiše obaveze praćenja i upravljanja, indirektno utičući na javne objekte. Uredba o uslovima

monitoringa („Sl. glasnik RS“, br. 11/10, 75/10, 63/13) propisuje metode merenja i granice za PM_{10} , $PM_{2.5}$, NO_2 , O_3 , SO_2 i CO. Pravilnik o preventivnim merama za bezbedan rad („Sl. glasnik RS“, br. 21/2009, 1/2019) zahteva dovoljno svežeg vazduha na radnim mestima, bez specifičnih granica za CO_2 , ali postavlja osnovu za ventilaciona rešenja. Propisi iz građevinarstva i energetske efikasnosti utiču indirektno kroz standarde materijala i sanaciju. Nedostatak specifičnog pravilnika za IAQ u školama predstavlja vakuum, pa se koriste međunarodne smernice (ASHRAE, 2022). Ovo ukazuje na potrebu ažuriranja za usklađivanje sa EU standardima, posebno uz klimatske promene (Rožanec et al., 2024).

Međunarodni standardi popunjavaju praznine: ASHRAE 62.1 (2022) definiše minimalne ventilacione stope – 5–7.5 L/s po učeniku, integraciju CO_2 senzora i kontrolu recirkulacije (ASHRAE, 2022). WHO Global Air Quality Guidelines (2021) postavljaju granice za ambijentalni vazduh, primenjive unutra: $PM_{2.5}$ (5 $\mu g/m^3$ godišnje, 15 $\mu g/m^3$ 24h), PM_{10} (45 $\mu g/m^3$ 24h), NO_2 (10 $\mu g/m^3$ godišnje), CO (4 mg/m^3 8h), O_3 (100 $\mu g/m^3$ 8h) (WHO, 2021). EN 16798-1:2019 definiše termički komfor na osnovu aktivnosti (ASHRAE, 2022). U skladu sa trendovima, Srbija treba unaprediti okvir standardizacijom granica za IAQ u školama, koristeći ASHRAE, WHO i EU, sa obavezom merenja CO_2 , $PM_{2.5}$ i vlažnosti, obukom osoblja i EU-finansiranim projektima za modernizaciju (Marques et al., 2023).

6. Preporuke za unapređenje kvaliteta vazduha u obrazovnim ustanovama

Preporuke za unapređenje kvaliteta vazduha u obrazovnim ustanovama uključuju tri glavna aspekta:

- Tehničke mere: Redovan monitoring ključnih parametara (CO_2 , $PM_{2.5}$, temperatura, vlažnost) sa kontinuiranim pristupom rezultatima, unapređenje ventilacionih sistema (moderni sistemi sa kontrolom protoka, hibridni modeli, redovno održavanje), korišćenje niskoemisionih materijala (npr. sertifikat Greenguard Gold) pri renoviranju, postavljanje prečišćivača vazduha u zagađenim oblastima, i optimizacija termičkih uslova prema standardima ASHRAE (2022).
- Obrazovne mere: Edukacija nastavnika, učenika i administracije o značaju kvaliteta unutrašnjeg vazduha, uvođenje procedura redovnog provetravanja

ja tokom pauza, razvoj programa održavanja sa jasnim protokolima reagovanja, uključivanje ekoloških tema u nastavne planove i aktivno uključivanje roditelja i lokalne zajednice u očuvanje kvaliteta vazduha.

- Političke mere: Usklađivanje nacionalnih propisa sa međunarodnim standardima, uvođenje zakonski obaveznih standarda kvaliteta unutrašnjeg vazduha sa redovnim proverama, obezbeđivanje budžetskih sredstava za modernizaciju školske infrastrukture i stimulisanje istraživanja za dalja unapređenja.

Implementacija ovih mera treba da počne pilot-projektima u urbanim školama radi postizanja skalabilnosti i efikasnosti, uz postupnu ekspanziju na druge ustanove.

Ove preporuke su zasnovane na recentnoj literaturi i smernicama, uključujući Marques et al. (2023), Tsantaki et al. (2022), ASHRAE standarde (2022) i preporuke Svetske zdravstvene organizacije (2021).

Mere za unapređenje kvaliteta vazduha u obrazovnim ustanovama integrisane na opisani način, pomoći će poboljšanju zdravlja učenika i zaposlenih, smanjenju bolesti povezanih sa lošim kvalitetom vazduha i povećanju akademskog uspeha.

7. Zaključak

Istraživanje kvaliteta unutrašnjeg vazduha u obrazovnim ustanovama otkriva složenu vezu između ekoloških, zdravstvenih i arhitektonskih faktora. Učenici i studenti u Srbiji i Evropi izloženi su visokim nivoima CO₂, PM_{2.5}, PM₁₀ i VOC, koji predstavljaju značajan rizik za zdravlje i smanjuju kognitivne sposobnosti. Podaci pokazuju da su uslovi u školama Srbije donekle slični, ali često gori od evropskih standarda.

Kvalitet vazduha u učionicama direktno utiče na fizičko zdravlje i akademski uspeh. Loša ventilacija povećava rizike, pa je neophodno uvesti obavezni monitoring, poboljšati ventilacione sisteme i pružiti edukaciju o značaju kvaliteta unutrašnjeg vazduha. Poseban fokus treba biti na održavanju nivoa CO₂ ispod preporučenih granica radi očuvanja zdravlja i bolje kognitivne funkcije učenika i studenata, kao i na tehnikama prozračivanja i kontroli ostalih zagađivača prisutnih u učionicama.

Buduća istraživanja treba da se usredsrede na dugoročne efekte i sezonske promene, uz usklađivanje nacionalnih propisa sa međunarodnim smernicama. Školske uprave, lokalne samouprave i ministarstva obrazovanja moraju implementirati kontinuirani monitoring, obezbediti adekvatnu ventilaciju, subvencionisati zdrave materijale, sprovesti obuke i integrisati ekološke teme u obrazovne programe. Podizanje svesti kroz radionice i koordinacija između različitih sektora ključni su za stvaranje zdravijih školskih sredina. Najnovija istraživanja iz 2025. potvrđuju da ulaganja u kvalitet unutrašnjeg vazduha donose značajne dugoročne koristi društvu kroz poboljšanje mentalnih funkcija i smanjenje zdravstvenih rizika.

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Impact of Indoor Air Quality in Educational Institutions on the Health and Academic Performance of Students and Strategies for Improvement

Abstract

Indoor air quality (IAQ) is a key factor affecting the health, cognition, and well-being of schoolchildren and students. In schools, where students spend a significant part of the day, a safe environment is a priority. This paper analyzes IAQ parameters: CO₂, PM_{2.5}/PM₁₀, VOCs, temperature, and humidity. Through a systematic literature review and comparative analysis of WHO, ASHRAE, EU, and national standards, the impact of pollution on the health and academic performance of schoolchildren and students is examined. The emphasis is on classroom ventilation, monitoring, and staff education. The conclusion offers recommendations for education and public health, guidelines for future research, analysis of long-term risks (cardiovascular and neurological diseases), integration of rapid-response sensors, the role of climate change, and highlights increased economic costs due to poor IAQ (losses in productivity and healthcare). Recent studies show that improved ventilation reduces cognitive deficits by up to 20%, emphasizing the need for urgent interventions.

Keywords

Indoor air quality, educational institutions, CO₂, PM_{2.5}, VOC, ventilation, monitoring, cognitive deficits, productivity.

POLITIKA DEVIZNOG KURSA U FUNKCIJI PRIVREDNOG RASTA I KONKURENTNOSTI SRBIJE

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Rezime: Devizni kurs je jedan od ključnih makroekonomskih instrumenata koji direktno utiče na konkurentnost privrede, posebno kada je reč o izvozno orijentisanim sektorima. Način na koji se kurs oblikuje i održava određuje relativne cene domaćih i stranih proizvoda, a samim tim i poziciju zemlje na međunarodnim tržištima. Stabilan i uravnotežen kurs omogućava izvoznicima da dugoročno planiraju proizvodnju, ulaganja i plasman svojih proizvoda, dok nestabilan kurs stvara nesigurnost i smanjuje njihovu sposobnost da konkurišu stranim proizvođačima. Srbija je u prethodnim decenijama suočena sa nizom izazova koji su ograničavali njenu konkurentnost, a jedan od najznačajnijih faktora upravo je bio neadekvatan kursni režim. U takvim uslovima privreda nije uspela da razvije stabilnu i diversifikovanu izvoznu strukturu, pa je zabeležena visoka zavisnost od uvoza, što je dodatno oslabilo devizni bilans zemlje. Uticaj kursa na konkurentnost izvoza posebno dolazi do izražaja u vreme globalnih ekonomskih kriza. Rizici povezani sa deviznim kursom dodatno su izraženi zbog visoke zavisnosti Srbije od uvoza kapitala i stranih direktnih investicija.

Ključne reči: devizni kurs, privredni rast, ekonomska politika, konkurentnost

Uvod

Devizni kurs je jedan od ključnih instrumenata ekonomske politike, jer istovremeno utiče na unutrašnju i spoljnu ravnotežu privrede, na tokove

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kapitala, cene i nivo međunarodne konkurentnosti. U Srbiji, posle 2000. godine, ovaj instrument dobija dodatni značaj usled procesa tranzicije, liberalizacije i otvaranja državne ekonomije prema globalnim tržištima. Stabilizacija kursa dinara predstavljala je centralni zadatak monetarnih vlasti u periodu nakon 2000. godine, jer je istorijski nasleđena visoka inflacija zahtevala strog okvir makroekonomske politike. U početnim godinama tranzicije, kurs je imao ulogu sidra koje je služilo za obuzdavanje inflacionih pritisaka i jačanje poverenja u domaću valutu. Takva politika doprinela je relativnom smirivanju cena, ali je istovremeno otvorila pitanje održivosti visoke uvozne zavisnosti privrede.

Kretanja deviznog kursa oblikovala su, na nivou privrednog rasta, izvoznju konkurentnost i dinamiku uvoza. Precenjen kurs u pojedinim periodima otežavao je izvoz i doveo do povećanja spoljnotrgovinskog deficita, dok je deprecijacija povremeno delovala stimulatивно na izvoznike, ali i stvarala inflacione pritiske. Ovaj dvostruki efekat pokazuje složenost odnosa između kursne politike i realnog sektora. Uticaj kursa na konkurentnost izvoza posebno dolazi do izražaja u vreme globalnih ekonomskih kriza. Srbija, kao mala i otvorena ekonomija, zavisi od tražnje na stranim tržištima, a kada dolazi do usporavanja privrede vodećih svetskih ekonomija, smanjuje se i mogućnost srpskih izvoznika da plasiraju robu. Ako se takvi spoljašnji šokovi poklope sa neodgovarajućom kursnom politikom, posledice po domaću privredu mogu biti još teže, jer pada i izvoz i ukupna stopa rasta BDP-a.

U ovom radu autori nastoje da, na osnovu zvaničnih pokazatelja poslovanja privrede Srbije, utvrde uticaj deviznog kursa na privredni rast, zaposlenost, inflaciju i konkurentnost privrede Srbije u periodu posle 2000-te godine do sada.

Politika deviznog kursa i privredni rast u Srbiji posle 2000. godine

Devizni kurs predstavlja jedno od ključnih makroekonomskih obeležja svake države. Njegovo kretanje utiče na konkurentnost privrede, nivo cena, zaduženost, stabilnost bankarskog sektora i životni standard stanovništva. U slučaju Srbije, nakon 2000. godine, kurs dinara prema evru prošao je kroz različite faze, koje su odražavale tranziciju ka tržišnoj ekonomiji, uticaje globalnih kriza i primenu mera Narodne banke Srbije (NBS). Analiza kursa u periodu od 2000. do 2024. godine pokazuje kako su deprecijacije i stabilizacije oblikovale privredna kretanja i ekonomske politike države.

Monetarne vlasti su u Srbiji postupno prelazile sa režima fiksnog na režim upravljano-plivajućeg kursa, pri čemu je Narodna banka Srbije koristila intervencije na deviznom tržištu kako bi sprečila prevelike oscilacije. Ovaj pristup obezbedio je relativnu stabilnost, ali je istovremeno izložio privredu spoljnim šokovima, posebno u vreme globalne finansijske krize 2008. godine.

Poseban izazov predstavljalo je pitanje kursne transmisije na inflaciju. Deprecijacija je u više navrata dovodila do rasta cena uvozne robe i energenata, što je stvaralo dodatno opterećenje životnom standardu stanovništva. Istovremeno, stabilan kurs doprinosio je nižim troškovima zaduživanja i većem poverenju banaka i investitora.

Efekti deviznog kursa vidljivi su i kroz promene u finansijskom sistemu. Jačanje bankarskog sektora i liberalizacija kapitalnih tokova učinili su devizni kurs još važnijim indikatorom makroekonomske stabilnosti¹⁴. Kurs je postao signal za investitore i domaće privredne subjekte o rizicima i potencijalnim kretanjima na tržištu kapitala.

Nadalje, značajan uticaj deviznog kursa ogledao se u štednim i kreditnim navikama stanovništva. Visok udeo devizne štednje ukazuje na to da kursna stabilnost ima direktne posledice na finansijsku sigurnost građana. Takođe, kreditna zaduženost u evrima povećala je izloženost domaćinstava i privrede valutnom riziku, što je dodatno naglašavalo važnost kursne politike.

Efekti kursa ogledali su se i u platnom bilansu, gde je deficit tekućeg računa često bio posledica visoke uvozne zavisnosti i niske izvozne baze, a promene kursa imale su ograničen kapacitet da dugoročno isprave ovu neravnotežu. Pored toga, kretanja kursa značajno su uticala na tokove stranih direktnih investicija, budući da stabilnost dinara predstavlja jedan od glavnih faktora investicione atraktivnosti zemlje.

Kumulativno posmatrano, efekti deviznog kursa na privredna kretanja u Srbiji posle 2000. godine ogledaju se u makroekonomskoj stabilnosti, konkurentnosti privrede i privlačenju kapitala. Analiza ovih efekata, uz oslanjanje na teorijska polazišta međunarodne ekonomije i praktična iskustva tranzicionih zemalja, omogućava dublje razumevanje specifičnog puta kojim se kretala srpska ekonomija u posmatranom periodu.

Kretanje deviznog kursa posle 2000. godine

Period od 2000. do 2013. godine karakterisale su značajne oscilacije deviznog kursa. Na kraju 2002. godine kurs je iznosio 61,51 dinara za evro, što je predstavljalo posledicu prethodnih dešavanja u domaćoj ekonomiji i

prelaska na tržišni sistem. Na kraju 2003. godine kurs je već dostigao 68,31 dinar, da bi se slabljenje dinara nastavilo naredne dve godine pa je na kraju 2005. godine evro dostigao vrednost od 85,50 dinara (Tabela 1.).

U periodu 2006–2007. kurs se privremeno stabilizovao, krećući se oko 79 dinara za evro, što je u velikoj meri bilo rezultat priliva deviza kroz privatizacije, direktne strane investicije i doznake iz inostranstva. Međutim, globalna finansijska kriza 2008. godine izazvala je naglu deprecijaciju dinara. Kurs je na kraju 2008. godine bio već 88,60 dinara za jedan evro, a 2009. godine 95,89 dinara. Tokom narednih godina deprecijacija se nastavila sve do kraja 2013. Godine kada je bio 114,64 dinara.

Tabela 1. Kretanje srednjeg kursa dinara prema evru, 2002–2013.

(stanja na dan 31.12.)

God.	2002.	2003.	2004.	2005.	2006.	2007.	2008.	2009.	2010.
Kurs	61,51	68,31	78,88	85,50	79,00	79,24	88,60	95,89	105,50
God.	2011.	2012.	2013.						
Kurs	104,64	113,72	114,64						

Izvor: Narodna banka Srbije

Devizni kurs u ovom periodu jasno pokazuje trend deprecijacije dinara, naročito nakon 2008. godine. Deprecijacija je imala dvostruke efekte: sa jedne strane poboljšala je konkurentnost izvoznog sektora, dok je sa druge strane povećala troškove uvoza i podstakla rast inflacije. Ovaj proces posebno je pogodio građane i privredu zaduženu u evru, jer su rate kredita postale znatno veće.

Visok stepen evroizacije označava intenzivnu upotrebu evra u domaćoj ekonomiji i vezivanje cena, plata i kamatnih stopa za kurs evra. Ovaj fenomen podrazumeva da dinarske cene velikog broja proizvoda prate cene u evrima, što govori u prilog činjenici da Srbija danas ima de facto dvovalutni sistem (Tasić, 2013). Vremenom se suština izbora odgovarajućeg sistema deviznog kursa svela na ekstreme: fiksni ili fluktuirajući devizni kurs, s tim da se rukovodjeni fluktuirajući model nametnuo kao najzastupljenija praktična varijanta fluktuirajućeg kursa (Kovačević, 2020).

Period od 2014. do 2024. godine obeležen je znatno većom stabilnošću kursa. Na kraju 2014. godine srednji kurs je iznosio 120,96 dinara uz blagi rast u naredne dve godine. Nakon toga usledila je stabilizacija, pa je 2017.

srednji kurs opao na 118,47, I relativna stabilnost se nastavila sve do kraja 2024. godine. Posebno je značajno što je u 2020. i 2021. kurs bio gotovo identičan, na nivou od 117 do 118 dinara za evro, uprkos izazovima pandemije COVID-19 (Tabela 2.)

Tabela 2. Kretanje srednjeg kursa dinara prema evru, 2014–2024.

God.	2014.	2015.	2016.	2017.	2018.	2019.	2020.	2021.
Kurs	120,96	121,63	123,47	118,47	118,19	117,59	117,58	117,58
God.	2022.	2023.	2024.					
Kurs	117,32	117,17	117,01					

Izvor: Narodna banka Srbije

Iz podataka Tabele 2. je vidljivo da devizni kurs od kraja 2017. godine pokazuje izuzetnu stabilnost, što se može posmatrati kao rezultat dosledne politike NBS i povećanog poverenja investitora. Stabilan kurs smanjio je valutni rizik, podstakao strane direktne investicije i omogućio predvidivost poslovanja. Istovremeno, očuvanje kursa doprinelo je niskoj inflaciji i očuvanju kupovne moći stanovništva.

Kretanje deviznog kursa posle 2000. godine značajno je uticalo na ekonomske tokove u Srbiji. U periodu intenzivne deprecijacije (2008–2013) rast kursa izazvao je povećanje inflacionih pritisaka i smanjenje životnog standarda. Istovremeno, određeni sektori izvoza ostvarili su koristi zahvaljujući povoljnijem odnosu cena. Stabilizacija kursa u periodu posle 2014. godine obezbedila je veću makroekonomsku predvidivost, što je od izuzetnog značaja za investicione odluke i kreditnu politiku.

Stabilan kurs pozitivno je uticao na finansijsku stabilnost, jer je olakšao servisiranje deviznog duga države i privrede. Građani i preduzeća sa kreditima u evru imali su koristi od izbegavanja naglih skokova rata, što je doprinelo stabilnosti potrošnje i poverenju u bankarski sektor. Sa druge strane, izvozno orijentisani sektori suočili su se sa izazovom konkurentnosti, jer stabilan kurs nije pružao dodatne povoljnosti kroz deprecijaciju. To je stvorilo potrebu za povećanjem produktivnosti i inovativnosti kao glavnih izvora konkurentske prednosti.

Analiza kretanja deviznog kursa dinara prema evru od 2000. do 2024. godine pokazuje dva jasno odvojena perioda: fazu deprecijacije i volatilnosti do 2013. godine i fazu stabilizacije od 2014. godine nadalje. Ova kretanja odražavaju tranzicioni put Srbije, izazove globalnih ekonomskih kriza i uspešnu implementaciju monetarne politike NBS u poslednjoj deceniji.

Devizni kurs u tom smislu nije bio samo ekonomski pokazatelj, već i ključni instrument očuvanja makroekonomske stabilnosti.

U narednom periodu održavanje ravnoteže između stabilnosti kursa i konkurentnosti privrede biće od presudnog značaja za dalji ekonomski razvoj. Devizni kurs, zajedno sa fiskalnom disciplinom, investicionom politikom i strukturnim reformama, ostaje stub održivog rasta i integracije Srbije u evropske i svetske ekonomske tokove.

Devizni kurs ima jedan od ključnih uticaja na makroekonomsku stabilnost, rast proizvodnje, inflaciju i spoljnotrgovinske tokove u Srbiji. Podaci Narodne banke Srbije pokazuju da je u periodu od 2015. do 2024. godine postojala jaka povezanost između kretanja kursa dinara prema evru i pokazatelja kao što su inflacija, rast BDP-a, stopa nezaposlenosti i deficit tekućeg računa.

Tabela 3: Ključni makroekonomski indikatori (2015-2024)

Godina	Rast BDP (%)	Inflacija (%)	Stopa nezaposlenosti (%)	Tekući račun (% BDP)	Srednji kurs na dan 31.12. (RSD/EUR)
2015.	1.3	1.5	18.9	-3.3	121.63
2016.	3.0	1.6	16.4	-2.8	123.47
2017.	2.4	3.0	14.5	-5.0	118.47
2018.	4.6	2.0	13.7	-4.6	118.19
2019.	4.8	1.9	11.3	-6.6	117.59
2020.	-1.0	1.3	9.7	-3.9	117.58
2021.	7.9	7.9	11.1	-4.1	117.58
2022.	2.6	15.1	9.5	-6.6	117.32
2023.	3.8	7.6	9.5	-2.4	117.17
2024.	3.9	4.3	9.4	-4.7	117.01

Izvor: Narodna banka Srbije (2025): Osnovni makroekonomski pokazatelji

Podaci Narodne banke Srbije pokazuju da je u periodu 2015–2024 devizni kurs bio relativno stabilan, što je doprinelo kontroli inflacije nakon 2020. godine i omogućilo povoljnije uslove za investicije. Periodi veće nominalne i realne fluktuacije (npr. 2020–2022) pokazali su snažan prenos na cene, što je uticalo na rast inflacije u 2022. godini. Vrednosti tekućeg računa

i veliki uvozni računi pokazuju da je konkurentnost još uvek izazov, te da prilagođavanje kursa može značajno uticati na balans spoljne trgovine.

Uticaj deviznog kursa na konkurentnost privrede

Uticaj deviznog kursa na privredu jedne zemlje je višestruk. Najveći uticaj u zemljama u razvoju i zemljama u tranziciji devizni kurs ima u oblastima alokacije resursa, ekonomskom razvoju, tekućem bilansu, inflaciji i finansijskom sistemu (Frenkel, Taylor, 2006). U zemljama u razvoju orijentacija ka stabilnom deviznom kursu može biti posledica opredeljenja ka evropskim integracijama, antiinflacione ekonomske politike i političkih razloga (Marinković, 2006). Optimalni režim deviznog kursa zavisi od specifičnih karakteristika svake pojedine zemlje (Stanišić, Janković, 2012). U slučaju izloženosti ekonomije spoljnim šokovima relativno bolje rešenje je fluktuirajući devizni kurs, a u slučaju rešavanja unutrašnjih poremećaja (borba protiv inflacije) prednost daje fiksnom režimu deviznog kursa (Miljković, 2008).

Devizni kurs je jedan od ključnih makroekonomskih instrumenata koji direktno utiče na konkurentnost privrede Srbije, posebno kada je reč o izvozno orijentisanim sektorima. Način na koji se kurs oblikuje i održava određuje relativne cene domaćih i stranih proizvoda, a samim tim i poziciju Srbije na međunarodnim tržištima. Stabilan i uravnotežen kurs omogućava izvozniciima da dugoročno planiraju proizvodnju, ulaganja i plasman svojih proizvoda, dok nestabilan kurs stvara nesigurnost i smanjuje njihovu sposobnost da konkurišu stranim proizvođačima.

Prekomerna apresijacija dinara može imati negativne posledice jer domaći proizvodi postaju skuplji na inostranim tržištima, što vodi ka smanjenju izvoza. S druge strane, depresijacija kursa u određenim okolnostima može privremeno povećati konkurentnost izvoza, ali istovremeno izaziva porast cena uvoznih inputa i inflatorne pritiske u domaćoj privredi. Zbog toga je neophodno uspostaviti ravnotežu u politici deviznog kursa koja će istovremeno podržati izvoznike i očuvati makroekonomsku stabilnost.

Relativna stabilnost dinara nakon 2010. godine sama po sebi je doprinela smanjenju inflacije i vraćanju poverenja u nacionalnu valutu. Međutim, visoka uvozna zavisnost i izražena evroizacija privrede usloveli su da promena kursa ima snažan prenos na cene, što je otežavalo vođenje nezavisne monetarne politike. Uticaj na konkurentnost bio je dvostruk: nominalna stabilnost

doprinela je makroekonomskoj sigurnosti, ali je realna apresijacija dinara u pojedinim periodima umanjivala cenovnu konkurentnost izvoza.

Srbija je u prethodnim decenijama suočena sa nizom izazova koji su ograničavali njenu konkurentnost, a jedan od najznačajnijih faktora upravo je bio neadekvatan kursni režim. Pogreške u vođenju ekonomske politike, spor tempo reformi, nedovoljna strana ulaganja i tehnološko zaostajanje dodatno su pogoršali uticaj nepovoljnih kretanja kursa. U takvim uslovima privreda nije uspeła da razvije stabilnu i diversifikovanu izvoznu strukturu, pa je zabeležena visoka zavisnost od uvoza, što je dodatno oslabilo devizni bilans zemlje.

Povećanje izvoza postalo je jedan od glavnih prioriteta ekonomske politike Srbije, jer obezbeđuje devizni priliv potreban za servisiranje spoljnog duga i smanjenje trgovinskog deficita. Međutim, izuzetno loša izvozna struktura, formirana još tokom perioda sankcija i tranzicije, zahteva duboke promene i modernizaciju. U tom procesu devizni kurs ima presudnu ulogu, jer njegovim prilagođavanjem može da se podstakne konkurentnost proizvoda i otvori prostor za tehnološko unapređenje privrede.

Uticaj kursa na konkurentnost izvoza posebno dolazi do izražaja u vreme globalnih ekonomskih kriza. Srbija, kao mala i otvorena ekonomija, zavisi od tražnje na stranim tržištima, a kada dolazi do usporavanja privrede vodećih svetskih ekonomija, smanjuje se i mogućnost srpskih izvoznika da plasiraju robu. Ako se takvi spoljašnji šokovi poklope sa neodgovarajućom kursnom politikom, posledice po domaću privredu mogu biti još teže, jer pada i izvoz i ukupna stopa rasta BDP-a.

Rizici povezani sa deviznim kursom dodatno su izraženi zbog visoke zavisnosti Srbije od uvoza kapitala i stranih direktnih investicija. Kada kurs nije stabilan ili realno postavljen, smanjuje se atraktivnost zemlje za investitore, dok istovremeno raste cena kapitala i otežava se zaduživanje realnog sektora i države. Takođe, dominantno prisustvo banaka sa sedištem u evrozoni, koja je pogođena dužničkim krizama, može dodatno preneti negativne efekte na srpsku ekonomiju, posebno kroz kanale kreditiranja.

Upravljanje deviznim kursom nije samo tehničko pitanje monetarne politike, već strateško sredstvo za jačanje ukupne konkurentnosti privrede. Njegova pravilna primena može doprineti smanjenju makroekonomskih disbalansa, podsticanju izvoza i većoj integraciji Srbije u globalne tokove. Istovremeno, kursna politika mora biti koordinisana sa fiskalnom politikom,

politikom obrazovanja, inovacija i tehnološkog razvoja, jer samo tako može da generiše dugoročne pozitivne efekte.

Devizni kurs u Srbiji ima višestruku ulogu, odnosno on oblikuje konkurentnost izvoza, utiče na devizni bilans, određuje investicionu klimu i deluje kao signal međunarodnim partnerima o stabilnosti domaće privrede. Ukoliko se vodi politika koja dovodi do kursnih oscilacija i realne apresijacije, smanjuje se sposobnost privrede da poveća izvoz i unapredi strukturu proizvodnje. Nasuprot tome, uravnotežen kurs može delovati kao katalizator strukturnih reformi, jačanja preduzetništva i tehnološkog napretka.

Jasno je da bez pažljivo vođene politike deviznog kursa Srbija neće moći da obezbedi održiv rast konkurentnosti. To podrazumeva i donošenje „nepopularnih“ mera koje uključuju smanjenje javne potrošnje, veću fiskalnu disciplinu, ali i širu podršku izvoznim sektorima. Sve dok kursna politika ne bude u funkciji jačanja realne privrede i izvoznih kapaciteta, Srbija će nastaviti da zaostaje za razvijenim ekonomijama i da se suočava sa visokim trgovinskim deficitom i nedostatkom deviznog priliva.

Zaključak

Izbor deviznog kursa je jedno od najsloženijih pitanja ekonomske politike jer se njime određuje osnova za očuvanje makroekonomske stabilnosti i unapredjenje konkurentnosti. Srbija je tokom svoje ekonomske tranzicije isprobala različite pristupe, što omogućava da se na njenom primeru sagledaju prednosti i nedostaci oba režima – fiksnog i fluktuirajućeg kursa. Izbor optimalnog režima zavisi od trenutnih ekonomskih uslova i ciljeva koji se žele postići. U periodu borbe protiv hiperinflacije i političke nestabilnosti, fiksni kurs je mogao da deluje kao najbolje rešenje. Međutim, u uslovima današnje globalne nestabilnosti i potrebe za većom prilagodljivošću, fluktuirajući kurs se pokazuje kao prikladnije rešenje jer omogućava adaptaciju na spoljne šokove i očuvanje makroekonomske ravnoteže.

Srbija ima velike strukturne probleme u privredi i nisku produktivnost pa je pitanje deviznog kursa tim više osetljivo, posebno imajući u vidu nisku konkurentnost privrede na međunarodnom tržištu. U narednom periodu održavanje ravnoteže između stabilnosti kursa i konkurentnosti privrede biće od presudnog značaja za dalji ekonomski razvoj. Devizni kurs, zajedno sa fiskalnom disciplinom, investicionom politikom i strukturnim reformama,

ostaje stub održivog rasta i integracije Srbije u evropske i svetske ekonomske tokove.

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CHALLENGES AND IMPORTANCE OF MANAGEMENT ACCOUNTING IN SMALL AND MEDIUM-SIZED ENTERPRISES

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ABSTRAKT: The paper analyzes the role and importance of management accounting in small and medium-sized enterprises (SMEs), with particular emphasis on human resources, strategic and operational functions, as well as the challenges in its application. SMEs often face limited financial and human capacities, which leads to incomplete or underdeveloped management accounting systems. The lack of qualified staff, centralized decision-making, and reliance on managers' intuition instead of analytical instruments represent key barriers to effective business operations. Special attention is given to the importance of risk management, whose implementation in SMEs can contribute to increased competitiveness, business value, and long-term sustainability. The paper highlights that management accounting should not restrict SMEs' flexibility but rather support decision-making through relevant and reliable information. It concludes that management accounting represents the foundation of effective corporate governance and a key success factor for small and medium-sized enterprises in the modern economy.

Keywords: small and medium-sized enterprises (SMEs), management accounting, human resources, strategic accounting and risk management

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1. INTRODUCTION

Human resources allocated to performing management accounting tasks in small and medium-sized enterprises (SMEs) must be aligned with the specific responsibilities of this function. Furthermore, it is essential to monitor current trends in staffing solutions and the requirements placed on accountants in SMEs (Keuper et al., 2009). Within SMEs, it is advisable to establish a dedicated department responsible for management accounting tasks. Although such a practice can be applied even in micro-enterprises, in companies with more than 25 employees, the position of a management accounting manager can be relatively easily introduced. This approach is particularly beneficial in situations where managers lack sufficient expertise or time to carry out management accounting tasks themselves, while still bearing full responsibility for both strategic and operational management.

2. HUMAN RESOURCES POTENTIAL FOR MANAGEMENT ACCOUNTING IN SMES

The scope of responsibilities for management accounting in SMEs position often exceeds the role of management accountants in large corporations. Instead of focusing solely on producing business analyses, the management accounting manager also has an important advisory function, actively participating in the evaluation of all business activities within the enterprise. Small and medium-sized enterprises (SMEs) often choose to engage external experts in situations where human, financial, or organizational resources do not allow for the development and utilization of internal capacities. In such circumstances, it is particularly recommended to hire a financial advisor, especially in smaller enterprises, where their contribution is evaluated in proportion to the time invested and the impact on strategic planning. An external consultant is responsible for tasks related to the creation and implementation of strategic planning, as well as the preparation of monthly management plans, which are then communicated to the management. In addition, the consultant may also perform certain management accounting tasks, including profitability analyses, and in cooperation with the accounting department, is often significantly involved in preparing annual management reports (Ederer & Spaldin 2005).

However, the possibilities of external consultants in this field are limited, especially when it comes to tasks that require constant and dedicated communication with SMEs. Furthermore, the costs of these services, as

well as the need for a high level of trust between both parties, represent additional challenges. In the long run, cooperation between SMEs and external institutions in the field of management accounting is not expected to play a crucial role. Management accounting functions are considered the core competencies that need to be developed within the enterprise itself, and therefore their permanent delegation to external consultants is regarded as an inadequate solution (Haufe Akademie). The organizational design of SMEs requires an optimized structure of management accounting, which depends on internal factors such as company size, organizational structure, available financial resources, and qualified personnel. Small and medium-sized enterprises (SMEs) should be aware that having qualified personnel is of crucial importance for maintaining competitiveness. In the early stages of business operations, the management structures of SMEs usually consist of a small board of directors and a limited number of managers, often reduced to one or only a few individuals. All key management functions rely on this small team, which results in a high level of dependence of the entire business on their decisions and activities. Consequently, management is recognized as a factor of particular importance for the survival and growth of the company.

According to Maser (1998), centralization of decision-making within a limited number of hierarchical levels places a heavy burden on management and carries the risk of neglecting certain managerial responsibilities that are difficult to delegate (Ossadnik et al., 2003). Dowling and Drumm (2003) emphasize that founders and owners of SMEs are often experts in specific fields, such as information technologies, software development, science, or engineering, which increases the likelihood of a shortage of professional staff in the area of corporate governance. Nevertheless, the fact that managerial functions are concentrated in the hands of a small number of individuals may also be seen as an advantage, as it enables faster decision-making within a smaller management team. In such an environment, managerial behavior gains importance and directly affects employee motivation and behavior. Corporate culture in SMEs is often shaped by the owner and is based on personal relationships of trust between them and the employees (Mader & Hirsch, 2009). One of the specific characteristics of SMEs is that instructions are usually given personally by the owner, while employee responsibilities are broadly defined and rarely limited to narrow functional tasks. This approach enables a more comprehensive understanding of business processes and, when combined with employer recognition, strengthens mutual trust and fosters strong employee motivation.

3. THE ROLE AND IMPORTANCE OF MANAGEMENT ACCOUNTING IN SMES

Most small and medium-sized enterprises (SMEs) operate under the assumption that management accounting is intended exclusively for large companies, often justifying this stance with the argument that they lack sufficient time for its implementation. In addition, there is a certain level of reluctance to engage in strategic thinking about the future of the business, particularly when operations are profitable, while some managers are hesitant to disclose the true state of their company. Nevertheless, a comprehensive understanding of SME performance and the identification of potential problems can only be achieved if all relevant information related to management accounting is systematically recorded. In contemporary practice, the absence of a developed management accounting system is often highlighted as one of the key challenges faced by SMEs. Research indicates that the lack of this managerial control function is a major factor contributing to poor business performance in a significant number of enterprises (Lopez & Hiebl, 2014).

The high rate of insolvency among SMEs can be explained by numerous factors—ranging from managerial errors in organizing and controlling business processes, to weak competitiveness, insufficient investor support, and misjudgments in business planning. However, it is evident that many of these risks could be mitigated or even completely avoided through the professional application of management accounting instruments. Beyond reducing the risk of insolvency, there are additional reasons why SMEs should utilize management accounting. In fact, three major issues in the decision-making process of SMEs can be identified in the modern economy (Posluschni, 2010):

1. The data available to enterprises are often outdated;
2. The data that exist are rarely standardized, which hinders comparative analysis or makes it extremely time-consuming;
3. Existing data generally lack non-financial information related to critical success factors such as customers, employees, and products, as these data are usually not aligned with business procedures.

Table 1. Most Common Sectors Among Newly Registered Entrepreneurs (2023)

Sector	Share (%)
Retail trade	18%
IT and software development	12%
Business consulting services	10%
Hospitality (cafés, restaurants)	8%
Transport and delivery services	7%

Source: Serbian Business Registers Agency (APR), *Entrepreneurship Activity Report 2023*.

Table 2. SME Investments by Category (2023)

Investment Category	Share (%)
Equipment and machinery	46%
Digitalization and IT systems	18%
Facilities and premises	15%
Green and sustainability projects	9%
Employee training and development	7%

Source: Ministry of Economy, *SME Investment Structure Analysis 2023*.

The aforementioned challenges highlight the need for small and medium-sized enterprises (SMEs) to implement management accounting into their business systems in order to reduce the risk of difficulties in everyday operations. It should be emphasized that the application of management accounting in SMEs differs significantly from its role in large corporations. Accountants in SMEs are required to possess a broad set of knowledge and skills, as they are expected to understand all aspects of business administration—from developing long-term strategic business plans to preparing monthly financial reports. In small firms, these tasks are often performed by a single individual who plays a crucial role in supporting the

owner in the decision-making process. Consequently, such an individual must have a thorough understanding of interpersonal relations, business processes, and the tasks specific to management accounting.

Strategic management accounting serves as the foundation of long-term sustainability for SMEs, as it integrates the use of both strategic and operational instruments with the process of making sound decisions. With a clearly defined strategic plan and appropriate management accounting tools, managers can gain a better understanding of the current position of the enterprise and take the necessary strategic measures. This enables them to forecast medium-term decisions in areas such as human resource and investment policy over a 12-month period, while also developing a long-term business vision and establishing a strategic direction for growth over the next 3–5 years. A comprehensive approach to management accounting also involves assessing the business environment and market developments in order to identify the enterprise's key strengths and weaknesses. In this sense, strategic management accounting becomes an indispensable instrument for supporting management in planning and control, as it provides relevant and reliable information. Accordingly, management accounting can be regarded as both a prerequisite and a cornerstone of corporate strategy, essential for the sustainable and competitive development of SMEs.

4. CHALLENGES OF SMALL AND MEDIUM-SIZED ENTERPRISES IN THE FIELD OF MANAGEMENT ACCOUNTING

Operational management accounting in small and medium-sized enterprises (SMEs), compared to strategic management accounting, plays a crucial role in understanding cost structures. Its application enables the timely identification of increasing costs, both in scope and structure, as well as the recognition of cost drivers, in order to implement appropriate rationalization measures. Instead of complex and time-consuming cost accounting systems, SMEs are advised to apply simple and practical methods that provide relevant information. Continuous application of operational management accounting makes it possible to assess performance efficiency, effectively lead employees, and optimally plan enterprise resources. Moreover, it serves as a valuable tool for evaluating operational results and initiating urgent corrective measures when outcomes are unsatisfactory.

The definition and monitoring of key operational data and performance indicators complement strategic and financial information, thereby providing a more comprehensive insight into company performance. Risk management is becoming an increasingly important element of management accounting in SMEs, particularly in project management, sales, finance, and business security. An effective risk control system contributes to enhancing organizational value, strengthening competitiveness, and achieving long-term success. Its function lies in supporting management in anticipating future events and identifying potential risks, enabling enterprises to adapt to a constantly changing business environment and ensure sustainable operations. The link between effective risk control and business success is evident—SMEs that rate their risk management systems as effective achieve above-average business results. Furthermore, the assessment of various types of risks associated with the development of new markets forms the basis for creating new opportunities without excessive exposure to market fluctuations.

Nevertheless, research indicates that SMEs rarely employ risk management as part of their management accounting systems. The primary purpose of management accounting is to improve the quality of managerial decision-making and enhance flexibility, which is one of the defining characteristics of SMEs. The instruments of management accounting should not limit the flexibility and adaptability of these enterprises but rather support and strengthen them. By applying management accounting, SMEs can significantly improve overall business performance, as the information provided enables better-informed decisions. However, there are numerous challenges and limitations to implementation. One of the key obstacles is the lack of financial resources, which often prevents SMEs from hiring qualified accountants or even a full-time bookkeeper. In addition, there is frequently a shortage of expertise in management accounting, caused by insufficient training of both employees and owners. Moreover, the additional burden of operational tasks makes it difficult to respond promptly to changes identified by management accounting. A shortage of human resources, particularly managerial staff, further constrains the ability of SMEs to monitor and control business efficiency. Managers are often compelled to simultaneously address a wide range of issues—including production organization, delivery schedules, supply continuity, human resources, and business strategy development—alongside strategic and accounting matters. These limitations apply not only to management activities but also to the integration and data exchange systems within the organization. Limited or underdeveloped financial resources often

prevent small and medium-sized enterprises (SMEs) from establishing well-structured processes within management accounting or from developing sophisticated economic systems that would provide adequate data for accounting and managerial purposes.

As a result, decision-making tools and systems in SMEs are generally less formalized and less sophisticated than in large companies, and in some cases, they are not used at all. Consequently, SME owners and managers often lack reliable information for planning and control, and in the absence of professional advice, financial decisions are frequently based solely on personal judgment and intuition. Ideally, the implementation and use of information in business processes should be carried out through a structured reporting system, while appropriate management accounting instruments can significantly reduce the risk of errors in the decision-making process. However, reports lose their value if they contain too little information or, conversely, if they overwhelm management with excessive detail. This issue often arises in practice because SME managers rarely use comparative analyses of financial indicators to identify the core problems, focusing instead only on trends. Additionally, SMEs face the challenge of collecting relevant external information, while the data they do obtain are often not adequately processed due to management's heavy workload.

A shortage of resources, particularly financial, further contributes to the absence of a clearly defined strategic development direction. Accountants are primarily engaged with operational tasks of day-to-day business, while strategic issues are pushed into the background. With the decreasing size of the enterprise, this imbalance becomes even more pronounced, as daily operations gain priority. The lack of a clear strategic focus reduces SMEs' ability to exploit opportunities and adequately respond to risks. This situation is most often explained by limited managerial understanding or insufficient human resource capacity. Accordingly, most investment decisions in SMEs rely heavily on managerial experience. Although capital investment decisions are of critical importance for development, they often tie up significant resources for extended periods, which underscores the necessity of thorough budgeting. Capital budgeting serves to provide reliable information on long-term, multi-period investment projects. However, research has shown that the lack of developed capital budgeting systems was already identified in 1988 and has not significantly changed since, which poses a serious threat to the sustainability of SMEs.

Strategic planning can be strengthened through models for monitoring investment projects that simulate financial consequences, thereby reducing the risk of unfavorable investments. This is particularly important given that financial and investment challenges are among the main causes of insolvency in SMEs. Errors in financial management are usually recognized only once a crisis emerges, which further emphasizes the importance of liquidity planning, budgeting, and investment monitoring. The application of appropriate management accounting instruments can help SMEs identify potential liquidity shortages in advance and thereby increase their chances of stable and sustainable operations.

CONCLUSION

The analysis shows that management accounting is of essential importance for the survival and development of small and medium-sized enterprises (SMEs). Despite the belief that this function is reserved for large companies, practice indicates that SMEs are the ones with the greatest need for it due to limited resources, a high degree of dependence on management, and an increased risk of illiquidity and market failure. The lack of qualified personnel, financial resources, and formalized systems represents key obstacles to the implementation of management accounting, while the engagement of external consultants can only serve as a temporary solution. Human resources hold particular importance—qualified professionals capable of linking strategic and operational functions with decision-making. Their role is not limited solely to analysis but also extends to advisory activities, planning and control, as well as risk management. Effective application of management accounting instruments contributes to greater competitiveness, business sustainability, and the long-term growth of enterprises. In this sense, SMEs must strategically invest in developing internal capacities, continuous employee education, and the introduction of tailored management accounting instruments. Only in this way can they ensure stability and flexibility in a changing business environment, reduce risks, and achieve competitive advantage.

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GEPOLITIČKE IMPLIKACIJE ENERGETSKE KRIZE IZAZVANE RATOM U UKRAJINI

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Rezime

Rat u Ukrajini predstavlja jednu od najznačajnijih prekretnica za globalno energetska tržište u 21. veku. Ovaj sukob doveo je do dubokih poremećaja u snabdevanju energenata, drastične volatilnosti cena i ubrzanog preusmeravanja energetskih tokova na globalnom nivou. Evropska unija, kao najveći uvoznik ruskog gasa pre 2022. godine, suočila se sa urgentnom potrebom diverzifikacije izvora snabdevanja i intenziviranja investicija u obnovljive izvore energije i LNG infrastrukturu. Istovremeno, Rusija je svoje energetske tokove usmerila ka Aziji, pre svega Kini i Indiji, što je promenilo ravnotežu u međunarodnoj trgovini fosilnim gorivima. Ubrzane su i globalne geopolitičke promene, u kojima energetski sporazumi postaju ključni instrument političkog uticaja i ekonomske strategije.

Cilj rada je da analizira glavne promene na tržištu energenata nakon izbijanja sukoba, uključujući nove trgovinske rute, strateške odluke država i posledice po energetska bezbednost, kao i dugoročne perspektive globalne energetske tranzicije. Istraživanje se zasniva na kvalitativnoj analizi relevantnih međunarodnih izveštaja (IEA, IRENA, OPEC, Evropska komisija), statističkim pregledima kretanja cena nafte, gasa i LNG-a, kao i komparativnoj analizi tržišnih tokova pre i posle 2022. godine. Rezultati ukazuju da je rat ubrzao proces diversifikacije u Evropi, ojačao LNG kao stratešku robu, produbio energetske veze Rusije i Azije, ali i otvorio pitanja o dugoročnoj stabilnosti zelenog energetskog prelaza u nestabilnom geopolitičkom okruženju.

Rat u Ukrajini i uvedene međunarodne sankcije Rusiji značajno su poremetile energetska sistema Srbije, koja je i dalje u velikoj meri zavisna od uvoza ruskog gasa i nafte. Posledice su se ogledale u povećanju cena energenata, narušavanju stabilnosti snabdevanja i potrebi za hitnim pronalaženjem alternativnih izvora, uključujući diversifikaciju dobavljača i ubranu primenu obnovljivih izvora energije. Trenutni izazov za Srbiju predstavlja očuvanje energetske bezbednosti i finansijska dostupnost energenata za domaćinstva i privredu u uslovima geopolitičke neizvesnosti i du-

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goročnih tržišnih fluktuacija. Sankcije su dodatno povećale pritisak na pronalaženje logističkih rešenja i strateških rezervi, što zahteva koordinisane državne politike i međunarodnu saradnju.

Ključne reči: *energetska bezbednost, geopolitička dinamika, Rat u Ukrajini, globalni energetske tokovi, energetska tranzicija*

GEOPOLITICAL IMPLICATION OF THE ENERGY CRISIS TRIGGERED BY THE WAR IN UKRAINE

Abstract

The war in Ukraine represents one of the most significant turning points for the global energy market in the 21st century. This conflict has caused deep disruptions in energy supply, severe price volatility, and an accelerated redirection of energy flows at the global level. The European Union, as the largest importer of Russian gas prior to 2022, faced an urgent need to diversify its sources of supply and intensify investments in renewable energy and LNG infrastructure. At the same time, Russia redirected its energy exports toward Asia, primarily China and India, which has altered the balance in international fossil fuel trade. Global geopolitical shifts have also accelerated, with energy agreements becoming key instruments of political influence and economic strategy.

The aim of this paper is to analyze the major changes in the energy market following the outbreak of the conflict, including new trade routes, strategic state decisions and implications for energy security, as well as the long-term prospects of the global energy transition. The research is based on a qualitative analysis of relevant international reports (IEA, IRENA, OPEC, European Commission), statistical reviews of oil, gas, and LNG price movements, as well as a comparative analysis of market flows before and after 2022. The results indicate that the war has accelerated the diversification process in Europe, strengthened LNG as a strategic commodity, deepened energy ties between Russia and Asia, and raised questions about the long-term stability of the green energy transition in an unstable geopolitical environment.

The war in Ukraine and the international sanctions imposed on Russia have significantly disrupted Serbia's energy system, which remains heavily dependent on imports of Russian gas and oil. The consequences are reflected in rising energy prices, destabilization of supply, and the urgent need to identify alternative sources, including diversifying suppliers and accelerating the adoption of renewable energy. The current challenge for Serbia is to maintain energy security and ensure the financial affordability of energy for households and industry amid geopolitical uncertainty and long-term market fluctuations. The sanctions have further increased pressure to find logistical solutions and strategic reserves, requiring coordinated state policies and international cooperation.

Keywords: *energy security, geopolitical dynamics, war in Ukraine, global energy flows, energy transition*

1. Uvod

Globalna potražnja za naftom i gasom kontinuirano raste usled demografskog rasta i tehnološkog razvoja, što ove energente čini ključnim strateškim resursima. Zemlje proizvođači ostvaruju značajan geopolitički uticaj, dok države zavisne od uvoza snose posledice spoljnopolitičkih i ekonomskih pritisaka. Države bogate resursima često se suočavaju sa sankcijama i spoljnim pritiscima, što ograničava njihovu samostalnu kontrolu nad eksploatacijom i distribucijom energenata.

Specijalna vojna operacija Rusije u Ukrajini 2022. godine dodatno je transformisala međunarodne energetske tokove, pojačala multipolarnost i naglasila važnost diversifikacije izvora. Rat je izazvao povećanje cena, oscilacije na tržištima i reorganizaciju snabdevanja, posebno u Evropi i Aziji, dok sankcije Rusiji utiču na globalnu stabilnost tržišta energenata.

Prema podacima Međunarodne energetske agencije, nafta se eksploatiše u više od 115 zemalja, pri čemu su najveći proizvođači Rusija, Saudijska Arabija i SAD. Sukobi i geopolitički pritisci stoga direktno oblikuju energetske tokove i međunarodne ekonomske i političke odnose, ističući ključnu ulogu energije u globalnoj stabilnosti.

2. Geopolitičke i ekonomske posledice sukoba u Ukrajini: sankcije, energetska kriza i globalni uticaj

Početak specijalne vojne operacije Rusije u Ukrajini 2022. godine izazvao je značajne geopolitičke i ekonomske posledice širom sveta. Na Generalnoj skupštini UN-a 2. marta 2022. godine, 140 od 193 države glasalo je za rezoluciju kojom se osuđuje ruski napad na Ukrajinu, dok je pet zemalja bilo protiv, 38 uzdržano, a deset nije glasalo. Rezolucija je pozivala na trenutni i безусловni povratak ruskih snaga u međunarodno priznate granice Ukrajine, ali nije predviđala direktne sankcije (United Nations, 2022, str. 3).

Međutim, SAD, Velika Britanija i Evropska unija odmah su uvele sankcije, uključujući četiri paketa EU sankcija protiv Rusije i Belorusije. Ove mere obuhvataju ograničenje ekonomskih i finansijskih transakcija, zamrzavanje sredstava pojedinaca i firmi, restrikcije u transportu i

energetskom sektoru, kao i isključenje ruskih banaka iz SWIFT sistema (European Commission, 2022, str. 12; IMF, 2022, str. 5). Sankcije su imale za cilj da smanje finansijsku i stratešku sposobnost Rusije i Belorusije, ali su imale i širi uticaj na globalne tokove energije i trgovinske odnose.

Pre sukoba, Rusija je bila ključni dobavljač energije za Evropu, obezbeđujući oko trećinu gasa i skoro polovinu nafte u EU (IEA, 2022, str. 45). Napad na Ukrajinu ubrzao je evropsku tranziciju ka diverzifikaciji izvora energenata i obnovljivim izvorima. Posledice sukoba uključuju rast cena hrane i energenata, ubranu inflaciju i ekonomsku nesigurnost, što posebno pogađa zemlje sa nižim BDP-om (FAO, 2022, str. 6; World Bank, 2022, str. 10).

Sukob u Ukrajini i primena sankcija pokrenuli su novu fazu u globalnoj energetskoj i geopolitičkoj dinamici, podstičući formiranje multipolarnog sveta i redefinisane međunarodnog ekonomskog poretka, sa dugoročnim implikacijama za energetske tokove, trgovinu i finansijske sisteme (Pegg, 2022, str. 8; OEC, 2022, str. 12).

2. 1. Globalni energetske tokovi i geopolitičke posledice sukoba u Ukrajini

Napad Rusije na Ukrajinu u februaru 2022. godine izazvao je trenutno povećanje cene nafte za oko 8%, što je prvi put od 2014. godine probilo psihološku granicu od 100 dolara po barelu, dok je do kraja 2022. cena dostigla rekordnih 115 dolara (IEA, 2022, str. 47). Cena prirodnog gasa porasla je istog dana za oko 30%, što je globalno osetilo čitavo evropsko i azijsko tržište (World Bank, 2022, str. 32).

Kriza je posebno pogodila Evropsku uniju, koja je bila snažno zavisna od ruskih energenata, ali i zemlje poput Srbije čija ekonomija zavisi od uvoza energenata (European Commission, 2022, str. 15). Ovaj sukob se nadovezao na posledice pandemije COVID-19, koja je prethodno poremetila globalne lance snabdevanja i usporila ekonomski oporavak (IMF, 2022, str. 10).

Ruska intervencija je primorala Moskvu da traži alternativne izvozne rute prema Aziji, prvenstveno Kini i Indiji, uključujući rizične metode pretovara na moru, kako bi zaobišla sankcije EU i SAD (Petro-Logistics, 2023, str. 5; OEC, 2023, str. 8). Evropske zemlje su, s druge strane, okrenule uvoz iz zapadnoafričkih zemalja i SAD-a, čime je došlo do povećanja cena i rastuće energetske neizvesnosti (Pegg, 2022, str. 12).

Lakše razumevanje geopolitičkog uticaja i nužne promene u rutama koje su postale neizbežne ilustruje se na slici 1. Takođe, alika pokazuje ključne gasovode koji povezuju Rusiju i Evropu, odnosno pruža detaljan prikaz ključnih gasovoda koji povezuju Rusiju sa zemljama EU, uključujući Severni tok 1 i 2, Jamal, Transgas, Turski tok i Plavi tok, što ilustruje energetske tokove i geopolitičku zavisnost Evrope od ruskih energenata.

Slika 1. Glavni gasovodi u Evropi i pravci transporta ruskog gasa



Izvor: Mapa gasovoda u Evropi (preuzeta i adaptirana s originala ‘Major Russian Gas Pipelines to Europe’ — Samuel Bailey, Wikimedia Commons, CCBY 3.0)

Sukob je dodatno učvrstio ekonomske veze unutar zemalja BRIKS-a, pri čemu Rusija skoro potpuno preusmerava izvoz energenata ka Kini i Indiji, dok je tržište Evrope primorano na diversifikaciju (Aljazeera, 2023, str. 3). Posledice ovog sukoba ukazuju na ubrzanu multipolarizaciju energetskog tržišta, redefinisanje globalnih trgovinskih tokova i izazove za energetski sektor širom sveta (FAO, 2022, str. 6; UN, 2022, str. 4).

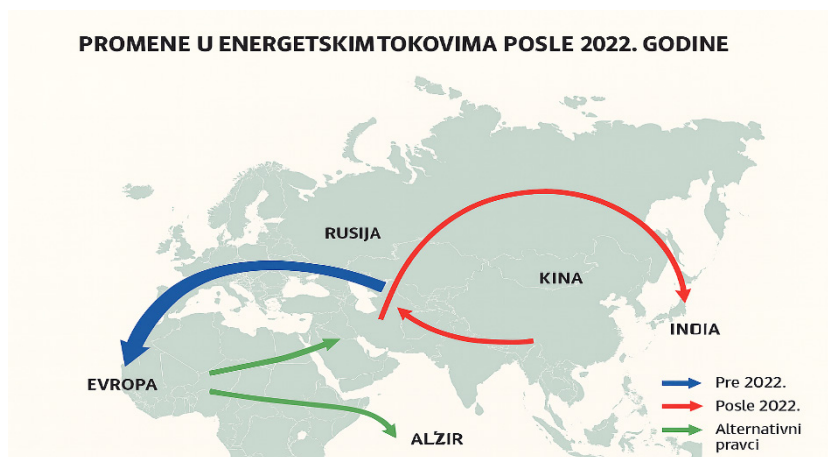
3. Strategijske reakcije država i dugoročne implikacije sukoba u Ukrajini na globalnu energetska stabilnost

Sukob u Ukrajini znaajno je ubrzao promene u energetskim strategijama evropskih država, posebno članica Evropske unije koje su bile visoko zavisne od ruskog gasa. EU je u kratkom roku primorala na diversifikaciju izvora energenata kroz povećanje uvoza ukapljenog prirodnog gasa (LNG) iz SAD, Katara i Zapadne Afrike, kao i kroz sklapanje novih dugoročnih ugovora sa Norveškom i Alžiirom (European Commission, 2022, str. 15; IEA, 2022, str.

47). Istovremeno, države članice intenziviraju ulaganja u obnovljive izvore energije i energetske efikasnost kako bi smanjile zavisnost od fosilnih goriva i ublažile volatilnost tržišta. Ove mere imaju i ekonomski i geopolitički karakter, jer omogućavaju EU da smanji stratešku ranjivost i ojača poziciju u pregovorima sa dobavljačima energenata.

S druge strane, Rusija je prilagodila svoje energetske tokove prema azijskim tržištima, posebno Kini i Indiji, koristeći postojeće i nove transportne rute kako bi zaobišla sankcije i očuvala svoje prihode od izvoza (Petro-Logistics, 2023, str. 5; OEC, 2023, str. 8). Ovo preusmeravanje energenata pojačava geopolitičku multipolarnost i stvara nove energetske saveze, dok evropske države moraju da balansiraju između sigurnosti snabdevanja i visokih troškova energije. Dugoročno, sukob u Ukrajini pokazuje kako političke odluke i međunarodne sankcije direktno oblikuju energetske tokove i utiču na stabilnost globalnog energetskog tržišta, dok zemlje zavisne od uvoza energenata, poput Srbije, moraju da razvijaju strategije diversifikacije i obezbeđenja strateških rezervi (World Bank, 2022, str. 32; Pegg, 2022, str. 12).

Slika 2. Promene u energetske tokovima nakon 2022. godine



Izvor: <https://energijabalkana.net/promene-na-naftnoj-karti-sveta>

Na slici 2 prikazana je mapa promena u globalnim energetske tokovima nakon 2022. godine. Prema ilustraciji, pre 2022. Rusija je najveći deo svojih energenata izvozila ka Evropi (plava strelica). Nakon 2022., deo ruskog izvoza preusmeren je ka Kini i Indiji (crvene strelice), dok su Alžir i drugi alternativni pravci postali značajniji za snabdevanje Evrope (zelene

strelice). Slika vizuelno oslikava globalnu reorganizaciju energetske tokova u kontekstu geopolitičkih promena.

3.1. Rusija – preusmeravanje energetike ka Aziji

Zatvaranje gasovoda „Severni tok 1 i 2“ 2022. godine predstavlja ključni događaj u novijoj istoriji energetike i geopolitičkih odnosa. Incident od 26. septembra, kada je došlo do naglog pada pritiska na Severnom toku 2, označio je sabotažu koja je imala dalekosežne posledice za energetske tokove i geopolitičke pozicije velikih sila (BBC, 2022). Ovi gasovodi su povezivali Rusiju i Nemačku, čineći ih ključnim segmentom energetske infrastrukture Evrope. Njihovo obustavljanje, zbog političkih i ratnih tenzija, primoralo je EU na traženje alternativnih izvora, uključujući gas iz Norveške i uvoz LNG-a iz SAD i Katara (IEA, 2022), što je dovelo do porasta cena energenata i povećane energetske nesigurnosti domaćinstava.

U ovoj situaciji, Nemačka je pokrenula privremene LNG terminale kako bi diversifikovala snabdevanje, dok su Poljska, Slovačka i Češka usmerile snabdevanje na nove gasovode i terminale (Slobodna Evropa, 2022). Zatvaranje Severnog toka i evropske sankcije prema Rusiji doveli su do značajne geopolitičke transformacije, otvarajući prostor za jačanje saradnje sa Azijom.

Ključni odgovor Rusije na gubitak evropskog tržišta predstavljaju gasovodi „Snaga Sibira“ i „Snaga Sibira 2“. Gasovod „Snaga Sibira“ povezuje zapadni Sibir sa Kinom i predstavlja strateški projekat osmišljen da obezbedi stabilan izvoz gasa ka azijskim tržištima. Ugovor između Gazproma i CNPC iz 2014. predviđa isporuku 38 milijardi m³ gasa godišnje tokom narednih 30 godina (Gazprom, 2022). Projekat prolazi kroz teška klimatska i geografska područja, a kapaciteti su već premašili planirane isporuke, čime je Kina postala glavni strateški partner Rusije u energetici (Gazprom, 2022).

„Snaga Sibira 2“, planiran za 2024. godinu, proširuje ovaj koridor i povezuje gasna polja zapadnog Sibira sa Kinom preko Mongolije. Projekat ima potencijal da nadoknadi deo gubitaka evropskog tržišta i značajno utiče na globalne tokove gasa, osnažujući ekonomsku i geopolitičku poziciju Kine (Slobodna Evropa, 2023). Pored Kine, kroz projekat profitiraju i zemlje tranzita, poput Mongolije, dok druge azijske i afričke države mogu indirektno koristiti niže cene LNG-a (Henderson & Mitrova, 2021, pp. 93–114).

Ova energetska reorientacija doprinosi jačanju multipolarnosti: Rusija smanjuje zavisnost od evropskog tržišta, Kina jača energetske kapacitete i

pregovaračku moć, dok se Evropska unija i SAD suočavaju sa potrebom za diversifikacijom snabdevanja (IEA, 2022). Rusko-kineski projekti gasovoda istovremeno imaju socio-ekonomske efekte u istočnim ruskim regionima, poboljšavajući infrastrukturu i životne uslove stanovništva. Ukupno, ovi projekti oblikuju novu energetska mapu sveta, sa Azijom kao centralnim potrošačem ruskog gasa i LNG tržištem pod pritiskom, dok se globalni tokovi energenata redefinišu u skladu sa geopolitičkim promenama.

3.2. Uticaj na Srbiju kao zemlju koja je zavisna od uvoza energije

Srbija je, prema relevantnim analizama, duboko zavisna od uvoza energenata — pre svega prirodnog gasa i nafte — što čini stepen energetske sigurnosti izrazito krhkim. U sektoru gasa, zavisnost od uvoza iz Rusije iznosi oko 80 % ukupne potrošnje, a gas se najčešće isporučuje po jedinoj ruti, što čini sistem posebno osetljivim na prekide snabdevanja (Madžarević i dr., 2018, str. 415–425). Ovo stanje ranjivosti potvrđuje i indeks bezbednosti snabdevanja („N1 index“) iz pomenutog istraživanja, koji ukazuje na visoku izloženost Srbije spoljnim šokovima (Madžarević i dr., 2018, str. 422).

Situacija je slična u sektoru nafte: većina sirove nafte i derivata uvozi se iz inostranstva, a domaća proizvodnja i prerada ne zadovoljavaju potražnju. Prema izveštajima, u 2022. godini oko 80% nafte koja se koristi u Srbiji poticala je iz uvoza — što pokazuje koliko je zavisnost od spoljnog snabdevanja bila izražena. (CEE Legal Matters, 2024; serbiaenergy.eu, 2023).

3.2.1. Sankcije prema Naftna Industrija Srbije (NIS) i rizici za energetski sektor

U 2025. godini, NIS, koji je ključan za snabdevanje Srbije naftom i derivatima, našao se na meti sankcija zbog svog ruskog vlasništva. Kao rezultat, transport sirove nafte preko dotadašnjeg glavnog kanala (cevovod iz Hrvatske – JANAF) je obustavljen, što je zapretilo da rafinerija u Pančevu uđe u režim „tople cirkulacije“ ili potpune obustave rada (Reuters, 2025). Takav scenario nosi sa sobom rizik od nestašica goriva — benzin, dizel, ložulje, pa i aviogorivo — sa ozbiljnim posledicama po transport, poljoprivredu, industriju i kućnu potrošnju.

Pored neposrednih problema snabdevanja, sankcije mogu dovesti do sekundarnih efekata: privredna preduzeća, logističke i finansijske institucije koje posluju sa NISom mogle bi se naći pod pritiskom, što može

destabilizovati širi ekonomski sistem. Ukoliko saradnja sa NISom ne bude prekinuta, moguće je da Srbija bude predmet novih kaznenih mera koje bi dodatno ugrozile bankarski, transportni ili finansijski sektor.

Zbog ovoga, energetska i ekonomska ranjivost Srbije dolazi u prvi plan — države sa tako velikom zavisnošću od uvoza, jednim dobavljačem i jednim kanalom transporta, neminovno se suočavaju s visokom političko-ekonomskom neizvesnošću (Madžarević i dr., 2018, str. 420–423).

Osim trenutne krize, Srbija se suočava sa strukturnim problemom: energetska sektor u značajnoj meri oslanja se na fosilna goriva (naftu, gas, ugalj), dok je domaća proizvodnja ograničena. Istraživanja ukazuju da je smanjenje uvozne zavisnosti moguće samo kroz diversifikaciju izvora i ulaganje u alternativne/generisane izvore energije (hidro, obnovljivi izvori) — što bi značajno povećalo otpornost sistema (Životić & Obradović, 2024).

3.2.2. Predlozi rešenja i strategije ublažavanja posledica

Na osnovu analize postojećeg stanja i literature, moguće su sledeće preporuke:

1. Diversifikacija snabdevanja i izvora energije koja bi podrazumevala razvijanje interkonekcija sa više dobavljača i više transportnih ruta (cevovodi, LNG terminali, potencijalno uvoz derivata iz drugih zemalja). Ovakva strategija smanjuje zavisnost od bilo jednog dobavljača ili rute (Madžarević i dr., 2018, str. 424). Takođe, moguće je i paralelno, aktivno ulaganje u obnovljive izvore energije i energetska efikasnost, kako bi se smanjila ukupna potreba za uvozom fosilnih goriva (Fejzić i dr., 2023; Duraković i dr., 2023).
2. Strateško restrukturiranje energetskog sektora podrazumeva rekapitalizaciju, reorganizaciju ili državnu kontrolu nad strateškim kompanijama (kao što je NIS), u cilju zaštite energetskog snabdevanja i uklanjanja rizika sankcija. Razvoj skladišnih kapaciteta i rezervi goriva, koji bi omogućili kontinuitet snabdevanja u kriznim situacijama.
3. Energetska i klimatska tranzicija zahtevaju implementaciju energetske tranzicije, povećanje udela obnovljivih izvora i uvođenje tehnologija kao što su vodonik i CCS (carbon capture and storage), što je naročito značajno u kontekstu smanjenja zavisnosti od uvoznog gasa (Duraković i dr., 2023). Postepeno smanjenje učešća fosilnih

goriva u energetsom miksu, uz jačanje zakonskog i institucionalnog okvira podrške zelenoj energiji.

4. Regionalna i međunarodna saradnja odnose se na saradnju sa susednim državama i integracija u šire energetske i infrastrukturne projekte (CE interkonekcije, zajedničke nabavke gasa ili LNGa), što bi povećalo pregovaračku moć i smanjilo ranjivost. Takođe, akcenat je potrebno staviti na proaktivne diplomatske politike prema partnerima (EU, međunarodne finansijske institucije), radi podrške u tranziciji i osiguranju investicija u energetska infrastrukturu i obnovljive izvore.

Kako bi se sistematizovali ključni rizici sa kojima se Srbija suočava u kontekstu energetske zavisnosti i mogućih sankcija, neophodno je identifikovati njihove neposredne posledice i potencijalne strategije ublažavanja. U Tabeli 1 prikazani su glavni rizici, opis njihovog uticaja na energetska i ekonomsku stabilnost zemlje, kao i predložene mere za smanjenje ranjivosti.

Tabela 1 Rizici i mere za ublažavanje energetske zavisnosti Srbije

Rizik	Opis / posledice	Predložene mere ublažavanja
Direktne sankcije NIS-u	Ograničenje uvoza nafte i derivata, moguće nestašice goriva, poremećaji u transportu, industriji i domaćinstvima	Diversifikacija dobavljača, razvoj strateških rezervi goriva, povećanje domaće proizvodnje i prerade, diversifikacija rute transporta
Sekundarne sankcije	Rizik ograničenja u međunarodnim finansijskim transakcijama, investicijama i trgovini, smanjenje investicionih tokova, otežan pristup rezervnim energentima (Henderson & Mitrova, 2022, str. 101; Pinfeld, 2020, str. 46)	Proaktivna diplomatska strategija, pravno usklađivanje sa međunarodnim regulativama, jačanje institucionalnih i regulatornih mehanizama za zaštitu nacionalnih kompanija
Prevelika zavisnost od jednog dobavljača energenata (Rusija)	Visoka izloženost prekidima snabdevanja, povećanje cena energenata, energetska ranjivost	Diversifikacija izvora energenata (LNG, alternativni dobavljači), razvoj obnovljivih izvora energije, energetska efikasnost i smanjenje potrošnje
Ograničeni kapacitet skladištenja i infrastrukture	Nemogućnost reagovanja na krize i prekide snabdevanja, nestabilnost tržišta	Investicije u skladišne kapacitete, modernizacija infrastrukture, izgradnja interkonekcija sa susednim zemljama

Strukturna ranjivost energetskeg sektora	Dugoročna zavisnost od fosilnih goriva, otežana energetska tranzicija, ekonomska i politička ranjivost	Razvoj strategije energetske tranzicije, povećanje udela obnovljivih izvora, implementacija inovativnih tehnologija (vodoinik, CCS), institucionalne reforme i zakonodavni okvir za zelenu energiju
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Izvor: Izrada autora

Pored direktnih sankcija koje su uvedene NIS-u, Srbija se suočava i sa rizikom sekundarnih sankcija, koje bi mogle biti primenjene od strane trećih zemalja, najčešće Sjedinjenih Američkih Država ili EU, prema subjektima koji posluju sa sankcionisanim kompanijama (Henderson & Mitrova, 2022, str. 98–102). Sekundarne sankcije predstavljaju oblik primene prinude na zemlje trećeg reda kako bi se osigurala efektivnost primarnih sankcija. U kontekstu Srbije, to bi moglo značiti ograničenja u pristupu međunarodnim finansijskim tržištima, bankarskim transakcijama, investicijama ili uvozu/izvozu energenata, čak i ako sama država formalno nije sankcionisana (Pinfold, 2020, str. 45–47). Takav scenario dodatno komplikuje energetska sektor i može dovesti do značajnih ekonomskih poremećaja, jer kompanije i banke iz Srbije mogu postati previše rizične za međunarodne partnere, što smanjuje investicione tokove i otežava pristup rezervnim energentima (Henderson & Mitrova, 2022, str. 101).

U tom smislu, sekundarne sankcije funkcionišu kao mehanizam spoljnog pritiska, povećavajući ranjivost energetska zavisnih zemalja i zahtevajući proaktivne diplomatske i regulatorne strategije za smanjenje rizika (Pinfold, 2020, str. 46). Dalje produbljivanje ovih problema može imati i šire socio-ekonomske posledice, uključujući povećanje nezaposlenosti i potencijalnu migraciju visokoobrazovanih kadrova iz Srbije, što dodatno ugrožava nacionalni razvoj i konkurentnost (Milosavljević & Anufrijeva, 2025). Ovakvi trendovi ukazuju na potrebu sveobuhvatnog strateškog pristupa u oblasti energetike, spoljne politike i upravljanja ljudskim resursima, kako bi se ublažili dugoročni rizici po ekonomski i društveni razvoj zemlje. Bez pravovremenih institucionalnih reformi i diverzifikacije energetska i ekonomskih partnerstava, Srbija bi mogla ostati trajno izložena spoljnopolitičkim pritiscima i unutrašnjim strukturnim slabostima, što dodatno komplikuje njen razvojni put.

Zaključak

Rat u Ukrajini 2022. godine predstavlja ključni prelomni trenutak u globalnom energetsom sistemu, dovodeći do dubokih poremećaja u snabdevanju energentima, značajne volatilnosti cena i redefinisavanja međunarodnih energetskih tokova. Sukob je ubrzao multipolarnost u globalnoj energetici, pri čemu Rusija preusmerava svoje energente ka azijskim tržištima, dok se Evropska unija primorava na diversifikaciju izvora, povećanje uvoza ukapljenog prirodnog gasa i intenziviranje ulaganja u obnovljive izvore energije. Ove promene ukazuju na to da politički i geopolitički faktori imaju direktan i momentalan uticaj na globalnu energetska stabilnost i ekonomsku sigurnost država.

Za zemlje koje su visoko zavisne od uvoza energenata, poput Srbije, sukob u Ukrajini i sankcije prema Rusiji predstavljaju ozbiljan izazov. Energetska zavisnost od jednog dobavljača i jednog transportnog kanala povećava ranjivost države, dok primena direktnih i sekundarnih sankcija dodatno komplikuje pristup energentima i finansijskim instrumentima, ugrožavajući kontinuitet snabdevanja i ekonomski stabilitet. Analiza Srbije pokazuje da trenutna energetska infrastruktura, ograničeni kapaciteti skladištenja i strukturalna zavisnost od fosilnih goriva zahtevaju hitnu reakciju u obliku diversifikacije izvora, razvoja strateških rezervi, povećanja domaće proizvodnje i ubrzane tranzicije ka obnovljivim izvorima.

Predložene strategije ublažavanja rizika, uključujući diplomatske i regulatorne mere, regionalnu i međunarodnu saradnju, kao i ulaganja u energetska efikasnost i inovativne tehnologije, predstavljaju ključne korake ka smanjenju ranjivosti Srbije i drugih energetski zavisnih zemalja. Dugoročno, sukob u Ukrajini pokazuje da energetska i geopolitička stabilnost ne mogu biti posmatrane izolovano od međunarodnih političkih odluka, te da je za održivu energetska sigurnost neophodna kombinacija strateške diversifikacije, tehnoloških inovacija i fleksibilne politike energetske tranzicije.

U širem smislu, kriza izazvana ratom u Ukrajini naglašava važnost međunarodne saradnje, proaktivnog planiranja i razvoja otpornog energetskeg sistema, koji može izdržati spoljne šokove i obezbediti kontinuitet snabdevanja energentima, uz očuvanje ekonomske stabilnosti i podršku održivoj energetskej tranziciji. Globalna energetska dinamika se trajno menja, a zemlje poput Srbije suočene su sa izazovom prilagođavanja i osnaživanja svojih energetskih kapaciteta kako bi se smanjila zavisnost i povećala otpornost u nesigurnom geopolitičkom okruženju.

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TWO REALITIES OF ARCHITECTURE: FROM TECHNOLOGICAL EUPHORIA TO IRONY OF POPULAR CULTURE

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ABSTRACT:

This paper examines and compares two seminal architectural manifestos of the 20th century: „Vers une Architecture“ (1923) by Le Corbusier and „Learning from Las Vegas“ (1972) by Robert Venturi, as articulations of fundamentally divergent theoretical positions, modern and postmodern. Le Corbusier advocates for functionality, universalism and abstract forms, conceptualizing architecture as a rational and technically efficient „machine for living“. In contrast, Venturi contests modernist dogma by affirming symbolism of popular culture as valid architectural language. Both authors engage with the material reality of their time. Le Corbusier literally adopts the forms of technical and industrial civilization (silos, airplanes, factory chimneys, ocean liners) as a model for architecture. Venturi ironically draws from the seemingly banal visual vocabulary of popular culture (commercial streets of Las Vegas, including neon signage, billboards and vernacular landscapes) using ambiguity to challenge modernist orthodoxy. Through this comparative analysis, the paper reflects on the paradigmatic shift in 20th century architectural theory, from the abstract universalism of modernism to the contextual embedded language of postmodernism. While Le Corbusier reduces architecture to essential functional components, Venturi emphasizes complexity, contradiction and layered meaning. Ultimately, the study concludes that the tension between these contrasting approaches remains vital, offering a framework for critical reflection on the interplay between form, function, context, and user experience in contemporary architecture.

Key words:

Le Corbusier, Robert Venturi, *Vers une Architecture*, *Learning from Las Vegas*, modernism, postmodernism, architectural theory, form and function, symbolism in architecture

INTRODUCTION

The architecture of the 20th century was marked by great theoretical conflicts that shaped the way we look at, and build space today. The book „*Vers une Architecture*“ [Fig. 1] by the Swiss-French architect Le Corbusier is a manifesto of modernist thought and a rational approach to construction. In this book, Le Corbusier declares that architecture should follow functionality, simplicity and universal principles of beauty, relying on analogies with machines, ships and cars as symbols of progress and precision. This text formed the foundations of the modernist paradigm, calling for the rejection of historical styles in favor of a new, logical and functional architecture. In contrast, the book „*Learning from Las Vegas*“ [Fig. 2] by Robert Venturi, Denise Scott Brown and Steven Isenour, presents a critique of modernism and its reexamination through the prism of postmodern thinking. Venturi rejects the idea of universality and functional „purity“, advocating an architecture that embraces symbolism, irony, complexity and meanings taken from popular culture. Through analysis of the city of Las Vegas, the authors indicate the importance of communication in architecture and restore the importance of ornament and sign. This comparative analysis of two opposing theoretical directions provides an insight into the transformation of architectural thought and values in the modern age.



Fig. 1: „Vers une Architecture“, book cover

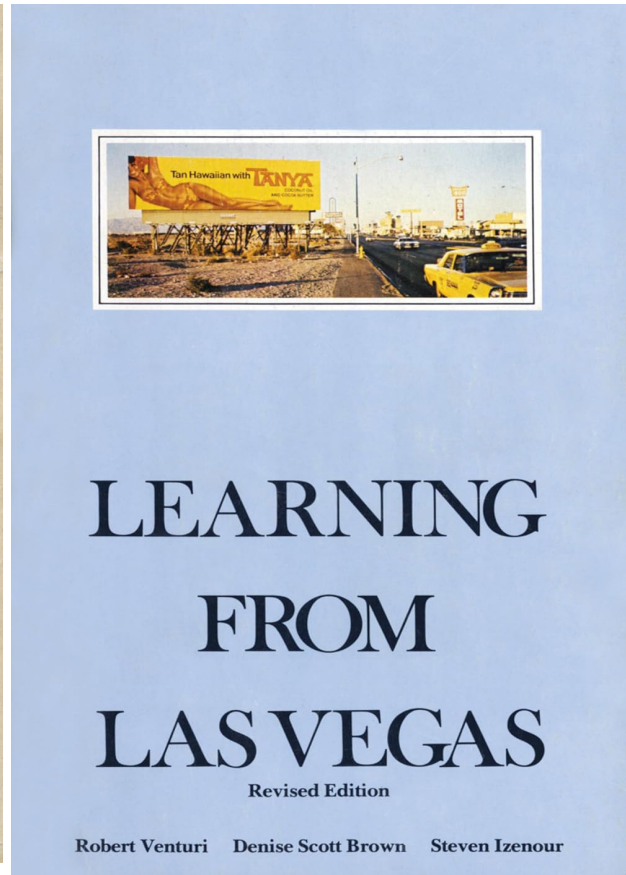


Fig. 2: „Learning from Las Vegas“, book cover

VERS UNE ARCHITECTURE

The book „Vers une Architecture“ by Charles-Édouard Jeanneret, better known under the pseudonym Le Corbusier, is one of the most important written works of modern architecture. First published in 1923, this book represents the manifesto of the modernist movement and a seminal text that shaped twentieth century architectural thinking. In this book, Le Corbusier emphasizes the principles of rationalism, functionality and aesthetics based above all on proportions, simplicity and technical progress. Also, he declares that architecture should reflect the spirit of the industrial age and be based on functional needs rather than ornamentation and tradition. The book „Vers une Architecture“ caused a strong impact on modern architecture, but also harsh criticism. While many celebrated his vision of functionality and rationality,

others felt that his approach neglected not only the emotional, but also the social aspects of housing. Critics have often pointed out that his cities, as well as buildings, can seem somewhat cold and inhuman.

The main principles of „Vers une Architecture“ are the primacy of functionality, the aesthetics of the modern age and criticism of every type of ornament. Le Corbusier was fascinated by the technical achievements of his time, such as cars, ships and airplanes. He believed that architects should learn from engineers who design functional, rational and aesthetically pleasing objects. For him, the airplane was a symbol of perfection, and he often used airplanes as a metaphor for the perfect union of function and form. The book declares that airplanes represent the pinnacle of human genius due to their rational construction. In addition to airplanes, the automobile also appears as an inspiration for house design: He compares the automobile industry to architecture, criticizing buildings as „obsolete“ compared to the efficiency and progress of automobiles¹.

The book „Vers une Architecture“ had a significant impact on contemporary architecture, shaping not only the aesthetic principles of modernism but also the approach to urbanism, design and functionality. Ideas presented became the main rappers for the development of 20th century architecture, while some of the key influences includes the influence on modernism, because Le Corbusier is considered one of the founders of the modernist movement, along with architects such as Walter Gropius, Mies van der Rohe and Alvar Aalto. Principles presented in the book, became the foundation for the International Style, which is characterized by clean lines, minimalism, the use of industrial materials (concrete, steel, glass), and primarily focus on functionality². Practical applications of these ideas can be seen in modernist buildings around the world, including residential and public buildings as well as business centers. Le Corbusier radically changed the concept of housing. His principles of functionality and efficiency had a huge impact on the design of residential buildings in the mid 20th century, especially in the post-war period when it was necessary to provide mass housing. The Unité d'Habitation project, first realized in Marseille between 1947–1952, became the prototype for apartment blocks around the world. The concept of integrating apartments, commercial spaces and common facilities has inspired many architects. His ideas about modulator (the previously mentioned system

1 Le Corbusier. (1986). Towards a new architecture. Dover Publications. 88-95

2 Le Corbusier. (1986). Towards a new architecture. Dover Publications. 30-50

of proportions) and serial production inspired prefabrication and an industrial approach to the construction of residential buildings.

Through this book and his later works, he promoted the idea of modern urbanism based on zoning and functional organization of space. His vision of tall buildings in green spaces has become a key element of urban planning, especially in North and South America, Europe and Asia. The idea that residential, commercial and industrial spaces should be physically separated became the basis for many urban plans of the 20th century. However, his vision of cities was often criticized as too rigid and dehumanizing. Examples such as the socialist blocs in Eastern Europe were often directly inspired by his ideas, but later proved unsuitable for human interaction and social cohesion³. Le Corbusier was among the first to integrate technology and industrial methods into building design. His approach enabled efficient construction using prefabricated elements, new materials, such as reinforced concrete and steel, as well as the application of industrial standards in architecture. These techniques became the basis for mass construction in the second half of the 20th century. His use of raw concrete (*béton brut*) in projects such as the *Unité d'Habitation* and the *Chapel at Ronchamp* (although not part of this book, they reflect its principles) became an inspiration for Brutalism, an architectural style that developed between 1950s and 1960s. Brutalism focuses on monumental forms and the use of materials with emphasized functionality⁴.

Although his ideas initially celebrated progress and modernization, they were later criticized for their perceived „coldness“ and lack of humanity. His models of social housing often proved to be unadapted to human needs, because they neglected social dynamics. Urban plans that relied on the separation of functions led to the creation of monotonous, unattractive and partially isolated communities. Nevertheless, architects and theoreticians today are reevaluating his work, recognizing the importance of a balance between functionality, aesthetics and human needs. Le Corbusier laid the foundation for many contemporary architectural practices. Its concepts and principles are still being studied and reinterpreted. His ideas revolutionized architecture and urban planning, paving the way for a more rational, functional and technologically advanced approach to design. Although some of his visions have been criticized for social and emotional flaws, his contribution is undeniable, while contemporary architects continue to find inspiration in his

3 Le Corbusier. (1986). *Towards a new architecture*. Dover Publications. 30-50

4 Curtis, R. (1996). *Modern architecture since 1900* (3rd ed.). Phaidon Press. 342-350

principles. From all of the above, it can be concluded that the book „Vers une Architecture“ was and remains the key manifesto of the modernist movement.

LEARNING FROM LAS VEGAS

The book „Learning from Las Vegas“, written by Robert Venturi, Denise Scott Brown and Steven Isenour, was published in 1972 and represents a key text of postmodernist architecture. This book is known for questioning modernist principles and highlighting the importance of popular culture, signs and symbolism in architecture. Their exploration of Las Vegas brought a whole new perspective on urban planning and design. The main thesis of this book and its context is analyze of the architecture and urbanism of the city of Las Vegas as an example of a city that relies on communication through signs, symbols and popular aesthetics. They argue that architecture does not have to be functionalist and minimalist (as proposed by modernism), but can be rich in meaning and references from popular culture⁵. Their key thesis is that Las Vegas, with its flashing advertisements, kitschy buildings and symbolic forms, has much to teach architects about communication and the relationship between people and space.

The authors introduce two concepts to describe different approaches to architecture⁶:

1. Duck: Building whose shape is entirely based on symbolism. The name comes from a duck shaped store in Long Island, which itself is a huge symbol of what it sells (ducks and eggs). This approach emphasizes form and metaphor as the main elements of architecture.
2. Decorated Shed: Simple building whose identity and meaning comes from the addition of signs or decorations represents the approach Venturi prefers because it allows for functional flexibility and communication through signs, an example being typical buildings along the Las Vegas freeway, such as motels or restaurants with large neon signs.

The authors use Las Vegas as a laboratory for research of architectural symbolism and the behavior of space users. Their analysis focuses

5 Venturi, R. (1966). Complexity and contradiction in architecture. Museum of Modern Art. 78-95

6 Venturi, R. (1966). Complexity and contradiction in architecture. Museum of Modern Art. 122

specifically on neon signs, where Venturi declares that these signs are crucial to understanding space and interaction, as they serve as guides through the city and convey messages over a distance. It also studies the freeway and the car as a kind of specific spatial experience, because Las Vegas was primarily designed for car users, not pedestrians, which is revolutionary in the context of urbanism. This dynamic changes the way the city is perceived. Venturi directly criticize modernist principles, especially abstract, universal aesthetics that ignore historical, social and cultural contexts. Authors believe that modernism favors functionality at the expense of symbolism and meaning. Also, that architecture should be inclusive, thus reflecting popular culture and everyday life. This criticism was part of the wider postmodernist movement, which emphasized pluralism, historical reference and symbolism in architecture. At the same time, they advocate the idea that architecture should speak through signs, decorations and context. He suggests that architects should recognize the importance of symbolism in shaping space, even when that symbolism comes from „low“ or „popular“ culture. Venturi's famous phrase from this book is „Less is a bore“, which represents a direct opposition to Mies van der Rohe's modernist slogan „Less is more“. Venturi thus emphasizes the need for richness of meaning and layering of architectural forms⁷.

The book significantly influenced postmodernist architecture and urbanism, offering an alternative to modernist dogma. Key influences include laying the groundwork for postmodernist architects such as Michael Graves, Charles Moore, and Philip Johnson, who used historical references, ironic elements, and symbolic forms in their work; analysis of Las Vegas inspired acceptance of commercial aesthetics and popular culture as legitimate elements of design. In terms of urbanism and spatial design, this book changed the way cities and spaces are analyzed, focusing on users, communication and symbolism. Finally, Venturi introduced a humanistic approach to architecture, which includes sociological, cultural and anthropological aspects⁸. It follows from the above that this is a provocative book that changes the paradigm of architecture and urbanism, calling for the rejection of the rigidity of modernism and the acceptance of the rich symbolism of everyday life. Their work illuminates the importance of communication, functionality and cultural context, providing a new vision of architecture that reflects the complexity and diversity of contemporary society.

7 Tafuri, M. (1976). *Architecture and utopia: Design and capitalist development*. MIT Press. 175-188

8 Brown, S. (2013). *Having words: Critical writings on architecture*. Architectural Association. 55

COMPARATIVE ANALYSIS OF THE BOOKS

The books discussed here represent two fundamentally different paradigms in architecture, reflecting profound changes in society, technology and culture during the 20th century. While Le Corbusier strives to create a universal, rational and functional architecture based on abstract principles, Venturi point to the importance of symbolism, context and everyday experience in architectural expression⁹. Le Corbusier, writing in the context of industrialization and social transformations at the beginning of the 20th century, sees architecture as a tool for reshaping society. In „Vers une Architecture“, he defines architecture as a discipline that should free itself from historical embellishments and traditions, focusing on rationality and functionality. Its principles, such as „machine for living‘ and „form follows function‘, express a belief in universal values and the power of technology to improve the quality of life. In his opinion, architecture should be strictly geometric, minimal and efficient, while decoration and local specifics represent superfluous elements that disturb the purity of the design.

In contrast, the book „Learning from Las Vegas“, represents a radical reaction to modernist rigidity. In this section, the authors analyze the urban landscape of Las Vegas, a city that symbolizes consumer culture, kitsch and the fragmentation of modern society. Instead of dismissing these phenomena as unimportant or inauthentic architecture, Venturi embrace and understand them as legitimate expressions of contemporary social life. They emphasize the importance of symbolism in architecture, where elements such as neon signs, advertisements and decorations become crucial in the communication between the building and its user. Their famous slogan „Less is a bore“, opposes Le Corbusier’s „Less is more“¹⁰, affirming richness, layering and diversity as the core values of architecture.

Le Corbusier’s idealism and Venturi’s pragmatism are also reflected in their approaches to urbanism. Le Corbusier projects cities as strictly rational, hierarchical structures in which each element (housing, work, recreation) is separated and functionally defined. His plans, like „Radiant City“, reflect a desire for order and control in urban space. On the other hand, Venturi analyze the urban chaos of Las Vegas, where functions overlap and space is shaped according to the needs of cars and markets. They do not offer visionary plans,

9 Frampton, K. (1992). *Modern architecture: A critical history* (3rd ed.). Thames & Hudson. 201-205

10 Curtis, R. (1996). *Modern architecture since 1900* (3rd ed.). Phaidon Press. 342-350

but indicate how architecture reflects social realities and values. One of the key differences between the two books lies in their relationship to meaning. For Le Corbusier, the meaning of architecture is inherent and derived from proportions, purity of form and universal rules. He believes that architecture speaks a universal language that transcends the specificities of culture or place. Venturi sees architecture as a tool for communication with its users, where meaning emerges from specific context, symbolism and cultural references. He advocates a semiotic approach, analyzing how architectural elements convey messages and how and in what way they are connected to everyday life¹¹.

The influences of these books on architectural theory and practice are profound. „Vers une Architecture“ laid the foundations of modernism, shaping the practice of architects such as Mies van der Rohe, Walter Gropius and Alvar Aalto. Their ideas dominated the mid 20th century, especially in the context of mass housing construction and urban planning projects. However, the rigidity of modernism drew criticism for its neglect of the cultural and emotional aspects of architecture. This is where the book „Learning from Las Vegas“ appears as a pioneering manifesto of postmodernism, which introduces pluralism, diversity and symbolism as central values of architectural practice¹². Venturi's book not only redefines architectural theory but also opens up space for experimentation with styles, forms and meanings.

The two books are not only opposed, but also complement each other. While „Vers une Architecture“ emphasizes universality and rationality, „Learning from Las Vegas“, celebrates context, symbolism and human spontaneity. Together, they form a dialogue between idealism and realism, between the universal and the local, each in its own way providing a basis for understanding the complexity of contemporary architecture.

THE INTERACTION OF THE BOOKS AND THE INFLUENCE ON ARCHITECTURE IN GENERAL

„Vers une Architecture“ by Le Corbusier and „Learning from Las Vegas“, by Robert Venturi, Denise Scott Brown and Stephen Isenour represent two key points in the history of architectural thought. These books, although at first glance opposed, together form a dynamic dialogue between modernism

11 Curtis, R. (1996). Modern architecture since 1900 (3rd ed.). Phaidon Press. 342-350

12 Frampton, K. (1992). Modern architecture: A critical history (3rd ed.). Thames & Hudson. 201-205

and postmodernism, shaping the fundamental direction of architecture during the 20th and 21st centuries. Le Corbusier's book places architecture on the pedestal of rationality and universality, striving for perfection through strict geometric forms, minimalism and functionality. His vision of architecture is not only aesthetic or technical, but socially transformative. „Vers une Architecture“ is a manifesto of faith in the power of architecture to shape a better society, freed from chaos. However, this idealism, when translated into practice, can seem rigid and alienating, ignoring the emotional, cultural and symbolic needs of space users.

In contrast to this book, „Learning from Las Vegas“, presents a critique of modernist uniformity, revealing that architecture must be in dialogue with its context, users and everyday life. Venturi and colleagues affirm pluralism and symbolism, indicating that architecture is not only a rational response to technical needs but also a means of communication and culture. Their exploration of the urban landscape of Las Vegas celebrates spontaneity, contradiction and layering, pointing to the importance of understanding social and economic realities.

The mutual relationship of the books is reflected in their contribution to the theory and practice of architecture. „Vers une Architecture“ laid the foundations of modernist practice, bringing order and rationality to the world of architecture, while „Learning from Las Vegas“, opened the door to the deconstruction of that system, allowing the expression of complexity, locality and symbolism. Although seemingly contradictory, these two books are not irreconcilable; they offer two opposite but complementary views on architecture. Their influence on architecture in general is also profound and pervasive. Le Corbusier's modernism shaped the appearance of numerous cities, bringing standardization and functionality, while Venturi's postmodernism introduced flexibility, irony and cultural awareness. Together, these books pose a fundamental question of architecture: should architecture guide society towards ideals or reflect its real, often chaotic, contradictory values?

The contribution of these books to architectural thought lies in creation of a space for dialogue between universal principles and local specificities, between idealism and realism. Their mutual relationship reminds us that architecture is not only a technical discipline, but also a social art, which should balance the functional, aesthetic and symbolic needs of people. Their combined legacy shapes contemporary architecture, which embraces both order and chaos, rationality and emotion, past and future. Criticism reflects the

complexity of their influence and the controversies they caused in architectural theory and practice. Both books have been praised for their innovation and influence, but have also been the subject of considerable criticism.

CONCLUSION

Comparative analysis of these books illuminates the profound ideological and aesthetic difference between modernism and postmodernism in architecture. While Le Corbusier promotes rationality, functionality and universality as the basic principles of contemporary architecture, Venturi emphasizes the importance of symbolism, context and complexity, calling for the acceptance of everyday aesthetics and pluralism of meaning. These opposing viewpoints point to the evolution of architectural thought of the 20th century in terms of elitism and populism, but also to the constant need for dialogue between form, function and meaning in contemporary space. However, there is a thin line between elitism and populism. Although Le Corbusier pleads for abstract forms (which he considers to be the origin of elite culture, because as abstract they are not understandable to everyone), he takes them *ad verbatim*, in a literal way, from the world of technology. On the contrary, Venturi, although at first glance it seems that he deals with the banal and popular, he actually does so through irony, which is definitely not a characteristic of someone who would be labeled a populist.

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